# Delft Outlook

Research & Education at Delft University of Technology

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FMAX / Sam Rentmeester


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# Gold from garbage

## *Delft technology reclaims valuable metals from incinerated domestic waste in an amsterdam test factory*

FMAX / Sam Rentmeester

Dutch garbage, including parts of gold and silver

**Domestic waste contains large quantities of copper, aluminum, nickel, zinc and silver. Until now, only around of this was reclaimable, and annually million euro of copper and aluminum disappears into the ground. A new Delft technology and Amsterdam innovation separates bottom ash into valuable non-ferro metals and clean building materials.**

Dap Hartmann

Households in the Netherlands collectively produce some 6 million tons of domestic waste in the 'gray fraction' (the garbage bags) per year. This amounts to 1,000 kilos per household per year. Of this, 80% is processed in waste energy plants; the rest is buried. Incineration makes a substantial contribution to the production of sustainable energy in the Netherlands. Moreover, a small country has a limited capacity for burying domestic waste, and incineration reduces the volume by 90%. The organic material in buried domestic waste produces methane ($CH_4$), a greenhouse gas that is 25 times more powerful than carbon dioxide ($CO_2$), which is released when these same carbon dioxide atoms are incinerated. In Europe, currently only 20% of the 220 million tons of domestic waste is incinerated annually. According to a recent European directive, in future that figure must rise to 70%.

Incineration reduces a ton of rubbish to approximately 200 kg of bottom ash and 25 kg of fly gas. Moreover, 25% of domestic waste's energy content is converted into sustainable electricity. Fly gas rises with the smoke gasses, and bottom ash – as the name suggests – remains on the bottom of the incinerator. When the incineration is complete, the bottom ash is filtered to 40 millimeters, and the large fraction is collected. A magnet removes the iron and steel. What remains is a pitch-black granular material. Until now, the bottom ash has had a negative economic value, but recently it has become a valuable metallic ore.

Attempts have been made to extract non-ferro metals from non-incinerated waste; for example, by VAGRON, in Groningen, but this was never successful, mainly because metal concentrations in un-incinerated waste are five times lower in weight and ten times lower in volume. The main problem is that metals are not present in pure forms. Copper wire has a plastic casing, a printed circuit board with copper tracks is 99% circuit board and 1% copper, and copper also only accounts for a small part of a battery. Incineration therefore is in fact a first separation step, because it separates the copper from the casings and carriers. The type of material

The pilot factory on the grounds of the municipal Afval Energie Bedrijf (AEB) in Amsterdam's harbor area.

Building materials, made from bottom ash, granules and sand – the granular fractions are delivered to cement producers, where it is converted into cement of a de nitive granular structure. The ner fractions reclaimed from the bottom ash are recycled in the limesandstone industry (illustration below) The color is the only di erence between this and traditionally manufactured chalksandstone. This reclamation technique can completely replace the sand from sand excavation projects.

The bottom ash that remains after the waste has been processed is in fact a new type of waste and, as such, presents a problem. Solution: AEB transforms the bottom ash into building material by removing the metal particles from the remaining ash. In partnership with TU Delft, an e ective process for this has been developed: wet non-ferro separation of bottom ash. AEB and TU Delft have registered three international patents for this technological process.

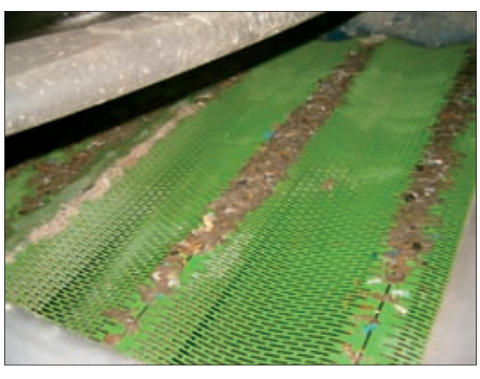
Afval Energie Bedrijf, Amsterdam Sources: 2005 AEB Annual Report

can also present problems. Much of the aluminum in domestic waste is in the form of aluminum foil, which is difficult to separate. Incineration however melts the aluminum foil down to fine, pure drops of aluminum, which is easy to separate.

## Eddy current separator

Peter Rem, of the Resource Engineering section of Applied Earth Sciences (CEG Faculty), has developed a method for extracting five times as much non-ferro metals from bottom ash as was previously possible. No chemicals are used to do this: only elementary physics and ingenious mechanical constructions. Rem has developed and patented a 'wet eddy current separator', which is based on a 150-year old principle that no practical application has actually ever been found for.

At the heart of a normal (dry) eddy current separator is a powerful magnet that revolves at extremely high speeds. The bottom ash falls past the magnet, creating eddy currents in the metal particles, which in turn generates an electromagnetic field. The metal particles temporarily become small magnets with a polarity opposed to that of the rotating magnet. While the other material falls unaffected downwards, the metal particles are deflected and land elsewhere. This dry eddy current has one major limitation though: a magnetic field of sufficient strength to deflect the particles out of the flow can only be created in metal fragments that are larger than approximately 5 mm.



Spanwelle- lter, with a continuously reforming exible lter screen, which prevents clogging.

The metal particles in which eddy currents are created rotate at several hundred revolutions per minute. And a rotating body experiences an upward force or lift as a result of the asymmetric turbulences that arise behind it: this is known as the 'Magnus-effect' and it plays a crucial role in, for example, a wave, but there are in fact no industrial applications known for it. Peter Rem hoped that the Magnus-effect would sufficiently deflect the metal particles from the main flow in order to separate them properly. The predictability of this subtle effect was however strongly compromised by the influence of turbulence and air resistance. Over a drop of half a meter, the deflection rate amounted to just one centimeter, which is insufficient for practical separation. In order to slow the particles down, Rem let them fall into a container of water. The result was amazing: the deflection rate increased tenfold!

It is easy to demonstrate how the Magnus-effect works in water. Take a bucket of water and let a (metal) cylinder roll into it from a sloping surface. The Magnus-effect will cause the cylinder to move in a backwards direction in the water. Non-rotating material does not experience this effect and lands - due to its forward motion – in another place. The Magnus-effect also gives rotating, randomly shaped particles a sufficiently large enough deflection to make separation feasible in practice.

## Test runs

Dry eddy current separators reclaim a half percent of non-ferro metal from the coarse fraction of bottom ash (larger than 10 mm). Approximately half of all bottom ash is contained in the fine fraction (0.5-10 mm). Up until now, the material flow has not been further processed, because it was impossible to separate non-ferro metals from it. But this can now be done using a wet eddy current separator. Owing to the large division of metal particles in the bottom ash, Peter Rem predicts that the fine fraction will consist of five times more copper and aluminum than the coarse fraction.

In March 2000, an article in the Dutch newspaper NRC Handelsblad about the wet eddy current separator reported on its potential application for reclaiming non-ferro metals from the fine fraction of bottom ash. This article prompted the Municipality of Amsterdam's Afval Energie Bedrijf (AEB) (Waste Energy Company) to call and discuss a possible partnership. AEB is a very large and innovative waste company, which last year produced 200,000 tons of bottom ash – nearly a quarter of the other eleven Dutch installations' production combined. The waste energy plant produces 530 GWh of electricity from this (approximately what the Netherlands uses in two days), as well as 140 TJ for usable heating. AEB is extremely positive regarding waste. Director Daan van der Linde does not regard waste as a final destination, but rather as a new beginning: "Waste is a raw material," is his motto.

The partnership between TU Delft and AEB began with a careful analysis of the composition of bottom ash. AEB delivered a half-ton of bottom ash to TU Delft's Resource Engineering section's laboratory, where the bottom ash was processed in the wet eddy current separator. The results were exactly as predicted: 3% of the bottom ash consisted of non-ferro metal, of which roughly half consisted of copper and the other half aluminum; 20% was found in the coarse fraction, and 80% in the fine fraction.

In addition to copper and aluminum, the bottom ash also contained rust-free steel (rfs: steel comprised of approximately 10% nickel and 20% chrome), lead, tin, zinc, silver and gold. How does all this actually end up in our domestic waste? There are copper wires from electrical equipment, aluminum foil from the kitchen, copper rings, rust-free steel screws, brass brackets, and so forth. There is 30,000 tons of non-ferro metals in the annual flow of 1 million tons of bottom ash in the Netherlands. In addition to copper and aluminum, this bottom ash contains 5,000 tons of rfs, 1,300 tons of zinc, and, not to be overlooked, 10 tons of silver (or approximately 10% of the demand for silver in the Netherlands). With a market price per ton of 2,500 for copper and 1,400 for aluminum, we are talking about approximately 60 million euro per year, of which currently 80% disappears into the ground.

The next question the AEB addressed to TU Delft concerned the possibility of designing a continuous process for processing the bottom ash, so that the costs would not outweigh the profits. To determine this, a test facility was built on the AEB site. Peter Rem: "If I think back, it is really is unbelievable. On Friday we took our equipment from the lab and drove to Amsterdam, and on the following Tuesday we were processing 20 tons of bottom ash per hour there. We worked for three days and processed a total of 120 tons of bottom ash."

The results of this experiment were carefully analyzed and published in a scientific journal. The non-ferro metal extraction remained constant at around three percent. It was also established that the remaining flow was free of non-ferro metals, and therefore could be used as clean building material. A fantastic result, especially given the simplicity of the test facility. It was therefore decided to start the third phase: the setting up of a pilot plant that could process 50 tons of bottom ash (approximately two full truckloads) per hour. For this, all that was learned in previous experiments was used to design larger capacity separators. By late 2003, the pilot plant was operational.

## Pilot plant

After graduating from Ostrava University of Technology in the Czech Republic, Lenka Muchová began conducting research at Corus, where she analyzed the environmental–aspects of the soot and sludge in the furnaces. When the pilot plant in Amsterdam was ready, she began her doctoral research under the supervision of resource engineering technologist Dr. Peter Rem. Muchová's research focused on optimizing the bottom ash processing, the quality control of the end product and the commercial applications of this. From the beginning to the end of the chain, every step in the process had a role to play. One of the questions that Muchová tried to answer was what influence the composition of the bottom ash had on the various separation steps in the chain. This could determine whether the process could be successfully applied elsewhere in the world, where perhaps domestic waste has a very different composition than the waste in the Netherlands. For optimizing the recycling process, it is vital to know exactly what the bottom ash consists of. To determine this, Muchová very carefully analyzed the contents of three different fractions (coarse, fine and sand); collectively, these fractions ultimately comprise 70-80% of the end product.

## Problem solving

The wet eddy current separator is only one apparatus in the entire bottom ash processing chain. There is also a density separator – another example of elementary physics and mechanical engineering ingenuity. When you place a piece of cooper and a piece of aluminum in a bucket of water at the same time, the copper sinks to the bottom first. Copper is heavier than aluminum and therefore sinks faster. So much for the elementary physics. The question now is: how to design a machine that can exploit this fact to separate copper and aluminum. In a laboratory experiment, Peter Rem figured out how to separate a single batch. He placed a mixture of light and heavy particles in the water. In order to observe the effect well, these two fractions were of different colors. As soon as the heavier fraction had sunk to the bottom, a sort of luxaflex formed above it. The lighter fraction then collected on the luxaflex. Extremely ingenious, very simple, but unsuitable for a continuous supply of material.

Fine granules for use in limesandstone, asphalt and cement.


FMAX / SAM RENTMEESTER

Fijne metaaldeeltjes uit huishoudelijk afval: smelt van zware non-ferro fractie uit bodemas

Rem therefore devised a separator that converted the difference in time into a difference in distance. This separator consisted of a cylindrical vat, in which a turbine revolved around a central axis. The blades created compartments that could be extracted as individual batches. The blade revolved slowly, which allowed the compartments behind to be filled with material that entered the separator at a fixed point. When looked at from above, the cylinder resembled the face of a clock, with each compartment being filled at 12 o'clock. The heavier fraction in the compartment sunk faster than the lighter fraction. The circulation speed was so consistent that the heavier fraction reached the bottom at 6 o'clock, the lighter fraction at 9 o'clock. The heavy and light fractions were removed at the 6 o'clock and 9 'o'clock outlets, respectively. And at 12 o 'clock the compartments were filled again for the following round. Thus, a very refined, continuous separation occurs based on density.

A consequence of working on an installation that a company will actually use is that every problem that arises must be solved. "No' is not an option, because then the factory would have to shut down. It is nice to work on solving such problems, but it can be very stressful, because solutions must be found. Fortunately, the bottom ash team is extremely innovative. The solutions are continuously refined and they are never considered as mere stopgaps. Often, such solutions can then be patented. People are extremely critical, however, because patents cost a lot of time and money. If there is no other direct (commercial) application available, then one does not patent it, except insofar as it is necessary for protecting the intellectual property of the project as a whole.

An example of such a problem was when the density separator's discharge clogged up. Lenka Muchová: "This was caused by copper wires that were often as much as 20 cm long. They slide normally through the filter, but then got stuck in density separator's outlet. The other material then got clogged up behind it, causing the discharge to stop. To solve this problem, we devised a special device that selectively removed these troublesome wires from the inflow. This wire separator made use of the specific shape that differentiated these wires from other materials. You often encounter this: a specific deviation creates a problem, and then you use the same deviation for devising a solution."

## Cement

After all the non-ferro metals were removed from the bottom ash, a residue flow remained that could be used as clean building material, for example for building roads, or for constructing sound barriers. This offers great advantages to the current situation, in which bottom ash must be covered well (with layers of clay and plastic) to prevent it from seeping into the ground water. In addition to the risk of seepage, the presence of aluminum in the bottom ash also presents a problem. Aluminum corrodes over time, and therefore expands rapidly. This is the reason for the typical cauliflower-like formations one often sees on road surfaces.

Clean bottom ash can also serve as a base for limesandstone, for use in cement and asphalt. By pure coincidence, the sand fraction adhered to the regulations (bulk distribution, degree of impurity) in place for its use in limesandstone and cement. This was very fortuitous indeed, because located just a stone's throw away from AEB is the Recycling Maatschappij Steenkorrel, a cement production company. If they could use the reclaimed sand from the bottom ash for producing cement, this would save twice the transport costs: AEB would not have to export sand, and Steenkorrel would not have to import sand. Using the clean bottom ash for cement production provided a more secure outlet for its use than for construction projects. Moreover, additional areas of application ensure greater independence for the contracting parties. With financial support provided by Novem, the technical properties of this cement are currently being studied.

## 'Zero emission'

Peter Rem is extremely pleased with the partnership with AEB, even if it has influenced his normal way of working: "Indeed, your freedom is more restricted. I'm used to publishing everything I discover, and in this way sharing my knowledge with the rest of the world. This is more difficult here. Some things must just remain secret, in order to keep ahead of the competition. We patent as many clever solutions as possible. Extremely ingenious solutions have been found for the ancillary problems we've encountered. But unfortunately, I can't tell you everything about them. Without the partnership with AEB, so many of these great things would have never been realized. I prefer to see a complete plant, with its density separator, wet eddy current separator and all the other excellent equipment reclaiming tons of copper and aluminum from bottom ash, than our laboratory set up of three years ago. It's then that you realize that we have really come a long way."

Thanks to the new processing process, bottom ash has found a valuable new use. Unfortunately, there currently remains a sludge fraction in which approximately 4% of the bottom ash ends up. Consequently, bottom ash processing is not yet a 'zero-emission process'. This sludge is dried and then buried. Research is being done to determine how this sludge fraction can also be processed, so that the dream will be fully realized: 100% recycling of incinerated domestic waste.

In future, reclaiming non-ferro metals from bottom ash will be of even greater importance. The grade of cooper in bottom ash is approximately two times higher than that found in the richest natural ore. Extracting copper from natural ore is a very expensive and environmentally damaging process, because copper ore does not contain metallic copper, but rather copper sulfide. Reclaiming metallic copper from bottom ash however is simple: all you need is a rotating magnet and a bucket of water. Copper is becoming increasingly scarce, thanks in no small part to the rapid growth of the Chinese economy. There is certainly a lot of copper contained in the earth's crust, but only a small quantity of it can be efficiently mined. It is has been whispered that there are insufficient supplies available for every Chinese person to build a house like we have, with the approximately 30 kilos of copper used for our pipes and electrical wiring. This is a startling thought. The price of copper is currently around 2,500 euro per ton – nearly double its price two years ago. For one ton of nickel you must pay 10,000 euro, and silver costs 200 euro per kilo. What the prices will be in five years, ten years and twenty-five years, nobody knows. But it is unlikely they will fall.

## New installation

AEB is currently working hard to enlarge the pilot plant, which has already been operational for a year.

## Sounds of coins

In addition to copper sprockets, brass coat rack hooks, cooper wire and rust-free steel screws, bottom ash also contains clinking coins. Dr. Peter Berkhout, head of the testing facilities at Applied Earth Sciences (CEG Faculty), conducted research to determine how many coins end up in our domestic waste. Based on a setting of 20 mm, Berkhout ltered a test sample of 45 tons of bottom ash (two full truckloads), in which most of the iron and steel had already been removed. The fraction that is larger than 20 mm accounts for approximately 5% (2.25 tons) of the total, and this fraction contained nearly all types of coins, except for 1 and 2 euro cent coins, 10 cent coins, Dutch guilder coins and other small coins. A dry eddy current separator removed the non-ferro metals, which Berkhout then sorted by hand. He washed all the coins, which were only recognisable as blackened discs, in a spin-tumbler, using sand and soap.

Part of a complete collection of coins that Peter Berkhout removed from a 'sample' of Amsterdam bottom ash: removing domestic waste-coins, including coins from the Netherlands, Belgium and Germany.

FMAX / Sam Rentmeester

Peter Berkhout found 69 euro coins, of which two were €2 euro coins and six €1 euro coins, with a total value of €21.55. The old Dutch guilder coins are magnetic, if smaller than 20 mm - except for the 5 cent coins, of which 104 of these were found in the bottom ash. Because 5 cent euro coins are lightly magnetic, only nine of these coins were found. The rest had already been removed by the magnet.

