DELFT OUTLOOK
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TU Delft

Behnam Taebi
Guardian national security

DINOSAUR SKULL IN 3D
Reconstruction by craft and data

Best Graduates 2020

THEME
Hydrogen

Cover:
The hydrogen filling station in Rhoon is just a bit off the road, and there is no large sign. That's probably not necessary, because the regular customers know how to find it anyway. There are now only a few in the Netherlands, but that is about to change. (Photo: Sam Rentmeester)

Foreword
Tim van der Hagen

Hydrogen

Hydrogen has been called the missing link in the energy system of the future. As an energy carrier for storage and transport it can pave the way for large offshore wind and solar parks. As an alternative for natural gas it can heat our houses via the existing gas infrastructure. As a tankable fuel, it can make shipping more sustainable. In short, green hydrogen is the future. The government agrees and this year presented an ambitious hydrogen view for the Netherlands.
To produce all this green hydrogen we need electrolysis plants that can use sustainably generated electricity to convert water into oxygen and hydrogen on a large scale. And this is just one step on the path from the vision to the reality. The good news is that we are conducting research on our campus into many aspects of the hydrogen economy, from fundamental research into nano-particles for increased production efficiency, to pilot projects for applications.
From a green future to a grey past: the 66-million-year-old bone fragments that found their way to Delft 129 years ago, have now been restored using the latest technology and the Triceratops skull has returned to its