In addition to Dutch coins, the bottom ash also contained a considerable number of coins from countries located in the region of the Netherlands, but also coins from more distant countries, like New Zealand, Thailand, China, Brazil and South Africa. You could compile some very interesting statistics from this information, and, for example, make correlations based on the distance from the Netherlands or the annual number of travellers to these destinations. Finally, 34 coins recovered were for use in the metro, co ee machines and gaming machines, as well as some coins that Berkhout could not identify.

The coins extracted from the non-ferro fraction had a total value of approximately €50 euro. Every ton of bottom ash therefore contains one euro in coins, of which half is in the form of euro coins. The question now is whether it is worth it to build a special separator for removing these coins from the non-ferro fraction, because, as a non-ferro scrap metal, the €2 euro coin only has a value of 1 euro cent. In the non-ferro fraction of the millions of tons of bottom ash that we produce in the Netherlands, there is expected to be approximately one million euro in coins.

To get a complete picture of this found small change, you must also consider the coins deriving from the magnetic fraction. It is not really worth it to do this for the moderate processing recovery of these coins. In the days when the Dutch guilder was the currency in the Netherlands, it would indeed have been pro table, because 10 cent coins, quarters, guilder coins and 2.50 guilder coins were all ferro-magnetic. But for the euro coins, the magnetic can only recover the coins of 1, 2 and 5 cents, which is not exactly a goldmine. You can certainly say that the change to the euro is good for the recycling of bottom ash.

AEB plans to build an installation that can process 300,000 tons per year. This new installation will be capable of processing all of AEB's bottom ash. Experiments in processing bottom ash from other countries will be done to determine if the waste has different properties. The results could help determine how the separator installation will be constructed, and thus maximize the profits of the end product.

Sustainable processing of bottom ash has the wind in its sails. As recently as 2002, the Dutch government planned to ban the use of 'out-of-category' bottom ash as a building material. But through the discovery of a good alternative, people have come to see the economic importance – the situation however must remain 'workable'. Now that AEB and TU Delft have convincingly shown that bottom ash is completely recyclable, new alternatives have emerged. The market for this innovative technology is much larger than just the Netherlands. The annual mountain of domestic waste produced in Europe costs 220 million per ton, of which 70% must ultimately be incinerated. This means that annually 30 million tons of bottom ash is produced – or around 100 times what AEB produces per year. If the composition of all this bottom ash is comparable to that in the Netherlands, then 500,00 tons of copper and 500,000 tons of aluminum can be reclaimed annually, with a total value of 2 billion euro. AEB and TU Delft will certainly reap some of the rewards.

FMAX / Sam Rentmeester

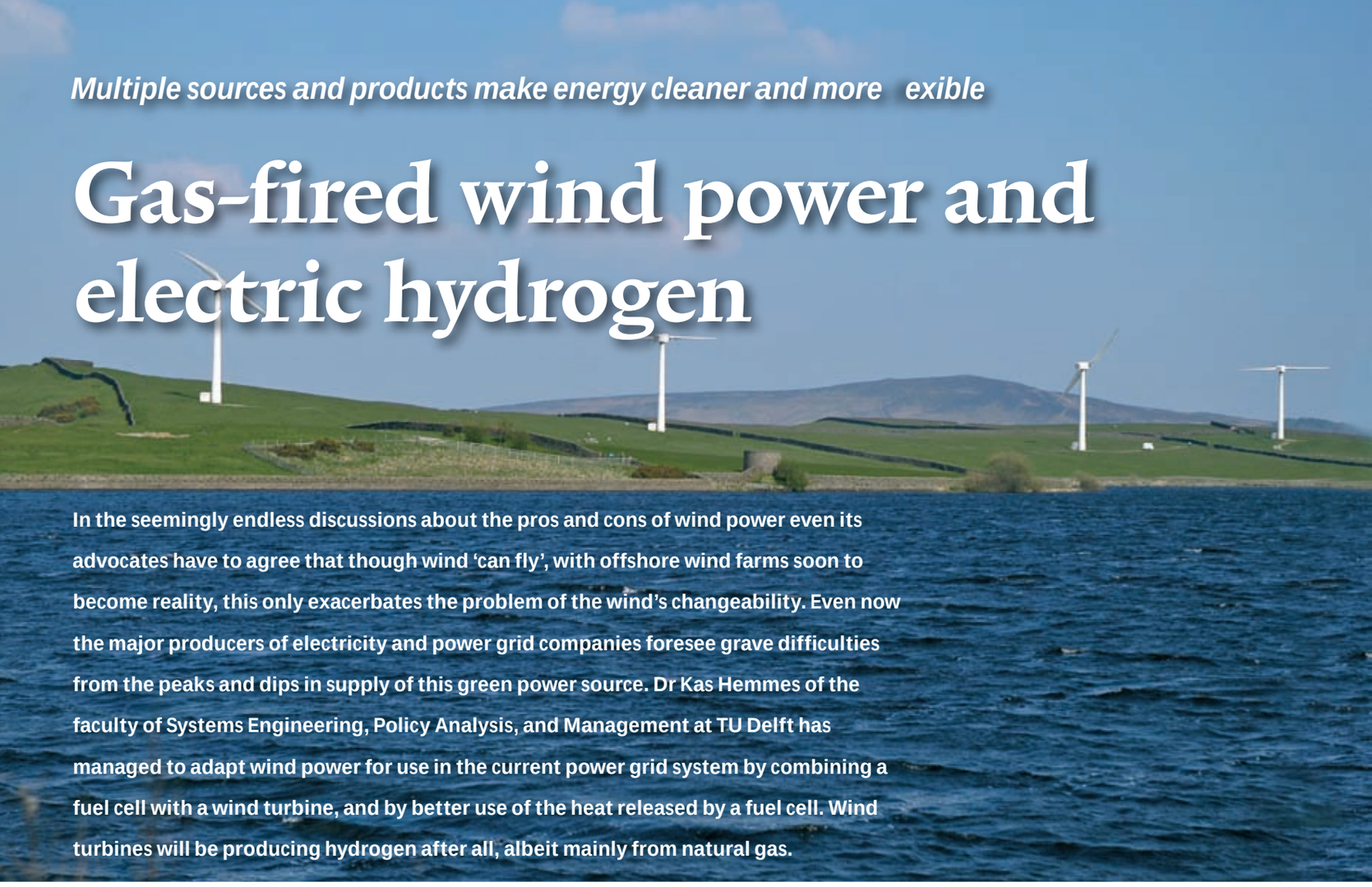
Iron that was separated from other waste is sent via AEB to the scrap yard – for recycling. The reclaimed non-ferro and extra-ferro metals, including rust-free steel (RVS), are sent to companies that use metal, such as aluminum and copper forges.

FMAX / Sam Rentmeester

Fine heavy non-ferro metals removed from the bottom ash include copper, zinc, lead and smaller quantities of rust-free steel, tin, silver and gold.

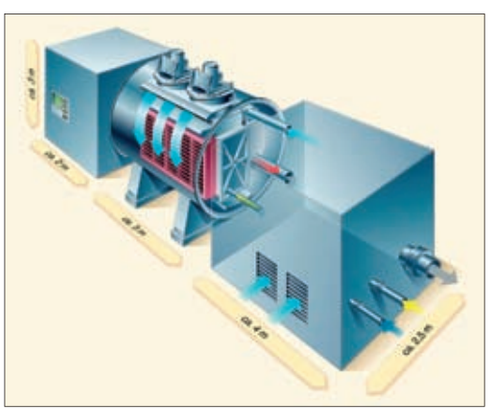
*Multiple sources and products make energy cleaner and more exible*

# Gas-fired wind power and electric hydrogen



**In the seemingly endless discussions about the pros and cons of wind power even its advocates have to agree that though wind 'can fly', with offshore wind farms soon to become reality, this only exacerbates the problem of the wind's changeability. Even now the major producers of electricity and power grid companies foresee grave difficulties from the peaks and dips in supply of this green power source. Dr Kas Hemmes of the faculty of Systems Engineering, Policy Analysis, and Management at TU Delft has managed to adapt wind power for use in the current power grid system by combining a fuel cell with a wind turbine, and by better use of the heat released by a fuel cell. Wind turbines will be producing hydrogen after all, albeit mainly from natural gas.**

"The problem with all power systems is almost always the mismatch between supply and demand," says energy scientist Dr Kas Hemmes of the faculty of Systems Engineering, Policy Analysis, and Management faculty at TU Delft. "The mismatch may be in location, as in: there is oil in Iraq, but we need it here; or in time: you cannot use all the electricity produced while the wind blows, but you still need power even when there is no wind."
Since the number of wind turbines is still relatively few, electrical power systems can generally manage to buffer the production peaks of wind turbines. But earlier this year there was a to-do about the likelihood of the numerous wind turbines in north Germany overloading the Dutch grid. Although gas-fired power stations can be stepped back a bit to make way for the extra electricity produced by wind turbines, the process is far from instantaneous. It also reduces efficiency and leaves production capacity idle.
Hemmes: "The complaint of gas-fired power stations is that they will be forced to shut down whenever the wind blows, which affects their selling price."



Molten carbonate fuel cell system. The system comprises a gas pretreatment unit (right), a hot module in which the fuel cell stack is integrated, and an electricity converter (left).

**Electrolysis** One solution that has received a lot of publicity is the use of surplus wind energy for the electrolysis of water into oxygen and hydrogen. It is the subject of calculations all over the world, even though it is hardly being applied. The hydrogen is stored to be converted back into electricity by means of a fuel cell when the wind stops blowing.
The drawback of the double conversion method, and of the storage itself, is that it causes extra losses. The real-world conversion efficiency of water hydrolysis to produce hydrogen is approximately 80 to 90 percent, and the efficiency of the fuel cell is even lower, according to Hemmes. What's more, besides the fuel cells next to the wind turbines, a electrolysis plant will have to be added, both of which will only be used occasionally, making the option far from ideal from a commercial point of view.
Hemmes has a better idea: build a large fuel cell next to each wind farm (e.g. of the popular Molten Carbonate Fuel Cell type) which is also fed with natural gas. A cell like that will be able to step back its electricity production relatively quickly when there is a lot of wind. In this low utilisation mode, the fuel cell can be used to produce more hydrogen.
It works like this. We know that a fuel cell produces more than enough heat to convert natural gas into hydrogen. This means that inside the fuel cell more natural gas can be converted into hydrogen (and carbon monoxide) than it needs for its own use. The hydrogen could be stored to be fed to the fuel cell in times of calm to replace the natural gas. The hydrogen could also be piped away into a hydrogen pipeline network, which would first have to be constructed, or it could be mixed with natural gas (an option for which plans already exist at national and European levels). In the setup conceived by Hemmes the storage capacity would no longer be needed, as it would be replaced by the effective use of the storage capacity of the natural gas network.

**Magic** A new configuration like this would be able to adapt rapidly to the fluctuations in incoming electricity as well as variable demand. "The major advantage of the concept is its flexibility," says Hemmes.
On top of that, the "conversion" of electricity into hydrogen is more efficient

than it is with electrolysis. Calculations show that for each additional kWh of wind electricity (as a result of which the fuel cell produces 1 kWh less electricity), hydrogen is being produced with energy content of approximately 3 kWh while the influx of natural gas remains the same!

"It seems like magic, a conversion efficiency of 300 percent," Hemmes says. The truth is that the apparently free energy comes from the heat produced by the fuel cell, which would otherwise be lost. Because natural gas is also being added, the heat can be put to good use. It should be noted that the hydrogen produced in the fuel cell system still forms part of a gas mixture.

"The overall system efficiency, which is the efficiency with which incoming energy gets converted into outgoing energy, is higher in the low utilisation mode, and approaches 90 percent," says Hemmes. "The outgoing energy comes in the form of electricity, hydrogen and carbon monoxide, not as heat as in total energy systems. Using steam, carbon monoxide can be converted into hydrogen in a practically energy-neutral process."

Hemmes has already filed for a patent on the process. He has just returned from Spain, where he held the keynote presentation at the European Hydrogen Energy Conference. The concept is highly reminiscent of a concept that is gaining popularity in the power industry, that of total energy systems, in which gas or some other source of energy is converted into electricity and useful heat, which can be used to heat houses and other buildings.

## Multi-source, multi-product

"This idea goes a big step further, though," says Hemmes, "for not only does the installation supply two products at once, electricity and hydrogen, it also uses two sources of energy, natural gas and wind power."

Hemmes has worked on the mathematics of these multi-source, multi-product systems together with Swiss researcher Martin Geidl. The wide variation of settings makes them very suitable for finding the optimum between efficiency, production capacity, and economy of use. Technically, the idea is also connected with a further integration of different systems for the production and conversion of energy, as well as the production of chemicals.

Another variant on the multi-source, multi-product idea is to use natural gas, air, and possibly wind energy, as sources for producing nitrogen. Inside the fuel cell, oxygen from the air reacts with natural gas, leaving a nitrogen-rich mixture. In the Netherlands nitrogen is often added to imported natural gas in order to bring the composition to the local standard mixture (which contains 14 percent nitrogen), a procedure that will also be necessary when hydrogen is added to natural gas in future. The current way of producing nitrogen is to extract it from air by means of an expensive cryogenic process. The process uses large quantities of energy, up to several megawatts of electricity.

"This would be a perfect way to produce nitrogen cheaply at the exact spot where it can be added to natural gas. In addition, the method produces electricity instead of consuming it," says Hemmes. He has taken out a patent on this idea, too.

## Economic benefits

In the end, the economic benefits of such systems will lie in the additional flexibility, according to Hemmes, especially when further research and development lowers the price of wind turbines and fuel cells even more.

"We haven't done all our sums yet," Hemmes says, "which is partly because it is very difficult to calculate the added value of flexibility. The energy industry tends to be focused on the lowest possible price at a constant production rate, but reality involves fluctuations in supply and demand and consequently, in price."

Various publications are in the offing now that the patents have been filed. This was also a prerequisite for speaking on the subject at a conference. Even though power company representatives in Spain did not show up in droves with plans to start building the installation on the spot, the response was highly encouraging, according to Hemmes.

"A keynote speech in itself indicates how much a new development like this is appreciated."

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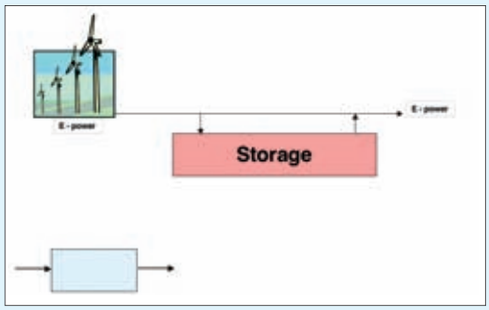
For information on adding hydrogen to natural gas, see www.vg2.nl.




The current views on the way the uctuations in wind energy should be bu ered involve some form or other of energy storage in normal batteries, in REDOX ow batteries, or in hydrogen.

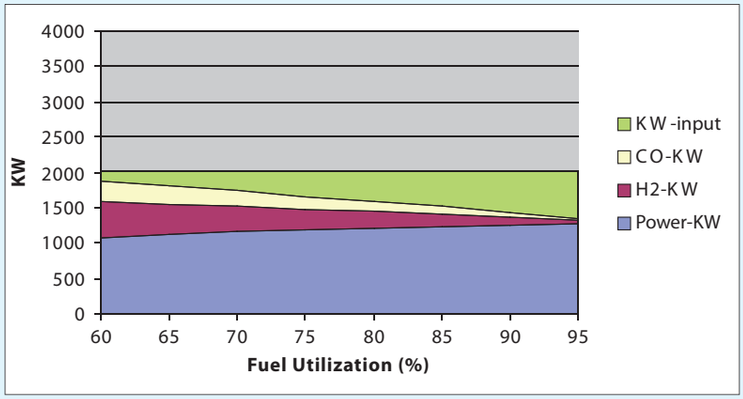
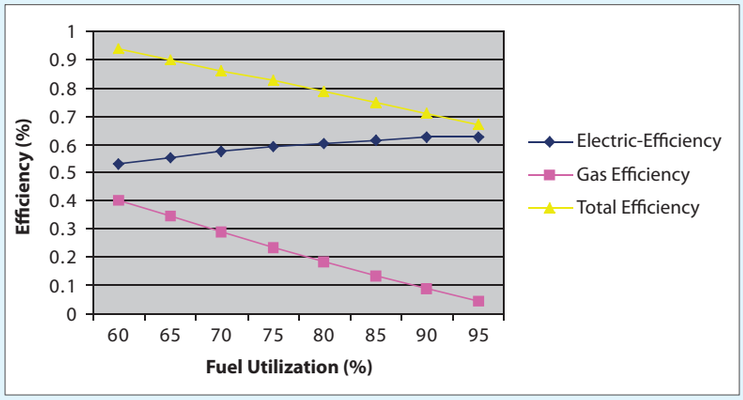
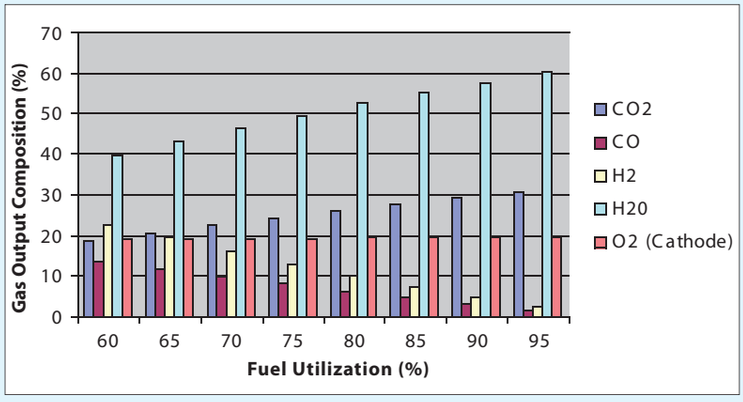



Diagram of the input and output energy of an internal reforming fuel cell system as a function of utilisation (the conversion ratio of natural gas into electricity and heat). The electricity production at – utilisation has decreased little relative to the standard operating conditions ( – utilisation). On the other hand, the production of hydrogen and of CO has increased considerably.




This diagram shows the system e ciency of the fuel cell as a function of the utilisation of natural gas. The gure shows both the electrical e ciency and the gas e ciency, both de ned as the output (in electricity and gas, respectively) relative to the natural gas input. The third plot repre-




sents the sum of both, i.e. the overall system e ciency.

Calculation results for the composition of the exhaust gases for the internal reforming fuel cell system in high power mode as a function of the natural gas utilisation. In addition to hydrogen the anode exhaust contains carbon monoxide and a relatively large amount of water.

Arno Schrauwers

## Nanomaterials

Professor Andreas Schmidt-Ott's group studies nanomaterials, in particular the connection between the structure at nanolevel (1 nanometre is one millionth of a millimetre) and the properties of the nanomaterial. To test nanomaterials, you rst have to be able to create them. Nanomaterials production involves a lot of measuring to make sure that you are actually producing what you want, which is where the respirable dust (or rather, soot) meter comes in useful. In the past Schmidt-Ott also carried out research into air pollution. The current soot meter research is in fact a by-product of research on air pollution and on nanomaterials.

With a simple setup consisting of a carbon sensor, a CO sensor, a data recorder, and a portable computer, Professor Andreas Schmidt-Ott and Andy Kurniawan were able to determine the exhaust emissions of passing cars. The emission values of these cars varied enormously.

**The Netherlands is having trouble with the EU standards for respirable dust (PM ). The Dutch Council of State recently blocked a number of residential development projects because local conditions failed to meet the PM standard. Research by the Nano Structured Materials group at TU Delft shows that some of the seven or so million motor vehicles currently on the road in the Netherlands are responsible for over of all respirable dust emitted by traffic. Although most of these super polluters are diesel-engined, they also include vehicles using lean-burn engines with direct fuel injection from Volkswagen, Mercedes, BMW, Mitsubishi, and Honda. The TU Delft nanotechnologists have developed a respirable dust meter that can be used to locate the worst offenders in moving traffic.**

Five per cent of all motor vehicles produce over 40% of all respirable traffic dust

# Respirable dust meter locates super polluters in traffic

The Netherlands, once a shining example in environmentally- conscious Europe, seems to have gone downhill a bit to its current status of Europe's tramp. One of the most recent environmental problems dogging the country is that of respirable dust. The Dutch Council of State recently blocked a number of building plans because local respirable dust conditions did not meet EU-wide standards. At the European Commission, Dutch State Secretary Pieter van Geel of the ministry of Housing, Spatial Planning, and the Environment argued for emission controls at source in the form of soot filters on diesel engines. To date it remains unclear whether the European Commission will grant permission for this partial solution. Whatever happens, vehicles with direct fuel injection engines producing respirable dust would also have to be fitted with filters.
Fortunately, the Dutch government now appears to have been presented with the ideal solution by the nanomaterial scientists at the Delft ChemTech department. Professor Dr Andreas Schmidt-Ott of the Nano Structured Materials section considers respirable dust a somewhat neglected subject.
"Some estimates put the annual number of deaths caused by respirable dust as high as 10,000 to 15,000 in the Netherlands alone. Those numbers far exceed the number of traffic deaths, which always hit the headlines. Traffic is the main producer of respirable dust in the form of soot particles, which in this case are ultrafine in size, less than 0.1 micrometres across. All in all, some 3% of the mortality rate can be attributed to the respirable dust emissions of motor vehicles."
It's not so much the age of a motor vehicle that causes problems as a lack of proper maintenance. At least, Schmidt-Ott suspects as much, based on a Californian study from 1995 in which CO and hydrocarbons were measured (i.e. no soot particles) and which also showed that a relatively small number of super polluters are responsible for a considerable part of the total emission."


Hollandse Hoogte

Although knowledge about the noxiousness of soot emissions has grown, the relative number of diesel-powered cars has increased. In part this may be attributable to the fact that over the past years diesel engines — which have always been more economical to run — have become even more fuel-e cient and less polluting. Diesel-engined cars have been tted with catalytic converters for some years now, and they recently became available with a soot lter. Nonetheless, in the Netherlands the diesel eet as a whole accounts for a major contribution to the total quantity of respirable dust in towns. Elsewhere in Europe, diesel emissions in towns have also become a problem.

**By the roadside** Until recently, the emission of respirable dust (which in the case of traffic amounts mostly to soot) could only be measured as an overall value, or by inserting a probe into a vehicle's exhaust pipe, as is done at the annual MOT test. There were no reliable methods for measuring the soot emission of individual vehicles as they pass on the road. Helped by previous research by German professor Schmidt-Ott and with the perseverance of Indonesian student Andy Kurniawan, we now have a system that can measure the soot emission of individual vehicles from the roadside, albeit in rather embryonic form.
"The measuring setup," Schmidt-Ott explains, "consists of a carbon sensor and a carbon dioxide sensor. The carbon sensor is a further development of some of my earlier work I did at the ETH in Zurich. The principle of the sensor is that you charge the carbon particles by means of an ultraviolet light source. Carbon particles are highly selective for a certain photoelectrical effect. The charge can be measured and forms an indication of the amount of elementary carbon (EC); in other words, soot. At the same time you measure how much carbon dioxide is emitted from the exhaust pipe. The relative quantities of carbon and carbon dioxide form a measure of the amount of carbon particles emitted per litre of fuel. As both of these materials are so easy to detect, there is no need for an exhaust probe, and you can simply sit by the roadside with your equipment. Ambient factors such as wind velocity have little or no effect on the measurements, as the minute soot particles behave like a gas. The only time you cannot us the system is when it rains, for then the carbon and gas particles will behave differently, which would affect the readings."
Of course, you cannot measure too far away from the exhaust pipes of passing vehicles if you want to avoid blurring the separate peak readings, which would make it very difficult to attribute readings to individual motor vehicles.
Schmidt-Ott: "Our method already is more sensitive and faster than the measuring equipment used in the United States to monitor passing motor vehicles."
The soot meter has been tested under field conditions, with Kurniawan limiting the test to passenger cars. He measured the emissions of some 1250 vehicles.
So will the method enable you to pick out the offenders?
Schmidt-Ott: "That much is certain. Experiments elsewhere included the use of lasers. The concentration of gases can readily be measured using lasers,

Volkswagen Media Services


Petrol-engined cars with direct fuel-injection have been being marketed for quite some time now. These engines produce soot that is many times ner than the type of soot from diesel engines. Recent epidemiological studies show that this ner soot poses an even greater danger to public health.

## Direct-injection petrol engines

The current discussion about the reduction of respirable dust focuses on diesel-engined vehicles (which is hardly surprising, considering the number of diesel cars). Nonetheless, cars tted with lean-burn petrol engines, in which the fuel is injected directly into the cylinders, also produce considerable quantities of respirable dust, tending to close the gap with modern diesel-powered vehicles. Although diesels produce about ten times as much respirable dust by mass as do direct-injection lean-burn engines, the number of particles is practically the same according to Dr Michiel Makkee, a lecturer at ChemTech. As an exhaust gas specialist he pioneered the soot lters currently tted to the products of French car maker Peugeot. This means that the respirable dust emitted by direct-injection petrol engines is of a lower magnitude of size than its diesel counterpart, and the smaller dust particles are the most lethal to our health. The larger particles tend to be ltered out by our nose and bronchial tract, but the smallest particles can travel down to the remotest parts of our lungs.

The European Commission is proposing that as of 2008 new direct-injection lean-burn petrol-engined cars should be tted with a closed soot lter, but so far the measure is still awaiting approval by the European Parliament. The current number of cars tted with a lean-burn engine is relatively low, which is why the Dutch environment minister is not unduly concerned about the respirable dust standard for such engines. However, the number of these cars is expected to increase rapidly. Direct-injection engines are the automotive industry's answer to the covenant between the European industry and the European Commission to limit the carbon dioxide emission of cars to 140 grams per kilometre. Although direct-injection engines are much more fuel-e cient than standard petrol engines, the latter, if properly maintained, produce practically no respirable dust at all.

but solid particles such as soot remain problematic. Even if that problem were to be solved, our method will still be much simpler to set up, since the laser technique requires light sensors on the opposite side of the road to determine the concentrations in the exhaust fumes. All our system needs is a box to live in and a set of batteries."

**Politics and legislation** None of this means that State Secretary van Geel will be able, any time soon, to send out his minions to track down super polluters, armed with an off-the-shelf respirable dust meter complete with data processing unit.

"This is just an experimental setup," Schmidt-Ott says. "The conversion of field readings to useful pollution concentrations still has to be done by hand, which has kept Andy very busy. Nonetheless, these are matters for further development."

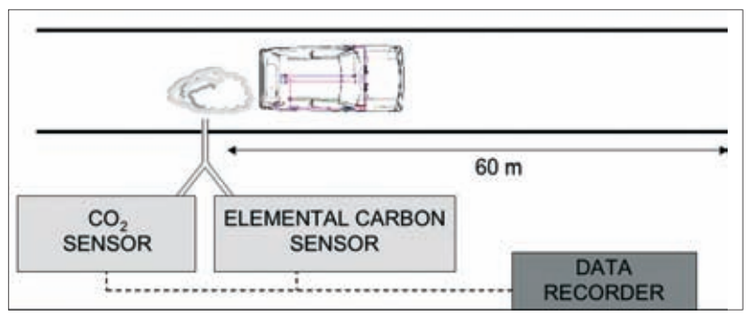
Schmidt-Ott has been getting a lot of response at conferences, and he expects that many more people will become interested and contact TU Delft when an article by himself and Andy Kurniawan is published in the highly regarded Environmental Science and Technology magazine.

"At a conference in Canada I had some interesting contacts with scientists from Japan, where respirable dust is also a problem. It would be nice if the Delft measuring method were to prove a breakthrough in this field. But funding is needed to develop the equipment into a commercially viable, portable device. Perhaps we the industry will help, but for the time being no one has made any concrete moves. We will simply have to wait for politicians' interest being aroused in the possibility of in situ soot emission monitoring."

"Current legislation is concerned solely with the standards for new motor vehicles, and these will become increasingly strict. However, if you fail to maintain a motor vehicle properly, within a few years its emission of respirable dust may have increased manifold, and will keep climbing. You won't even hit the MOT limit before the emission is a thousand times as much as the original value. If you want to be serious about solving the respirable dust problem, you should start by measuring the emissions of individual motor vehicles. This measuring system lets you easily spot the most polluting cars, but it takes legislation to actually make it work. The first step might be to check whether the cars actually meet the MOT standard."

Linking the system to a camera and a registration number recognition system would enable a summons to be sent to each polluting motorist to have a new MOT test done at short notice. All it takes now is for The Hague (or Brussels) to act.

For more information, please contact Prof. Dr. Andreas Schmidt-Ott, phone +31 (0)15 2783540, e-mail a.schmidt-ott@tnw.tudelft.nl, or Andy Kurniawan, phone +31 (0)15 2783995, e-mail a.kurniawan@student.tudelft.nl.




Air from the street is continuously sucked in through a tube connected to a carbon sensor and a CO sensor, the signals of which are fed to a data recorder. The measuring location is metres before a crossing, in other words a point at which most of the tra c will be decelerating. This avoids unrealistically high emission readings from cars that might otherwise be accelerating. The current measuring setup is capable of distinguishing between exhaust plumes of cars passing at intervals of at least seconds.

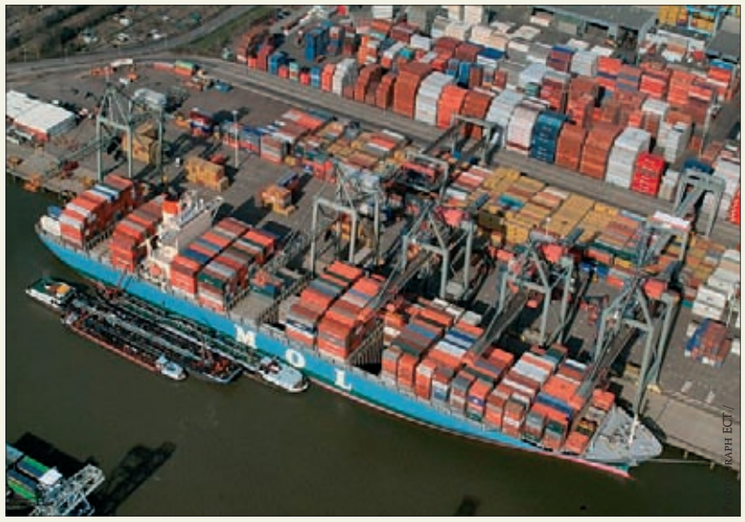
Photograph Ronald Tilleman / www.

*Improved use of railway infrastructure requires chain director and change of culture*

# Transfer hubs

*Additional terminal transport system speeds up rail-to-rail container transfers*

The Kijfhoek shunting yard near Barendrecht. This is where many of the wagons coming from Europort are sorted by destination. Most container trains do not come through the Kijfhoek yard, as they already received their destination cargo at the sea terminal. Each day to container trains leave for the hinterland.

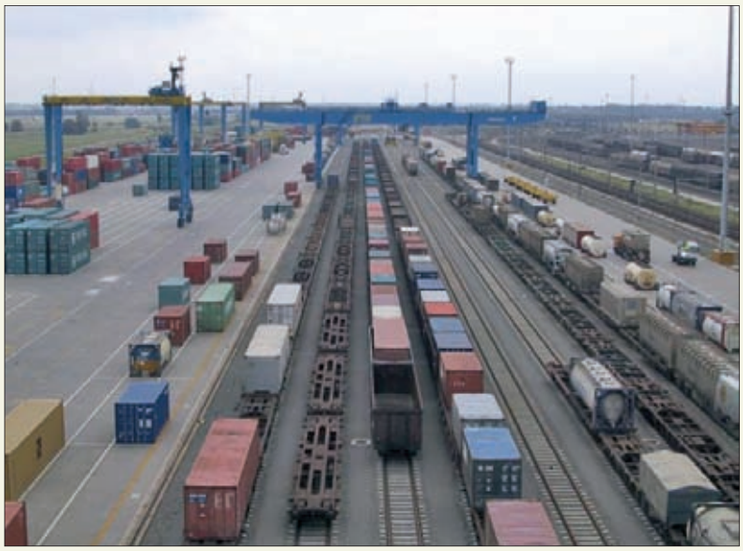



Photograph ECT Rotterdam

The source of containers for all transport to the hinterland is the sea terminals of the various transshipment companies, including ECT and Short Sea Terminals.

Astrid van de Graaf

**Road transport systems suffer from congested roads, environmental legislation, and the threat of pay-as-you-go systems. All grist to the mill as far as the railways are concerned. Unfortunately cargo transport by rail is not exactly renowned for its flexibility and reliability, and the quality offered for the price is not competitive enough for all markets. One of the main bottlenecks is the time-consuming shunting operations. Researcher Yvonne Bontekoning at the OTB research institute of TU Delft compared the performance of various shunting and transfer techniques. The fastest turned out to be a terminal with an ingenious supporting transport system. However, it would have to process at least nine goods trains a day to become economically viable. Unfortunately, things are different in the real world, which is why Bontekoning thinks the best solution for now for optimising the use of our rail infrastructure is to adapt the existing rail-to-road terminals.**

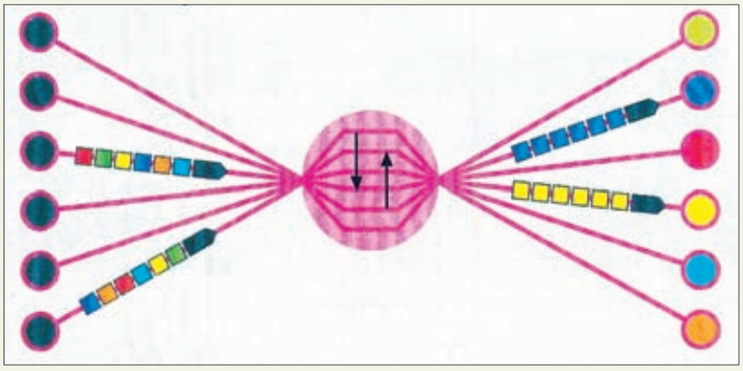


[INTERFERRYBOATS, ANTWERPEN] HTTP://WWW.INTERFERRYBOATS.BE

The Main Hub of Antwerp, with eight parallel tracks. Gantry cranes sort the containers by destination.


EWS RAILWAY / WWW.EWS-RAILWAY.CO.UK

The gantry cranes are tted with a spreader that can be rotated so containers will always be loaded onto the train with the door ends facing each other. One of the reasons this is done is to prevent theft.



To move as much goods tra c as possible o the roads, which are plagued by congestion, it would be e good idea to introduce hub-and-spoke systems. These allow smaller volumes (less than half a train daily) to be shipped economically by rail. The circles on the left represent di erent sources, such as sea terminals and inland terminals in di erent areas. At the source terminals the containers for di erent destinations are loaded onto a train. When the trains arrive at the hub, the containers are sorted by destination by either of two di erent techniques. The containers can be lifted by a gantry crane from one wagon to another, or the wagons are shunted to be reformed into single-destination trains.

We tend to forget they are there, since goods trains operate mostly at night. At the end of each day, lorry drivers drop off their containers at the terminal in Rotterdam. The next morning the containers arrive in Duisburg, Germany, where they are loaded onto new lorries. Each day, some 25 to 35 trains like this depart from Rotterdam for destinations in the hinterland. This is the generally accepted model for transporting freight by rail, known as the point-to-point model. At the start and end terminals the containers change transport mode. Intermodal transport combines the advantages of the various transport options. The advantages of transport by road are flexibility and accessibility, while trains offer the existing network without congestion.

"Point-to-point transport requires large numbers of loading units like containers so that trains can travel daily to each destination. The large volumes and direct transport without stops on the way keep the transport price per loading unit low," says Ir Yvonne Bontekoning, a traffic & transport researcher at the OTB research institute, an interfaculty institute within TU Delft. Besides the point-to-point model there is the so-called hub-and-spoke network, in which the rail tracks (the spokes) converge in a central node (the hub). At the hub, trains carrying loads for different destinations are split up and their parts reassembled into trains each with a single destination. This type of network is starting to fade from the railway landscape, and being replaced by point-to-point transport.

## Time-sensitive products

Big volumes are needed to make trains a viable proposition. A goods train carries about 30 to 45 containers and can be 400 to 600 metres long. In the current system, there is simply no room for small volumes. To get small transport back onto the tracks, hub-and-spoke networks need to be reintroduced, according to Bontekoning. Small consignments of cargo can be assembled into mixed trains at various starting stations, to be redistributed at the hub for the various end destinations. However, a scenario like this will only work if the transfer stage can be made quicker than it currently is. Shunting a train of wagons takes about six hours.

"Trains shouldn't be standing still, trains should roll," says Bontekoning. "At least, that is what the European commission thought when they decided to make the improved use of the existing rail infrastructure one of the main policy objectives of the fourth framework programme (1994-1998). This decision led to a flurry of activity. Companies, consultants, and scientists came up with all sorts of concepts to get goods transport back on the rails."

Terminet was a project by TU Delft that investigated the effect of new networks and transfer techniques. Bontekoning, previously a management trainee at the Rotterdam-based container company ECT, joined the project as coordinator. Armed with the know-how and experience she gained, she started her doctoral thesis.

"If you want to maker better use of the rail infrastructure and move goods traffic from the roads to the railways, your best bet is to go for the small volumes of time-sensitive products such as fruit and flowers, or urgent shipments. Companies that keep their stock levels low must be certain that the containers will arrive in the morning. Reliability and speed are essential if a company is to make the transition from road to rail."

## Terminal test

To make the transport of small, time-sensitive loads by rail a viable proposition, the transfer process must be speeded up. How can this be done? What are the available transfer techniques, and which of them offers the best performance in a hub? Bontekoning thinks of her research for her doctorate as a consumer test: which of the existing techniques offers the fastest handling of containers at the lowest price?

Goods transfer techniques come in two basic varieties, shunting train wagons, or moving separate containers. Shunting involves rearranging entire trains until all the wagons for the same destination have been formed into a new train. The technique itself comes in two varieties, gravity shunting and flat shunting. In flat shunting, the wagons are pushed by a shunting engine, whereas in gravity shunting the engine pushes the wagons up and over a shunting hump, from which they are left to roll downhill, where points are switched to send them onto the right sorting tracks.

"Shunting takes a lot of time. The couplings between the wagons have to be released by hand, and the hoses of the braking system have to be disconnected." As an alternative for shunting, containers can be transferred between trains

at the hub. Two types of container transfer terminals are currently in use, start and end terminals for road/rail transfers, and a new generation of hub terminals, which are used for rail-to-rail transfer during the night, and for rail-to-road transfer and vice versa during the day.o

**Latest hub** The new generation hub features the latest innovations in transfer techniques and is fully robotic. There is only one thing wrong with it. The hub has yet to be built to its full size. The system has been the subject of much research and studies, and a prototype of the gantry crane and transport system has been built and extensively tested. The new hub is much quicker, but it is also very expensive.

The supporting transport system is one of the main innovations of the new hub concept. The large cranes each service their own area in different parts of the transfer site. They straddle their territory like a bridge, suspended from which a spreader travels to and fro to pick up containers from one train and deposit them onto empty wagons or the transport system's wheeled pallets. At right angles to the travelling direction of the spreaders, two extra transport tracks run beneath the cranes, on which the magnetically guided wheeled pallets move the containers from one crane to the next.

Bontekoning: "Cranes are big, heavy and cumbersome. Even a fast gantry crane can only move forwards and backwards at a slow pace. Putting the containers onto a wheeled pallet saves lots of time, in spite of the fact that it is an extra step. The transport system supports the cranes in their most time-consuming travelling direction, which is sideways."

She has calculated that some 60 to 70 minutes transfer time can be saved by using six cranes spread out over the terminal. More cranes means less transfer time. Cost however, is a different story, since each additional cranes makes the transfer operations more expensive.

**Cost and time** According to Bontekoning the absolute upper limit for goods transport by rail is EUR 50 per loading unit.

"In fact, the cost should be as low as 25 to 30 euro. In Germany, transfer prices of EUR 15 are not uncommon for time-insensitive products such as coils of steel, since the investment in infrastructure has been spread out over a long period by the government, so prices need to cover little more than the exploitation costs."

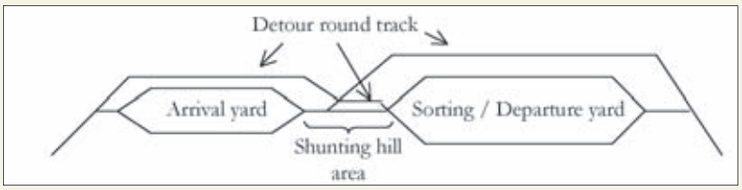
The maximum stopover time at the hub must be considerably less than the current five to six hours. What's more, the total transport time may not exceed the transport time by road. With this to go on, Bontekoning calculated a maximum stopover time of 120 minutes at the transfer station.

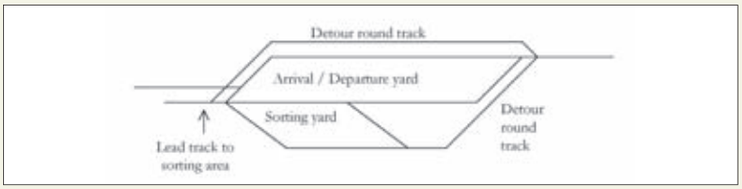
"Those two hours include everything, the transfer itself, delays, waiting times, power cuts, and cranes that are out of order. Given this transfer time and a travelling speed of 80 kilometres an hour, a goods train can travel 800 kilometres during the night, which takes it a fair distance into Germany or France."

Bontekoning did calculations for the four different transfer techniques in a model simulation, arranging them according to transfer time and cost per loading unit. The new generation hub with four to six cranes emerged as the best option.

**Synchronous** These innovations and calculations are all very well, but which conditions does it take to make the new hub stand any chance? Well, to operate the new hub economically at least nine trains must be processed every day, preferably in three batches of three trains each. That is quite a lot, compared with the current situation in the Netherlands. And it is not the only condition. To rapidly switch containers between trains, the goods trains must arrive exactly on time. The ideal arrival pattern is to have a train come in every five minutes, so all the trains involved in the transfer can be present within five to 25 minutes.

"The actual transfer of goods takes 20 minutes. Of course, for safety reasons trains cannot arrive simultaneously. By keeping the arrival intervals as short as possible, in an ideal case the entire cargo can be redistributed within 44 minutes. The containers of the first train can be pre-sorted on pallets. If everything runs according to plan, the transfer of containers from three mixed trains can be over and done with in an hour. Given ten cranes the transfer can be done within fifteen minutes. The method beats any shunting system hands down since disconnecting the air hoses and changing engines alone takes more than half an hour."




Two di erent shunting methods are in use in the Netherlands, hump shunting and at shunting. Hump shunting uses an engine to push wagons onto a hump from which they roll down one by one by gravity alone, to be directed by a set of points onto the right sorting track to form a new train. In at shunting the engine picks up the wagons singly or in small groups to move them to di erent sorting tracks. Although this method is very time-consuming, it takes up less space and requires fewer infrastructure facilities.

(Photograph Ronald Tilleman/ www.tilleman.

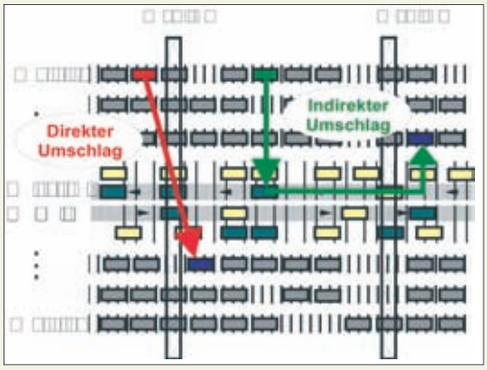
Modern hump sorting yards feature automatic braking systems tted between the tracks. These calculate exactly how much each wagon must be braked in order to bring it to a timely standstill on the sorting track. This prevents the wagon from crashing into the previous wagon.


(Photograph Ronald Tilleman/ www.tilleman.

Before the train can be pushed up the hump, the air hoses of the braking system that run between the wagons must be disconnected and the couplings unscrewed. At the highest point the coupling is released by an assistant wielding a stick.

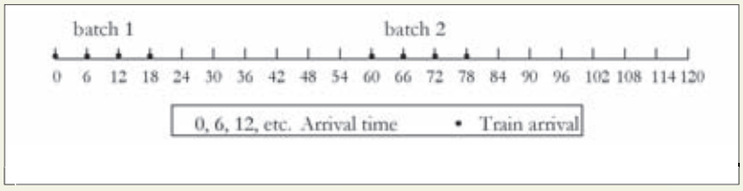
Noell Crane Systems Würzburg, Duitsland
http://www.noellcranesystems.com/

The exchange of containers at the Noell hub is speeded up enormously by a smart system of magnetically controlled wheeled pallets that carry the containers between the relatively sluggish cranes. A pilot plant at Hamburg has already been successfully tested.




Knut Alicke / IFL, Uni-Karlsruhe

Containers can be transferred in either of two ways, directly and indirectly. In direct transfer, a crane is used to pick up a container from one train and load it onto another train, whereas in the indirect system one crane picks up the container and loads it onto a wheeled pallet, from which another crane picks it up to move it onto the receiving train.




Knut Alicke / IFL, Uni-Karlsruhe

Essential for the proper operation of a hub-and-spoke system is the synchronised arrival of trains that form a batch. This means that the trains arrive within only a few minutes of each other. To minimise waiting time, the trains of the next batch must not arrive before the previous batch has been processed.

## Unreliable

Unfortunately, real life is different. There is a simple reason why the new hub system has not yet been implemented. The reliability of the complete chain will have to be improved first. Far too many trains are still running late. A delay of 30 minutes or more ruins the whole scheme. The delay figures show that in international transport only 70% of goods trains arrive within 30 minutes of the planned time. In addition, 23.5% come in more than an hour late. This is far too much, according to Bontekoning. Nationally the percentage of trains arriving within half an hour is much higher, at 90%, but even that is not enough. An acceptable figure would be 95%.

The lack of reliability was one of the main reasons why a number of hub-and-spoke networks with shunting yards were discontinued. The hub at Metz in France was closed in 2004 after 10 years of service. X-net, the hub at Herne in Germany, folded after only 2 years. Both these hubs were owned by the Intercontainer/Interfrigo company.

"The closing down of these hubs is in fact at odds with EU policy, which is to promote the transport of goods by rail. The point-to-point model appears to be the trend in the railway industry, and has been since the 1990s.

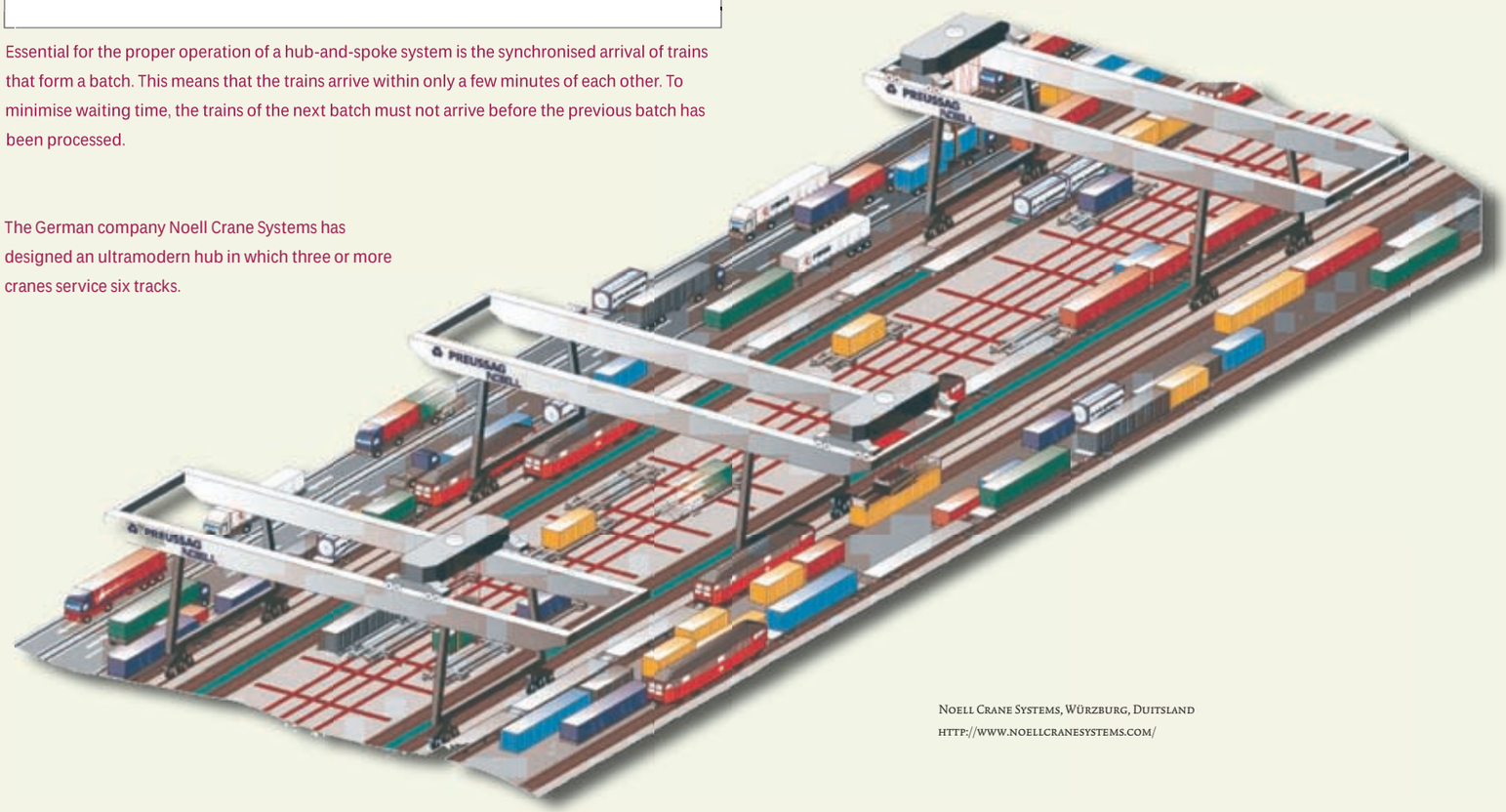
The conditions that would enable the new generations of hubs to operate economically simply are not being met. There is too little cargo on offer, the network lacks reliability, and synchronous arrival patterns cannot be arranged. So what can be done? According to Bontekoning the best solution would be to expand the existing terminals to make them suitable for rail-to-rail transfer.

"The essential point is to have the support of a transport system. This can take the form of magnetically guided wheeled pallets, or AGVs (Automatic Guided Vehicles), or manually operated lorries, which are highly flexible and fast."

## Liberalisation

Technically speaking goods transport by rail can play a much larger role than it does at present, but first the planning and organisation side of things will have to be sorted out. This is far from easy with so many interested parties in a transport industry that has just deregulated. Bontekoning: When the networks, traction and train services were all in

The German company Noell Crane Systems has designed an ultramodern hub in which three or more cranes service six tracks.



Noell Crane Systems, Würzburg, Duitsland
http://www.noellcranesystems.com/

one hand. organising goods transport may not have been easy, but so far deregulation hasn't really improved matters. But it is early days yet, and the process is slow and laborious. Existing and potential clients I interviewed said they though the current railway industry culture would be blocking progress for a while yet."

In fact, Bontekoning considers it nothing short of a miracle that any goods trains remain running at all.

"At each border crossing, engines and drivers have to be changed. This is an international regulation. Dutch drivers are not allowed to drive trains on the German railways, and vice versa. All the time, new engines prove unavailable, or a driver fails to turn up. The culture of sluggish government organisations all over Europe is also partly to blame. Their employees cling on to the rights they have acquired over the years. Now they are now being joined by new players who are cheaper, with more flexible employees who quite like having an all-round job."

Liberalisation certainly offers opportunities, according to Bontekoning.

"Liberalisation per se is not a bad thing, certainly not in areas in which the government acts weakly or simply sits back. Rome was not built in a day either. Many problems remain to be solved, and that is what the EU is doing. One thing you do notice is how shipping companies like P&O Nedlloyd are starting to handle the traction part themselves. Purely out of dissatisfaction with the current state of affairs, they are working themselves deeper into the chain. The only thing missing is the urgency to innovate. What the transport industry needs is a market leader to force suppliers into offering performance and innovation by setting strict delivery conditions. Unfortunately, the rail transport industry still lacks a chain director of such stature."

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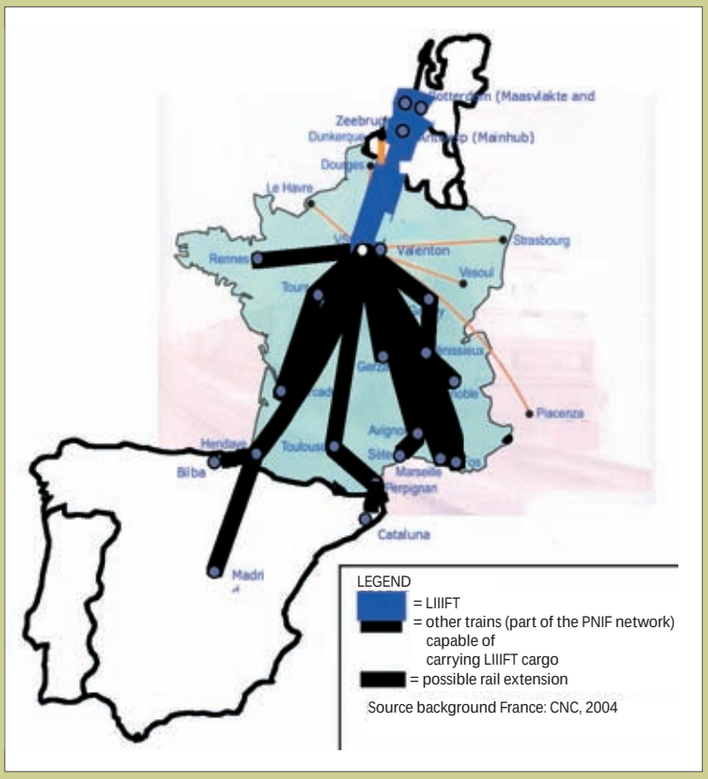
SBB, Zwitserland / www.sbb.ch

Most goods trains run at night, so shunting yards tend to be busy mainly at night, with most of the tracks lying empty during the day.

The time window available to trains for moving from source to destination terminal is called the night jump. Slower transfer techniques mean less distance travelled during the night jump. At an average speed of km/h a train can travel over km during a -hour night jump (from p.m. to a.m.), if the transfer can be completed in one hour, which should be possible with the new transfer technology. Given a transfer time of hours (hump shunting), a train will travel less than km.

KombiVerkehr, Ludwighafen, Duitsland

Road/rail terminal at Ludwigshafen, Germany. Existing road/rail terminals would o er the best candidates for the hub transfer technique, provided the cranes are supported by a local transport system. It may not even be necessary to use a robotic wheeled pallet system like the one at the Noell Megahub, or based on AGVs (Automated Guided Vehicles). The existing terminal lorries could be used instead. In this way, investments can remain limited, and the terminal would not be dependent on one type of service network, the hub-and-spoke system.




*Cost-cutting by upscaling*

## Trains stretching over a kilometre

"The concept of running kilometre-long trains is not so strange. Once you start thinking about cost-cutting, upscaling soon becomes an option," says Ir. Ekki Kreutzberger, senior transport & infrastructure researcher at the OTB research institute. This is why a number of European countries have been experimenting with long trains, i.e. about a kilometre long rather than the current length of 500 to 700 metres. In the United States many trains are operated that are several kilometres long.

The use of long goods trains on the Rotterdam-Antwerp-Paris line is the central concept of the LIIIFT (Long, Innovative, Intermodal, Interoperational Freight Trains) project, which is being implemented by a French/Belgian/Dutch consortium. The project partners are Fret-SNCF, B-Cargo, ProRail, ERS, CNC, the Rotterdam Port Authority, OTB, and French technology companies, Martec and Advanten. A major rst step in the project is to investigate whether a market exists for trains up to a kilometre in length. You will not nd any running in Europe today.

Technically speaking, the LIIIFT concept is feasible. Matters such as traction, stresses and communication between engine and wagons are being looked at in a fresh light. In addition, such legal technicalities as acceptance procedures are being reviewed. Surveys suggest that there is a market for trains at the current length, based on ve departures a week. Longer trains might already be viable between Antwerp and Paris. The forecasts indicate that in some scenarios the goods ow will have increased su ciently in ve years to run long trains on the entire route. The reduction in price due to upscaling plays a major role.

"Even so, much depends on the future development of the rest of the rail network. Planning a LIIIFT will determine to a large extent whether enough freight will be forthcoming for the long train," says Kreutzberger. This has become a topic now that the PNIF network, a national hub-and-spoke network in France, has closed down to make way for more direct transport services.

The development adversely a ects the potential market of the LIIIFT. Filling the LIIIFT with cargo for French destinations other than Paris, say Lyon or Marseille has now become more di cult. Paris as the only destination of the LIIIFT is not an option yet, so new train services will have to be introduced to replace the PNIF services. This is a serious possibility, and the LIIIFT consortium is currently working on elaborating the concept and preparing a pilot project.

Ma Hailin / Camera Press / Hollandse Hoogte

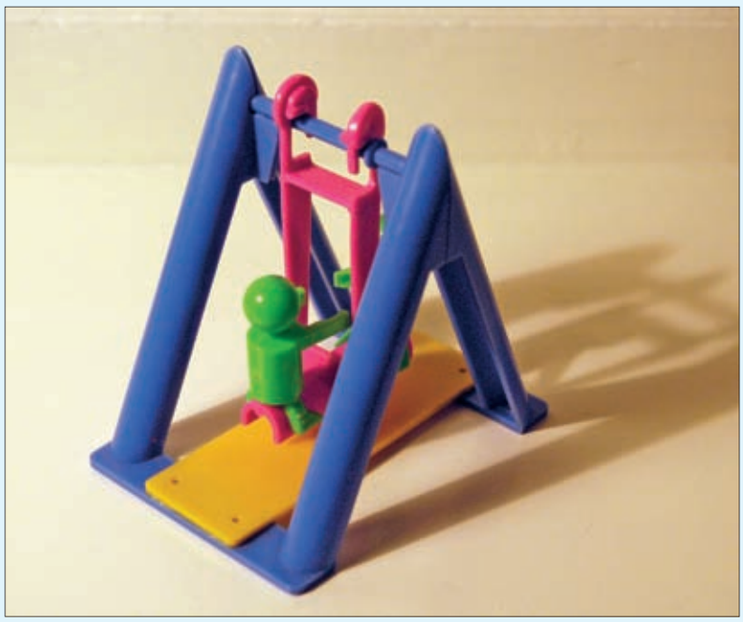
# A question of stability

**It is easy to see whether a system in equilibrium is stable when there are only two forces acting on it, as in a swing. But until recently, this was impossible for an equilibrium involving three forces, as in a hammock. A team of structural engineers at TU Delft have discovered a mathematical method of determining the stability of an equilibrium involving any number of forces of any nature, including gravity, springs, and magnetism. In addition the researchers have developed an elegant graphical method to determine the stability of certain states of equilibrium practically at first sight. This knowledge will be of particular interest to designers of robots, artificial hands, ships, and all sorts of other systems that have a delicate equilibrium.**

Dap Hartmann

"The point of application of a force makes no difference for the equilibrium, but for the stability it is very important," says Dr Ir Just Herder, a lecturer at the Biomechanical Design department of the faculty of Design, Engineering, and Production. "In other words, in situations in which forces themselves do not change, but their points of application on an object do, the resulting motion of the object can be very different."
Herder designs indifferent spring systems, which are mechanisms with springs that are in constant equilibrium, and which can be moved effortlessly in spite of the presence of considerable forces. Such systems, which are very often used for people with muscular disorders or an artificial hand, operate on the boundary between stability and instability. To people using such a system to support an arm, their arm feels just a light as an astronaut's does in space.
Some industrial production robots have also been made indifferent using compensation springs, so they can operate round the clock without spending a lot of effort to lift their own weight. As a result they can be fitted with smaller motors. The system is used mainly in robots that need to be able to make rapid movements. Slower systems, like draw bridges for instance, use counterweights.

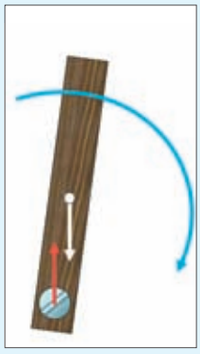
**Swing** A swing is a highly stable system. It is subject to two forces that keep each other in check. Gravity pulls the swing to its lowest point, and the swing's suspension provides an identical force upwards. The forces act in opposite directions and along the same line. This keeps the equilibrium stable. In a system in which the forces point towards each other the equilibrium is unstable. A simple experiment will illustrate this. Tie a length of string to each end of a pencil and pull the strings with equal force. The tensile forces are applied to two different points, and point away from each other. This makes the equilibrium stable. If someone else were to rotate the pencil along its short axis, its equilibrium will be disturbed, but it will be restored as soon as the other person releases the pencil.
An unstable equilibrium is the result of two forces pointing towards each other and acting on different points of application, e.g. when a pencil is balanced on its tip. Halfway up the pencil shaft, gravity will exert a downward force, while at the bottom end, a supporting force acts on the tip. In theory this means that the pencil is in equilibrium, but the slightest breath of air would be enough to disturb this equilibrium. As soon as the pencil moves away from the vertical, a couple is created that amplifies the rotation. The pencil simply falls over.



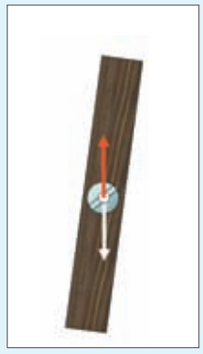
A swing is stable in its lowest position. If this equilibrium is disturbed, the swing will eventually return to this condition..

A simple experiment illustrates the di erence in behaviour between three states of equilibrium

with identical forces acting on di erent points. A board is attached to a wall by a screw through its upper end, and free to rotate. If the board is moved from its state of equilibrium, it will return to its original position. A state of equilibrium involving two forces pointing away from each other is stable.



If the screw is inserted through the lower end of the board, although a state of equilibrium exists while the board is upright, the board will not return to its original position if it is disturbed. A state of equilibrium involving two forces pointing towards each other is unstable.



In the special case in which the centre of gravity and the point of suspension coincide, the board will be in a state of equilibrium whatever the position. The state of equilibrium is indi erent.

## Two forces in equilibrium

A swing left to its own devices will hang perfectly vertical. At any time, two equal forces will be acting on it in opposite directions. Gravity will pull the seat straight down, and the suspension hooks provide an identical upward force. A pencil balanced on its tip also has two counterbalancing forces acting on it, but there must be a big di erence, since you cannot set a pencil on its tip without having it fall over. So what is going on? It is all to do with stability. After a minor rotation of the swing the two forces no longer act along the same line of action. As the lines of action separate, a couple is formed that attempts to restore equilibrium. It is a like a marble lying at the bottom of a bowl. A small push will bring the marble out of its state of equilibrium, but it will return to equilibrium of its own accord. This is a stable equilibrium. The curvature of the bowl determines the degree of stability, which is proportional to the amount of energy it takes to disturb the equilibrium.

Mathematically speaking a pencil set on its tip may be in equilibrium, but its condition is not stable. The di erence is that the upward force acts on the bottom end of the body, while the downward force (gravity) acts on a point halfway up the pencil, so in this situation the forces are pointing towards each other. Any minor disturbance will upset the equilibrium. Again the forces will form a couple, but this time it ampli es the motion in the direction of the disturbance, increasing the rotation. This is like a marble sitting at the top of a hemispherical surface. As soon as the equilibrium is disturbed, the marble will roll o , and it will never return to its original position. This is an unstable equilibrium.

There is a third form of stability, known as an indi erent equilibrium, in which a new equilibrium is created every time the existing state is disturbed. An analogy would be a marble on a at table. Any disturbance will cause the marble to roll to a new position, where it will sit in a new state of equilibrium. This is a boundary situation between stability and instability. It may sound dangerous, but in fact it is very useful. After all, moving the marble around the table takes very little e ort, and it will stay put of its own accord. The same thing happens in the spring-balanced Anglepoise desk lamp, which you can adjust to any position with the push of a nger.

A pencil set on its tip is in a very delicate state of equilibrium. In fact it is impossible to keep it there, since the slightest disturbance will cause the pencil to fall over. The state of equilibrium is unstable.

**Resultant** If a body that is being subjected to only two forces remains in equilibrium, most people will be able to see at a glance whether the equilibrium is stable. However, as soon as a third force comes into play, as in a situation where levers are used, it becomes more difficult to make up your mind.

A situation with three forces can be reduced to a situation with only two forces in equilibrium. Taking the vector sum of two of the three forces leaves you with the resultant force. Together with the remaining third force this brings you back to a situation with two forces. At that point you should be able to assess the situation by eye. Unfortunately the act of taking the vector sum causes vital information to be lost which is essential for assessing the stability, since it is unknown where the application point of the resultant force is. Without an application point it is impossible to assess whether the contribution of the resultant force to the stability equals that of the two original forces that make up the resultant.

Herder explains how he managed to solve the problem together with Dr Ir Arend Schwab, a lecturer at the faculty's Mechanical Engineering department: "We represented the stability of a body about its original equilibrium position in a motion equation, which is a set of mathematical equations that describe the motion of the body due to forces. It includes inertia, mass, and external forces such as spring forces and damping. The motion equation enables you to see how a body behaves when subject to forces. We added the requirement that the resultant force must provide the same contribution to the behaviour – the stability – as the two original forces. It turns out that the nature of a force affects its contribution to the stability. In this case, its nature is the relation between the size and the direction of the force acting on an object, as well as the position of the object. Gravity is an example of a constant force: wherever I position an object, it will always weigh the same. Spring forces on the other hand, will increase as the spring is extended. This means that spring forces and constant forces result in different effects. Therefore an object that is stable as a result of spring forces may well be unstable when subjected to constant forces.

The contribution to the stability is expressed by a rigidity matrix. This matrix indicates what will happen to the forces as a result of minor disturbances (translations and rotations) of the body. It turns out that for constant forces the rigidity matrix contains just a single term. Only rotation of the body introduces a change, because it changes the moment."

The application points of the two forces and the intersection of the subsidiary lines are located on a unique circle. For constant forces the application point of the resultant force turns out to be located on the same circle, on the intersection with the resultant line of action.

Herder: "My supervisor, Jan Cool, was the first to notice that all these points are located on a single circle. Isn't it amazing? It's so simple and elegant. I ploughed through yards and yards of literature, and in the end it was a colleague in the United States, Dr Jim Papadopoulos, who at the time worked at MIT and Cornell University, who helped me out. It was found that Edward Routh had come up with an identical construction in 1893, but he didn't draw any conclusions from it, and he never used it in any designs."

**Anglepoise desk lamp** The elegant circle construction applies only if the three forces are constant in both size and direction. For other forces, such as spring forces and magnetic forces, matters are a bit more complicated. Herder was particularly interested in spring forces, because these are very suitable for storing energy. They weigh less than counter weights and can operate independently of the direction of gravity.

A spring in a state of rest has a certain length. For a normal spring there is a linear relation between a spring's extension and the force it requires. Most springs are prestressed to some extent, i.e. the coils are pressed together with a certain force. Such a spring will only start to extend once the prestress force has been overcome. Past that point the extension will become proportional with the force. In fact the spring would like to be shorter, but its own coils are in the way. The theoretical shortest length of a spring is referred to as its free length. A very special case is a spring that is prestressed to such an extent that the free length is equal to zero. This means that the force will now be proportional to the length of the spring rather than its extension. The use of this type of spring when designing statically balanced mechanisms can be very practical, because it greatly simplifies the mathematical equations involved and also provides a perfectly balanced solution.

A number of years ago Herder while doing patent research discovered that the Anglepoise company, based in Waterlooville in the south of England, still existed. Among other products, the company makes the famous desk lamp that bears the company name, and which uses exactly such springs. Herder now visits Anglepoise regularly for consultancy reasons, but also because of the friendship that has grown with the people of the family business.

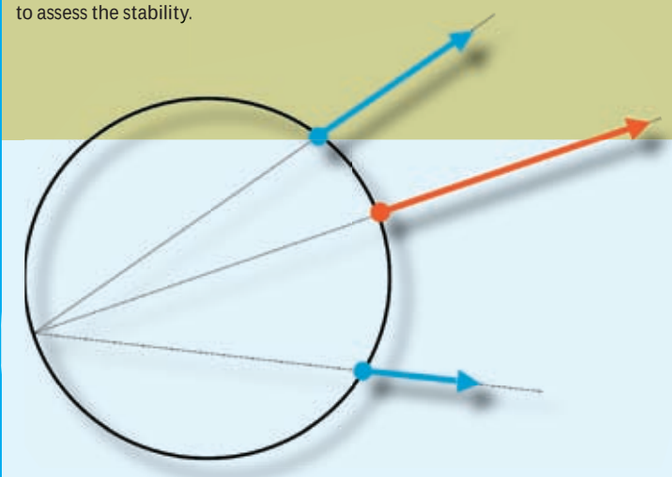
**Floating hinge** Although from a mathematical point of view prestressed springs are very simple things, the rigidity matrix for springs contains no zeroes. Except in a few special cases, such as when two springs act on the same point, there is no dynamically equivalent spring that will give the same contribution to the stability of the equilibrium as two separate springs. Surprisingly enough, a dynamically equivalent constant force can be found for two springs. However, it does have an application point different from that of the resultant force of two constant forces. A working model has been made of this principle to demonstrate the effect. So far Herder has not been able to find an explanation for this. Whatever the case, it shows that indifferent systems come in a surprising variety.

The researcher gets the model and demonstrates that it has no physical hinge, just a virtual, i.e. floating, point of rotation that nonetheless remains stationary. "This system evolved even before we had derived our theory. It all started with the question of whether the hinge in a known basic element – a rod carrying a weight on one end and a hinge on the other end – could be removed to reduce friction. The idea was to consider the hinge as an element that can generate a force, rather than a motion guide. I was going to have to find a different force generator to restore the equilibrium. The obvious solution appeared to be to use a spring. With two springs and one mass you already have three forces in the system, which means that you can remove the physical hinge. The whole arrangement will sag a little, but it soon reaches a perfectly balanced equilibrium. The system now has a virtual stationary point of rotation."

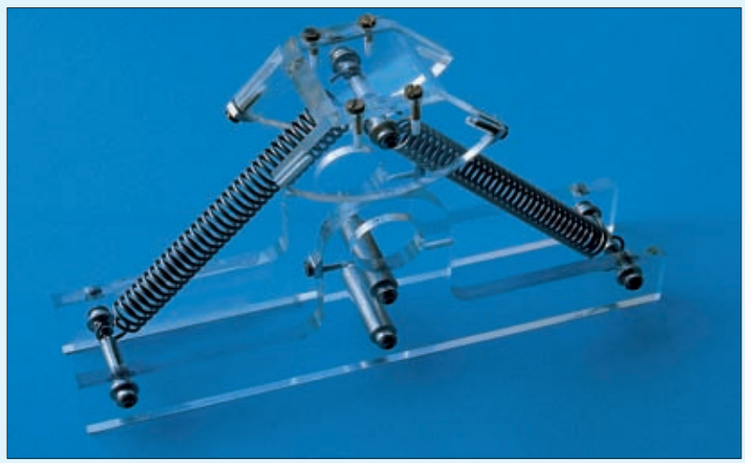
The structure is amazingly simple, and the floating hinge looks almost magical. Even in the absence of prestressed springs, the principle can be demonstrated with unexpected aids. Herder: "We had a visit from an American professor, Andy Ruina of Cornell University, a very clever man, and he wanted to recreate the balancing mechanism to see for himself how it worked. To replace the weighted rod, I used a broom that was standing there, and instead of springs, we used latex protective sleeves from surgical instruments that were lying around. As it happened, the latex behaved exactly like a spring with a zero free length. That's how we constructed the balanced broom". The broom will stay suspended in any position, i.e. it is in a state of indifferent equilibrium.

## Combining two forces: the resultant force

A force is a vector with a size and a direction, and it can be represented by an arrow. The orientation of the arrow indicates the direction, while its length expresses the size. For two forces that do not act in the same direction, the resultant force can be easily found using geometry. Draw subsidiary lines through both vectors and nd their point of intersection. Translate the vectors along the subsidiary lines until they start at the intersection point. Use the vectors to construct a parallelogram. The diagonal of the parallelogram represents the resultant force. In this way, the size and direction of the resultant force can be accurately determined. Unlike the application point however, which has been moved arti cially to the intersection of the subsidiary lines. The location of the application point is however essential if we are to determine the stability. Although a vector sum does give us the statically equivalent force, it does not give the dynamically equivalent force. This geometrical method gives no clue as to the application point of the resultant force and therefore cannot be used to assess the stability.

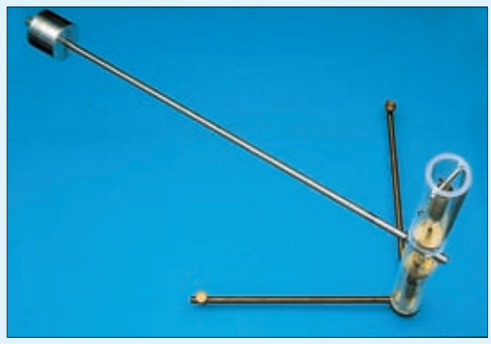


The application point of the resultant force (red), which provides the same contribution to the stability of an object as the two original forces (blue), acts on the intersection of the resultant line of action and the circle that can be constructed through the application points of the original forces (blue) and the intersection of their lines of action.

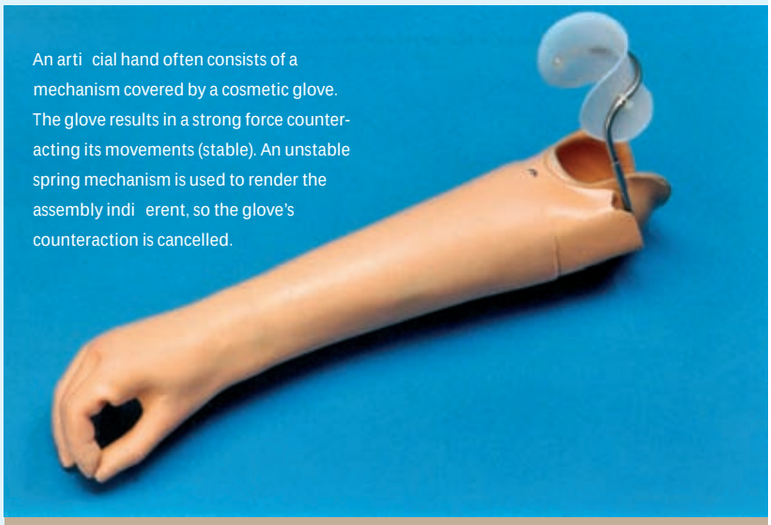


Demonstration model with two springs acting on the same point of the moving part, which is in a state of equilibrium in any position. The springs counterbalance each other.


Anglepoise desk lamp with special springs. It is exactly balanced and will retain any attitude it is given, even if there were no friction in the hinges.



Demonstration model of an indi erent equilibrium. The weighted rod will remain stable in any position. The dynamically equivalent resultant of the two springs acts on the centre of gravity of the mass. This is an example of a oating hinge.



An arti cial hand often consists of a mechanism covered by a cosmetic glove. The glove results in a strong force counteracting its movements (stable). An unstable spring mechanism is used to render the assembly indi erent, so the glove's counteraction is cancelled.

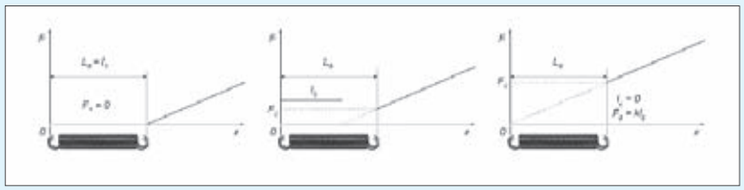
## Arti cial hand

People su ering from some form of muscular disorder can often still control their muscles, but they lack the power to move their arms. An indi erent support mechanism can take the burden so that the patient's arms can be moved with the smallest of e ort. Another useful application of indi erent spring systems is in arti cial hands. Just Herder shows a drawing and explains: "This is a mechanism covered by an arti cial skin. The latter must be very tough if it is not to wear out in normal use. The material is PVC, about a millimetre and a half thick. To open the arti cial hand, the glove must be stretched, which takes a lot of energy. The necessary energy is supplied by a compensation spring. When the hand closes, the spring stores the energy supplied by the glove. If you match the two energy ows, the system will always be in a state of equilibrium — an indi erent system. You no longer feel the sti glove, as you no longer need to make an e ort to move the hand. The main bene t is however that it introduces a "sense of touch" in the prosthesis. In body-driven arti cial hands, the shoulder muscles provide the necessary force through a "string". If the prosthesis refuses to close any further, you can feel this in your upper arm muscles."

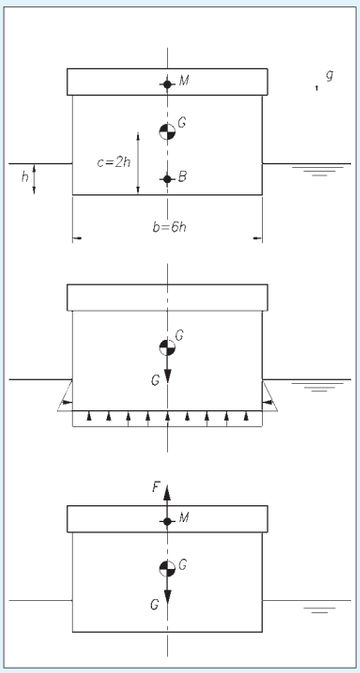
## Shoe box in water

Now that a system with three forces in equilibrium can be reduced to a dynamically equivalent system with two forces in equilibrium, it is also possible to determine the stability for a system in which many more forces act to create equilibrium. So, Arend Schwab applied the method to a ship in the water. In this case, gravity and the hydrostatic pressure keep each other in check. If a disturbance occurs, for example a small rotation about the longitudinal axis of the ship, the big question is of course, will the ship return to its position of equilibrium or not, in other words, will it float or capsize? The equilibrium of the ship is stable if its metacentre is above its centre of gravity. The metacentre has always been a bit of a mystery to researchers. Schwab demonstrates that the mysterious point is exactly the same as the dynamically equivalent application point of the hydrostatic forces. He constructed the equation of these hydrostatic forces as a function of the rotation, and recombined all the separate forces into a resultant force. That brings us back to the situation with two tensile forces. As a bonus, the method also explains why a shoe box floating in water will be perfectly stable even though its centre of gravity is way above the surface of the water. Nice to know for certain.

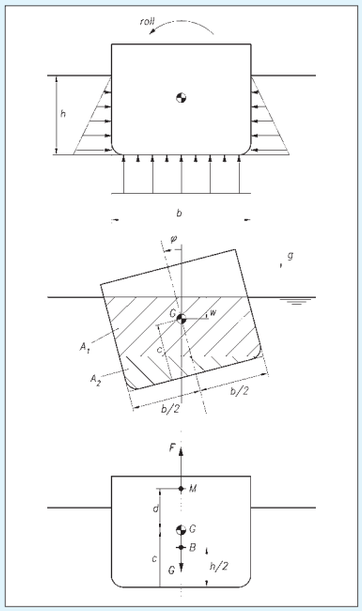
For more information please contact Dr Ir Just Herder, phone +31 (0)15 2784713, e-mail j.l.herder@wbmt.tudelft.nl.



This gure shows the force-length characteristics of three draw springs that at rst glance appear identical. On the left is a spring without any prestressing, in the centre is a slightly prestressed spring, and on the right is a highly prestressed spring, in which the characteristic passes through the origin. This is the type of spring used in the Anglepoise desk lamp.




A shoe box oating in water appears to be unstable because the centre of buoyancy (B) is lower than the centre of gravity (G), while the forces are pointing towards each other. However, the dynamically equivalent application point of the hydrostatic pressure (the metacentre, M) is higher, which makes the shoe box stable.




Arm support for people su ering from a neuromuscular disorder. The spring mechanism counteracts the force of gravity. The user's arm is suspended and can be moved without any e ort.

When you grab an object it is important to know whether your grip is stable. If it is not, the object will shoot out of your hand as soon as you apply any force to it.

# Electrical pulses protect concrete

In any reinforced concrete structure, at some point in time an electrochemical reaction will occur that will cause corrosion products to form around the rebars with a volume that is about six times that of the steel itself.

**Even concrete is not as hard as it looks. Sea water, salt on icy roads, and indirectly even carbon dioxide from the air can corrode the steel of the reinforcing bars and so threaten the strength and integrity of a bridge pier, jetty, or viaduct. Dessi Koleva, a chemical engineer from Bulgaria, spent her doctoral research at the Faculty of Civil Engineering and Geosciences devising a method for the cathodic protection of steel rebars. The method is cheaper and also has fewer side effects on the microstructure of concrete.**

Joost van Kasteren

There is no need to derust reinforcing steel before the concrete is poured, since a very thin protective layer will eventually form that prevents the steel from corroding. Where things go wrong is when the protective layer breaks down.

BEELDBANK.VENW.NL, RIJKSWATERSTAAT

Many salts used for de-icing are chlorides that in the long term will cause corrosion in concrete structures.

The service life of concrete structures sometimes falls far short of the normal life expectancy, due to corrosion of the reinforcing steel. In the 1970s and 1980s for example, a wave of concrete decay swept over the Netherlands. This was caused by the practice, common in the 1960s and 1970s, of adding calcium chloride to the concrete mix to accelerate the setting process. The chloride ions in the accelerant proved to have a disastrous effect on the reinforcing bars, which started to corrode. Since rust has a much greater volume than steel, the concrete started to flake, and in some cases the steel rebars even became exposed.

Although the use of calcium chloride in concrete is now prohibited, this has not removed the problem of corroding reinforcing steel and concrete decay. A few years ago a viaduct across the Tilburg – Eindhoven motorway had to be replaced for this reason, and concrete sections of the approaches of a bridge near Krimpen aan den IJssel were found to be cracked. These will certainly not be the last of such cases. Research by Gerard Gaal, who was awarded his doctorate last year at the Faculty of Civil Engineering and Geosciences, shows that the Netherlands is in for a prolonged spell of decaying bridges and viaducts.

**De-icing** The main cause of the decay is the salt that is used to de-ice Dutch roads during the winter. In most cases this is ordinary cooking salt, sodium chloride. The chloride ions penetrate the concrete and – just like the chloride ions of the setting accelerant did a few decades ago – corrode the reinforcing bars. The corrosive power of chloride ions used to be underestimated. It was assumed that corrosion of the reinforcing steel was practically impossible because concrete forms a highly alkaline environment in which the high pH value (approximately 13) would offer sufficient protection. A logical supposition in itself, if it weren't for the fact that chloride ions can penetrate this type of protection. The ions infiltrate through the protective layer and can cause a festering, pitted corrosion of the steel.

In addition to de-icing salt, carbon dioxide from the air can also affect the reinforcing steel, albeit indirectly. This particular phenomenon can often be found on concrete balconies that are exposed to the full blast of the weather. The chemical process involved is complex but basically, at the boundary between air, water and concrete, carbon dioxide from the atmosphere dissolves to form an acid (bicarbonate). The bicarbonate reacts with calcium compounds in the concrete to form calcium carbonate. As a result of the carbonation of concrete the acidity can increase to the point where the alkaline protection breaks down and the reinforcing steel starts to corrode.

**Electrochemistry** Various methods are being tried to prevent the corrosion of reinforcing steel and the subsequent deterioration of concrete structures and buildings. Bridges and viaducts are now given an improved cover (a thicker layer of concrete), premature drying of the concrete is prevented (post-treatment), and sometimes an impermeable layer is included that closes off the pores. In addition, these days high-strength concrete, which is almost impossible for chloride ions to penetrate, is used more often. An alternative that was developed in the early 1970s is cathodic protection, in which a continuous weak direct current of a few milliamps flows between the reinforcing steel and the encasing concrete.

Cathodic protection is based on the fact that corrosion is an electrochemical process in which the dissolving of iron (the anodic reaction) is linked with the production of hydrogen and oxygen. As the iron dissolves, two electrons are released which convert oxygen and hydrogen into hydroxyl groups ($OH^-$) through a complex series of reactions. The iron ions ($Fe^{2+}$) react with these hydroxyl groups to produce a form of iron hydroxide which, after some intermediate stages, is transformed into the familiar dark brown flaking material, rust.

Combined with the adsorbed water molecules the volume of rust is about six times that of steel. The result is that the corrosive action pushes away the concrete, causing cracks to form and finally, pieces of concrete to break away.

**Hydrogen** The application of a small electric current renders the reinforcing steel immune to corrosion, as it were. The currents involved are very low. Higher currents are sometimes applied to the reinforcing steel to force chloride ions away from the boundary between concrete and steel or conversely, to stimulate realkalisation of the boundary layer. These higher currents can

only be applied for short periods at a time, due to the risk of hydrogen forming as the result of the separation of water. If the hydrogen cannot escape this will render the reinforcing steel brittle, which is not the intended effect.

"However, at low currents chloride extraction and realkalisation can be a welcome side-effect of cathodic protection," says Dessi Koleva. Trained as a chemical engineer at the University of Sofia, the capital of Bulgaria, she came to the Netherlands a few years ago at the invitation of Van der Heide Corrosion Protection and Engineering BV. Funded by the European Union through a Marie Curie Host Fellowship she is currently doing research on cathodic protection. A prerequisite for this type of scholarship is that the research must be scientifically interesting as well as being relevant for the industry.

**Microstructure** Cathodic protection works by connecting one pole of a current source to the reinforcing steel and the other to a metal (e.g. titanium) screen that is attached to the concrete surface and which acts as an anode. The screen is usually covered with an epoxy resin coating. Instead of titanium, a conductive mortar or coating can also be used to act as the anode.

Although the method has been in use for some decades (albeit on a limited scale in the Netherlands), the exact details of why cathodic protection is so effective remained unknown. Koleva has done extensive fundamental research on the subject. Contrary to common practice in this type of research, she used standard methods such as resistance measurements, but she also looked into the microstructure of concrete and reinforcing steel and into the changes at the boundary between steel and concrete.

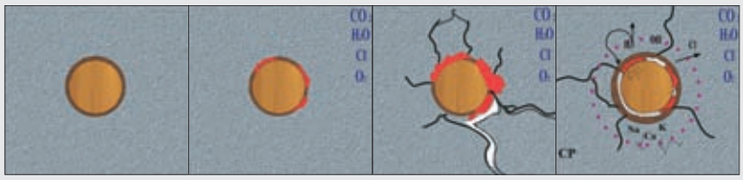
For her research Koleva used cylindrical test pieces 100 mm long with a diameter of 40 mm, made using normal Portland cement with a water/cement ratio of 0.6 and a sand/cement ratio of 3:1. At the centre of the cylinder was a rebar of 6 mm diameter. The bottom third of a test set of cylinders was immersed in a saline solution. A number of these cylinders were cathodically protected, whereas the remainder were left to corrode. A third set of cylinders acted as reference and was immersed in demineralised water.

**Platelets** Interesting differences in morphology and microstructure were observed between the protected and the unprotected samples. The test pieces, both with the oxidised and the cathodically protected rebars, were expected to contain a mix of iron oxide, hydroxides and iron hydroxides. However, the protected samples were found to contain a lot fewer crystals of all these oxides than the unprotected samples. Also, corrosion products such as high-valency oxides (hematite and magnetite) were found. In addition, the crystalline structure of the corrosion products was found to differ greatly. In the unprotected concrete the corrosion products were found to have formed what appeared to be platelets. The resulting increase in volume is to a great degree responsible for the forming of microfissures in the concrete. In the case of the cathodically-protected reinforcing steel, however, few or none of these platelets were observed to form. In other words, the effect of cathodic protection lies mostly in preventing the formation of large-scale morphological changes such as the platelets.

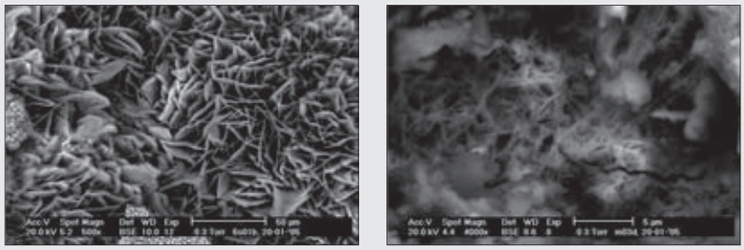
Having demonstrated what the efficacy of cathodic protection is actually based on, Koleva used the same techniques of analysis to investigate whether the protective action could be improved by applying the electric current as a square-wave pulsed direct current instead of continuously. One of the drawbacks of cathodic protection with a continuous current supply is that the heterogeneity of the concrete causes the current to be non-uniformly distributed. This results in areas that are overprotected, at the cost of other areas. The porosity of the concrete also changes, in particular at the steel/concrete boundary. This can cause small cavities to form, which in turn can lead to the formation of microfissures.

"All in all," says Koleva, "reason enough to see whether the application of a pulsed current might at least alleviate the problem."

**Pulse** The use of a square-wave pulsed current is nothing new in itself. The technique is already in use to prevent rising damp in brickwork and concrete. A screen of titanium is applied to the affected concrete or masonry, and close to the wall a copper rod is driven into the ground. A current source is then used to apply low-voltage pulses, which extract the water molecules from the wall. This Electro-Osmotic Pulse (EOP) system has been used since the 1990s,



The process of rust-forming and cracking as the result of electrochemical processes.



Electron microscope images of corrosion products on steel (left) and in concrete (right) close to the corroding steel.

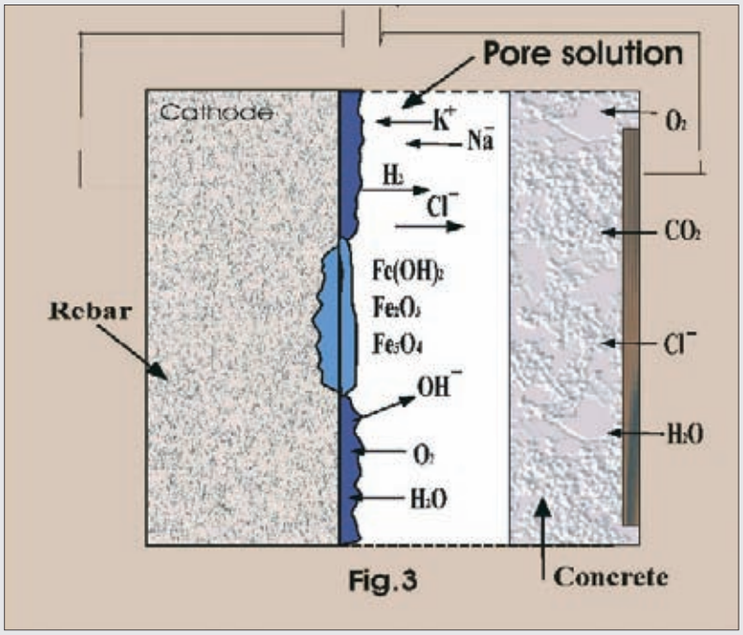
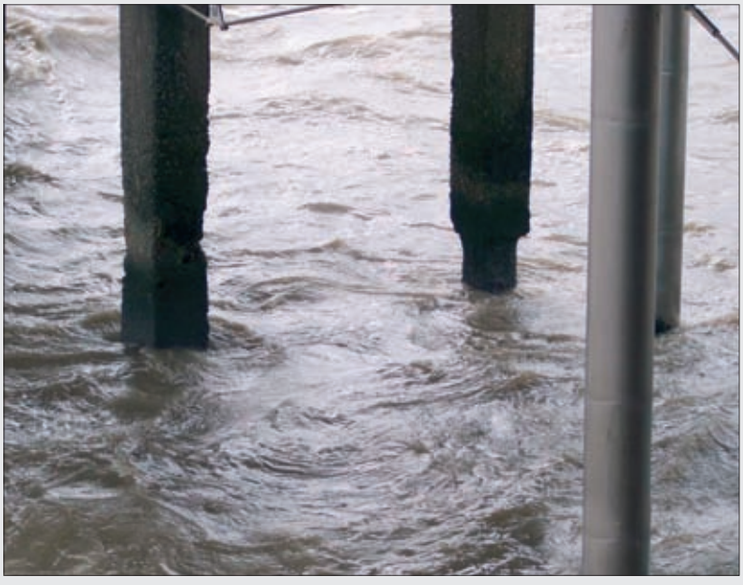



Fig.3

Schematic diagram of corrosion processes. A current applied to the rebars prevents the iron from dissolving.



Heavily a ected supports under the pier at Blankenberge (Belgium), a typical example of what happens if concrete is left unprotected.

Another example at Blankenberge Pier. If in a saline environment like this, concrete damage is repaired with coatings alone, i.e. without using cathodic protection, the corrosion processes will return time and again.

Rob Polder / TNO Bouw

The bascule building of the Noord Bridge was tted with cathodic protection in , when the concrete was found to be severely a ected. Even so, very few structures in the Netherlands use this type of protective technique.

Test pieces used by Dessi Koleva in the climate chamber at the faculty of Civil Engineering and Geosciences.

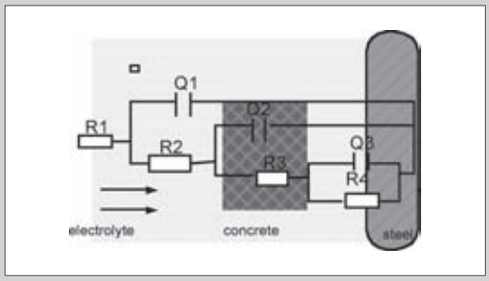
and according to Internet advertisements will show results within a fortnight. What is new about Koleva's research – and which has been covered in a patent application – is the use of a specific square-wave pulsed current supply for the cathodic protection of reinforced concrete. Pulse techniques are also used to protect underground pipelines.
In order to demonstrate the improvements over the traditional cathodic protection methods, Koleva again used cylinders, but this time they contained two rebars to see what the effect of the distance between them was on the electrical resistance. In addition she prepared a number of prisms of non-reinforced concrete. To make these, she used demineralised water in one set, a saline solution in the next, and a mix of both in the rest. The electrical resistance, or rather the electrical resistivity (specific resistance), of each of the prisms was measured, and at set intervals their chemical composition was analysed. This enabled Koleva to measure the transport of ions over time, both as a function of continuous and of square-wave currents.

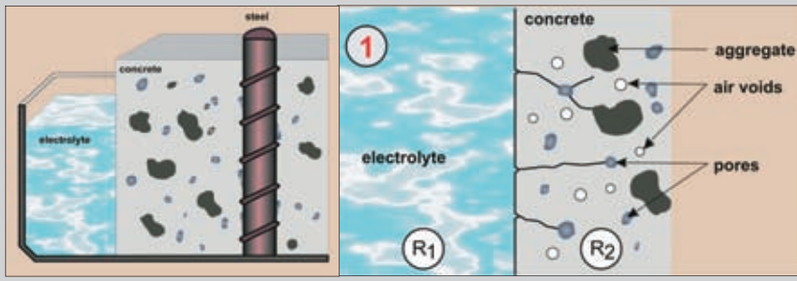
**Electron microscope** To begin with, the cylinders of reinforced concrete were exposed to a saline solution to initiate the corrosion process. Next, some of the samples were cathodically protected using a continuous current, while others were protected using a square-wave current. Several methods were then used to catalogue the electrochemical parameters of the reinforcing steel. In addition, the microstructure was visualised using an ESEM electron microscope. Thanks to a technique developed by colleague Jing Hu (who has since gained her doctorate) Koleva was able to quantify the structural properties of the material based on the two-dimensional images produced with the electron microscope. Finally, the morphology and the chemical composition of the samples of reinforced concrete were analysed at regular intervals.

Photograph Leggedoor Beton- & Vochtweringstechniek BV, Gasselternijveen

An already a ected object has to be protected cathodically, that's why it's put in a web of titanium which later on is covered by a protective layer. The 'web' then just will function as an anode.

The electrochemical processes and ion transport not only a ect the steel, but also the concrete. Koleva looked at the boundary areas and used electrical circuits to measure the e ects on the



Koleva's research shows that there is a clear difference between the effects of continuous and of square-wave currents on the microstructure of reinforced concrete. A continuous current causes undesirable changes in the microstructure, as the heterogeneity of the bulk material clearly increases, while the porosity decreases. As a result the specific resistance increases, so more electricity is required. The hypothesis is that the most important change occurs at the boundary between concrete and rebars. The electron microscope images clearly show that a cavity, a zone of increased porosity, is being formed between the steel of the rebars and the concrete, as well as between the cement and the gravel aggregate. The cavity in turn serves as the starting point for the formation of microfissures.

The square-wave current cause hardly any of these microstructural changes, either in the bulk material or at the boundary between the reinforcing material and the concrete.

Koleva: "On the one hand the application of a square-wave pulsed direct current appears to offer sufficient cathodic protection, while on the other it causes little or no undesirable changes in the microstructure. And because a pulsed current requires less electricity, it is also cheaper, which is particularly important to commercial users."

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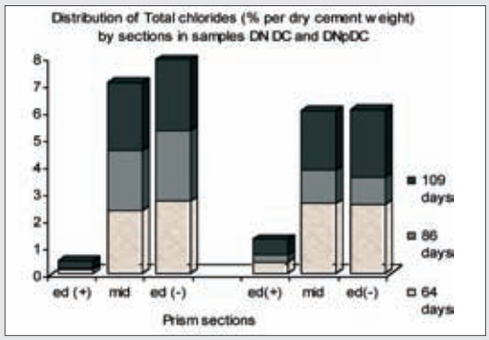
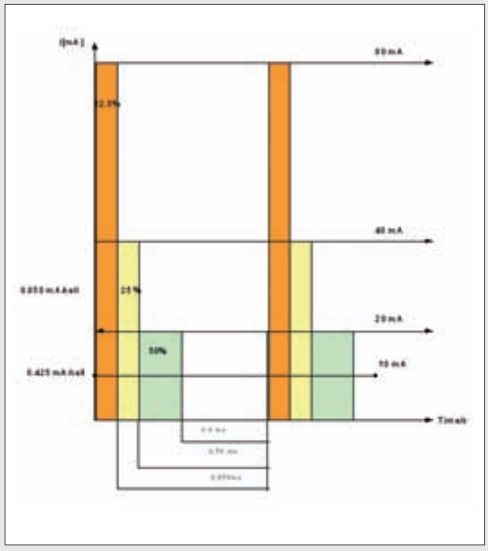
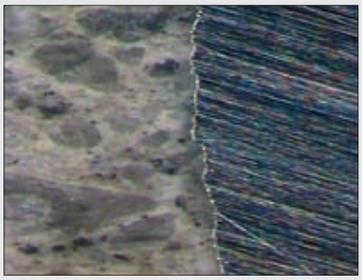



The e ect of di erent electrical conditions on the distribution of chloride ions.



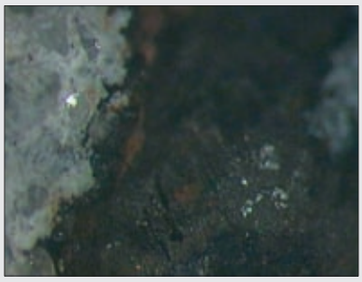

Various pulse regimes used by Koleva in her tests.

**Optical microscope image of the steel/concrete boundary.**



Without corrosion.

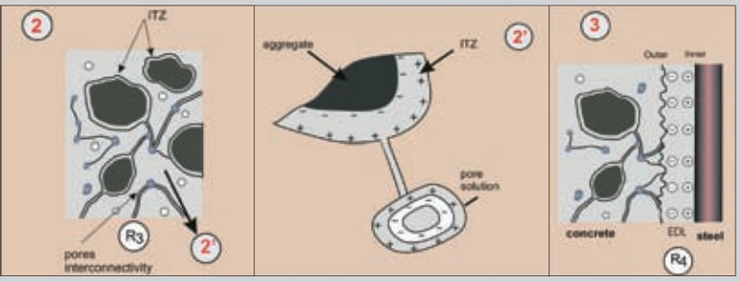
With corrosion.

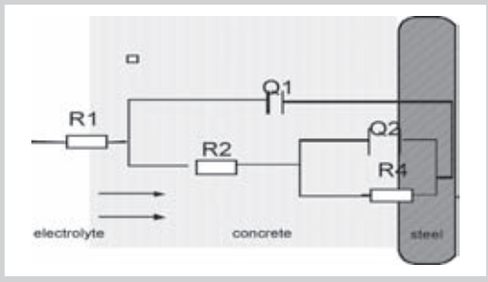


Steel pushed to corrosion, but now with cathodic protection.

Test pieces used by Koleva in the climate basin at the faculty of Aerospace Engineering being sprayed with de-icing salts. Koleva investigated the e ect of cathodic protection under such conditions.

steel surface and the electrical data of concrete.



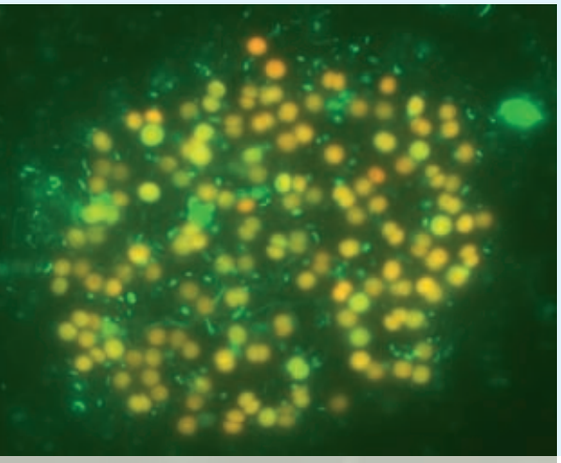
Gaby van Caulil

**In Gijs Kuenen discovered a microbe that his colleagues thought could not exist. Recently it was discovered that the creature is responsible for half the world's marine nitrogen production.**

**Farewell portrait of the discoverer. "Gijs managed to put the Delft School of Microbiology back on the map again."**

# Anammox, the cleaning creature that could not exist

## *Beijerinck, Kluyver, Kuenen – A goodbye to a remarkable microbiologist*



This technology uses special bacteria — unknown till recently — to convert ammonium together with nitrite into nitrogen gas.

### Nonexistent bacteria are everywhere

It just goes to show that you can be wrong about something you cannot see. Bacteria that were considered non-existent until 1986, now turn out to be all around us and in large numbers. In 2003 Dutch microbiologists published an article in Nature describing the discovery of anammox in the Black Sea. During an expedition last year the ammonium-eating microbe was found o the coast of Namibia, at a depth of a hundred metres. The anaerobic ammonium demolishing squads were found in fty samples from all over the world, from the ice cap of Antarctica to the Yangtze river in China. Anammox bacteria probably in uence the worldwide nitrogen cycle. With their discovery, oceanographers were able to solve a 40-year old problem, the gap in the oceans' nitrogen cycle. The idea was that denitrifying bacteria converted nitrate and nitrite into nitrogen gas. In a low-oxygen environment, this will produce ammonium, but this was never found. Biogeochemicists now use the anammox bacteria to explain the disappearance of ammonia in aqueous environments with low oxygen levels. In the better textbooks the nitrogen cycle now includes the bacteria that turned up by chance in a Delft reactor twenty years ago.

Perhaps it was the melancholy mood that usually pervades a farewell, but the tribute may turn out to be well-founded. Jacob Fokkema, the Rector Magnificus of TU Delft, took it upon himself to add his colleague, Professor Gijs Kuenen (1940, Heemstede) to the list of famous Delft microbiologists: Beijerinck, Kluyver and Kuenen. On 2 December 2005 Fokkema addressed Kuenen on the occasion of the latter's valedictory address as Professor of General and Applied Microbiology at TU Delft.

History will show whether professor emeritus Kuenen earned his place in the hall of fame, but his successor, Jack Pronk is confident: "In another century, the name of Gijs Kuenen will be synonymous with anammox, his greatest discovery."

Several other microbiologists have since been busy unravelling the mysteries of the structure of anammox bacteria, but they all agree that "Gijs" is the spiritual father of the creature.

Pronk: "He is a visionary, early to spots things. In the 1980s he plotted the way of getting to the bottom of this strange process."

In actual fact it was the population of Delft that got him on the right track.

"When I arrived in Delft in 1980, the local Gist-Brocades plant was a constant cause for complaints," Professor Gijs Kuenen (1940) recalls. "There were all kinds of smells coming from solvents and from the autoclaved molasses in the yeast production plant. The whole of Delft was complaining, and it wasn't doing the public image of Gist-Brocades any good either."

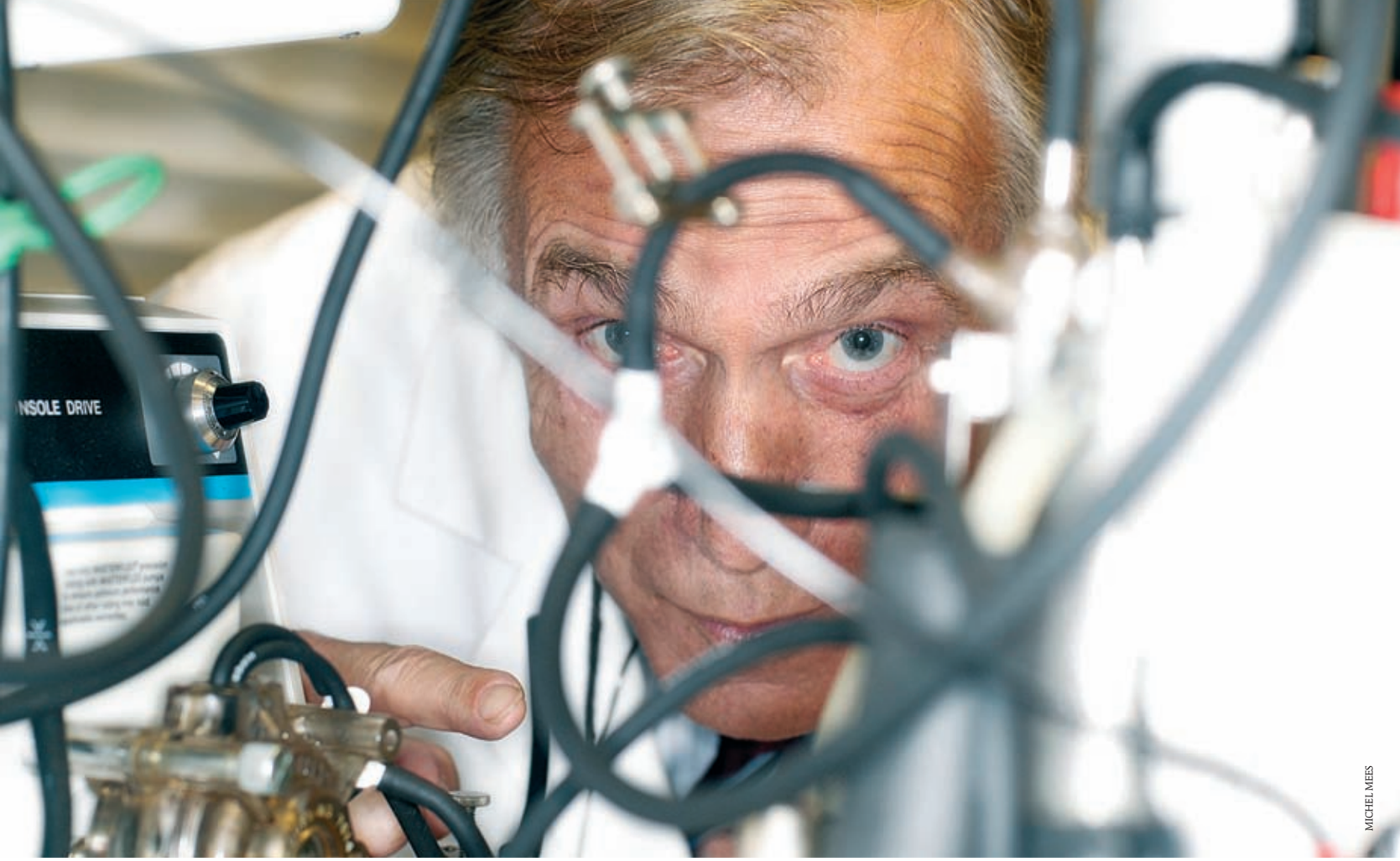
At first the yeast company, which today forms part of the giant DSM chemical concern, pumped the smelly waste water to The Hague. In 1986 however, Gist-Brocades decided to clean the waste flow in-house in an attempt to recover the useful methane content. In a test setup, Arnold Mulder of Gist-Brocades used bacteria to break down the sulphate-rich waste material in oxygen-free tanks. Inside the tanks, sulphides were being formed that produced a smell of bad eggs. As nuisance from sulphurous compounds was exactly what he was trying to avoid, Mulder added an extra step with nitrate.

Kuenen: "The sulphate got broken down exactly as planned, but Mulder noticed something else. The ammonium concentration also dropped, and the gaseous nitrogen content rose. In 1977 Austrian scientist Engelbert Broda had predicted the existence of such a process, but most microbiologists remained sceptical. No such reaction had ever been found in nature, and neither had the microbe. According to the dogma oxygen was required to break down ammonium."

Kuenen was working as a consultant for Gist-Brocades and he suspected that anaerobic bacteria were involved.

"It was a courageous move," former research student Marc Strous recalls in Nature, which included a background story on anammox in its 27 October 2005 issue. "Kuenen started to study something which his colleagues were convinced did not exist."

In the basement of the Kluyver Laboratory doctoral student Astrid van der Graaf – these




MICHEL MEES

days a permanent contributor to this publication – confirmed her professor's assumption. From the lumpy deposits in the laboratory's flasks she cultivated deep red bacteria that were able to perform the anammox reaction – anammox being short for anaerobic ammonium oxidisation. They named the bacterium Brocadia anammoxidans, the name of the genus referring to its place of discovery, a reactor vessel at the Gist-Brocades plant. Since then, two other anammox genera have been described, one of which has been named Kuenenia, with a single (so far, at least) member, Kuenenia stuttgartiensis. This microbe was discovered five years ago in the sludge of a waste water treatment plant at Stuttgart, Germany. German and Dutch scientists named the micro-organism after the Delft biotechnologist.
"Just colleagues being playful," is the discoverer's modest comment.
It wasn't long before Kuenen saw in anammox the makings of a new form of waste water treatment. Removing nitrogen in the form of gaseous $N_2$ is much simpler than when it comes in compound form, as ammonium, nitrate, or nitrite. The application has since been covered by two patents, and the treatment technique is currently being marketed by the Paques company.

## Natural cycle

"Nevertheless, the industry still has to convert ammonium in two stages. In addition to ammonium, anammox requires the same quantity of nitrite. In the first, oxygen-rich, reactor Nitrosomonas bacteria convert half the ammonium into nitrite. In the next vessel, anammox turns it into nitrogen. One of my doctoral students, Olav Sliekers, discovered last year that the whole process can be done in a single reactor. In a limited-oxygen atmosphere both kinds of bacteria can do their work at the same time. If we manage to do this in a full-scale process, we will be able to reduce costs even further."
Kuenen also realised that the new microbe could be playing a leading role in the natural nitrogen cycle. Over the past two years it was discovered that anammox is responsible for what may amount to half of all the $N_2$ being produced in the oceans. With this discovery, Kuenen becomes a direct successor of Beijerinck, who also refined the nitrogen cycle. Around 1900 the famous microbiologist wrote that freely living bacteria could also fix nitrogen ($N_2$). Until that time the consensus had been that nitrogen could only be fixed by rhizobacteria, micro organisms that live in symbiosis with plants, usually in the root system. Anammox became the primary research line at TU Delft's Kluyver Laboratory. Marc Strous and Mike Jetten identified the bacteria as planctomycetes, which form a special evolutionary branch, since they possess properties of all three domains of life. According to their DNA they should be classified as bacteria, but their organelle structure is more akin to that of eukaryotes (organisms with cells containing a nucleus, which include all plants and animals), while the lack of peptidoglycans in their cell walls places them in the domain of the archaea (micro organisms that live in extreme environments). Today Jetten is a professor at

Professor Dr J.G. Kuenen was at the cradle of a number of considerable microbiological successes that were achieved over the past years, some of them in the eld of biological waste water treatment. Kuenen is convinced that a real technological breakthrough can be achieved in the next ten to twenty years by making the leap to a bio based society, in which new biological methods of producing and recycling food, drugs, fuel, and other complex materials will play a major role.
"We will in other words be making the transition from chemical production plants to bio factories. The smart application of micro organisms such as bacteria and yeasts will be essential."

*"Waste water scientists tend just to try and see what happens to find out how things work."*

*"Gijs is a visionary, he is early to spot things. In the 1980's he was already plotting the course for getting to the bottom of this strange process."*

Nijmegen University, and he has taken the anammox research with him. Some people find it hard to understand why Kuenen let his showpiece slip away from him. The man himself doesn't seem to have much of a problem, though: "We work close together with the people from Nijmegen. It still gives me a lot of pleasure every day."
Although Kuenen trained at Groningen University, he considers his modus operandi to be true to Delft.
"To begin with, there is my straightforward curiosity regarding the survival strategies of bacteria in their natural environment, but besides that I have always stressed the importance of quantitative thinking. The quantitative approach was partly the result of the wide range of applications that exist for microbiology. You simply cannot make do with any offhand guess about the outcome. You need to know the exact figure. In fact, if someone were to improve the yield of yeast production by only one percent, they would stand to make enormous profits. The industry is always there to pressurise us into being accurate in our measurements. That's typical of Delft."
Delft microbiology has always had strong ties with industrial applications. Nonetheless, it has had its dips too, even in scientific matters. When the microbiologist Albert Jan Kluyver died in 1956, Torsten Wiken from Sweden took over. Standards started to slide, and by the time Wiken left in 1978, the lab was even facing closure. In 1980 Gijs Kuenen arrived to turn the situation around. Former doctoral student Lesley Robertson remembers that time well: "Gijs completely overhauled the department. His influence was enormous. Before then we all used to sit in our own little rooms, and he got us all to cooperate again. The Delft School of Microbiology has since become world-famous."
Successor Jack Pronk, not without pride: "When I'm in the US and say that I am a professor at the Delft School of Microbiology, people instantly become enthusiastic. We have Gijs Kuenen to thank for that."

## Mentor

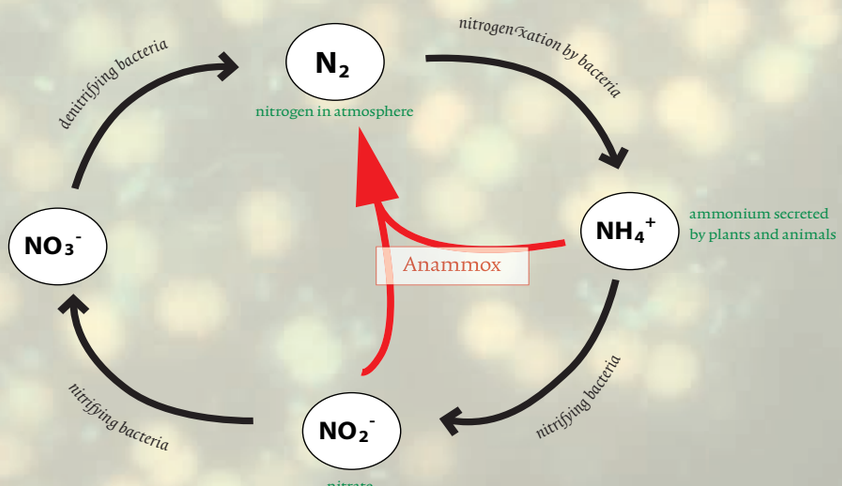
An inspiring mentor, is the opinion of Pronk. Ex-colleague Henk Lubberding thinks along the same lines: "Whenever he gave a presentation, halfway through you would find yourself thinking that there was simply no time to waste before you started work on the subject."
Pronk: "If a speaker cannot make it to a conference, we turn to Gijs. Just hand him a piece of chalk and some old sheets – no need for computer presentations – and he will have the audience at his feet. And he will be just as passionate giving a lecture to a class of freshmen as he is at an international conference."

Rotterdam, Dokhaven. In the first industrial-scale Anammox reactor incorporating technology developed in Delft was started up. The installation removes a large proportion of the nitrogen from the waste water produced by the city of Rotterdam. The operational costs are only ten percent of what a conventional reactor would cost, and the Rotterdam process uses considerably less energy.

## Anammox dispenses with expensive methanol

Gijs Kuenen soon realised that anammox could be used to treat waste water at a lower cost and with less impact on the environment. The concept has now become reality in the form of a ten metre high blue and white stack constructed in Rotterdam. It is used by the Sluisjesdijk sludge treatment plant to extract nitrogen from sludge water.
During the first treatment stage of waste water, bacteria round up all sorts of organic and inorganic compounds. The bacteria then settle on the bottom as a sludge. As the sludge ferments, poisonous ammonium is released. NH4+ is noxious to flora and fauna alike. Too much ammonium in a pond will kill all the fish. This is why runoff must not contain more than 10 mg of nitrogen per litre.

In the conventional method ammonium (NH4+) is broken down by bacteria into nitrite (NO2-), then into nitrate (NO3-), and lastly into nitrogen gas (N2), which is simple to remove from water. The last step is usually done by denitrifying bacteria. These need methanol however, which costs 25 to 50 cents per litre — a good-sized sludge treatment plant easily spends a million euros a year on methanol alone.
This is where anammox process saves money. The bacteria can skip the last step and do without the methanol altogether. Anammox is a short-cut in the nitrogen cycle. It converts ammonium and nitrite directly into nitrogen gas. The anammox bacteria can remove over 90 percent of the ammonium, which is sufficient to meet the runoff standards and save a million euros a year.



Even Kuenen himself is aware of his knack of inspiring others.
"It's not very hard, since I am simply passionate about microbiology. I love real-world scenarios. Every couple of years I take a few months off to travel. Israel, Chile, Denmark, America. To isolate bacteria from the mud, cultivate them, and then measure what I've got. I'm returning to Chile in February. They have thioplocas, which are giant sulphur bacteria that are visible with the naked eye. You can actually pull them from the mud on a thread."
In his valedictory speech, Kuenen once more made a case for another of his passions, sustainable industry.
"I'm convinced that the bio based economy will be, should be, a part of our future. We have to move towards a new kind of industrial chemistry. A kind that is not based on oil or gas, but on renewable raw materials from our agriculture. We shall have to start making much better use of the enormous waste flows that are released by our food production processes. Seventy to eighty percent of what we grow in our fields, straw, leaves and wood, simply goes to waste because we don't know what to do with it."
"Take wheat for instance. It produces lovely ears, but the rest is a mix of cellulose, hemicellulose, and lignin. Most of that can be converted into compounds that can be put to good industrial use, even as an energy carrier. In our lab we can already convert pentose sugars from cellulose and hemicellulose into alcohol. Once that can be done on a large scale without using too much energy, you could use it as green fuel to power your car."

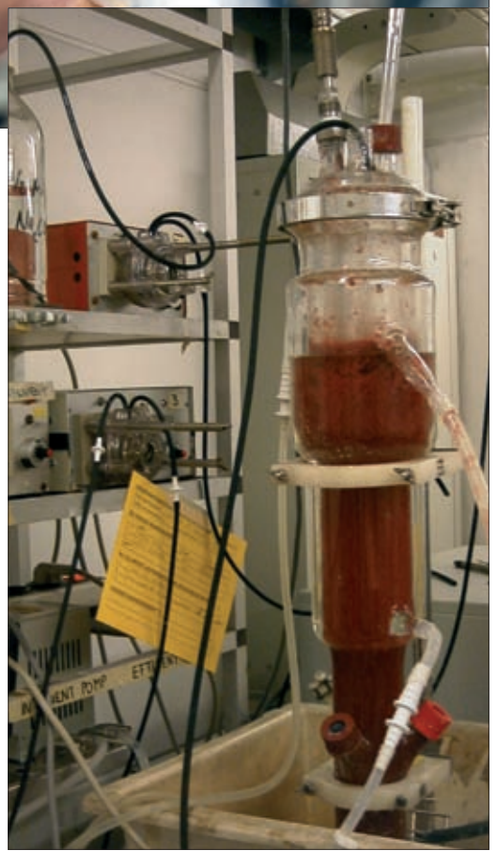
## Dutch Institute

Kuenen hopes that a Dutch Institute of Industrial Biotechnology will be established. Within it, the industry and universities will be cooperating to find microorganisms that can make our waste flows work for us. Delft biotechnologists are currently discussing the possibilities with DSM, Akzo Nobel, Nedalco, Genencor, TNO, Wageningen University, and the ministries of Economic Affairs and of Public Housing, Spatial Planning and the Environment.
"The government will chip in if the industry goes for it. We have some good proposals to bring in the industry. It simply has to work. We have the knowledge in this country, and learning to understand and use micro organisms is the key to a sustainable future."
Whatever the outcome, the Delft microbiologist himself has certainly made a considerable contribution towards a sustainable future. Anammox has already been mentioned, but the paper mills at Eerbeek, the zinc plant at Budel, and even factories in Egypt treat their waste water with bacteria discovered by Gijs Kuenen. He managed to use sulphur-eating bacteria to convert sulphide from waste water into insoluble sulphur, which is easy to separate from the liquid.
In doing so, Kuenen broke down another dogma. "Together with the team around me I was able to demonstrate that the use of substrate mixes was a common feature. This contradicted the conventional wisdom that micro organisms will always eat substrates one after the other, but never simultaneously. You will find it in all the literature, even in some modern biochemistry text books: give a micro organism two kinds of sugar it likes, and it will eat first one, then the other. It turns out that in the natural environment this happens not quite so often, since there will always be some limiting factor."
This new insight has found use all over the world. "People in the waste water treatment industry tend to simply try things to find out how they work. But if you really understand why one organism does this, while another does that, you will be much better able to control the process."

*With acknowledgements to Bionieuws and editors of Delta.*

MICHEL MEES

Kuenen: "My credo is that micro organisms, with their untold possibilities for recycling and producing raw materials and bio fuels, will show us the way to the bio economy. Learning to understand and creatively make use of micro organisms is the key to a sustainable future."



Bacteria marriage in gas lift.
Laboratory setup at TU Delft.

# WHO & WHERE

*Delft University of Technology has eight faculties, each of which is engaged in education and research in one or more disciplines. The University was founded in 1842 by King William II. With 13.000 students, 2.800 scientific staff members and 2.000 technical and administrative employees, it is the largest university of technology in The Netherlands.*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Delft University of Technology Library (DUTL) supplies information and provides services, particularly in the area of the technical sciences.
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The DUTL is intended for students and staff at the Delft University of Technology. However, as the task of the library is to provide scientific and technical information at a national level, its facilities are also available to the general public. As well as all areas of technology and natural sciences, the library also contains a general collection in the social sciences, economics etc. This relates not only to books or periodicals, but also to standards, reports, reference works and congress proceedings. Literature not in the collection or not on hand can be obtained through Delft University's Central Library from other libraries in the Netherlands or abroad.

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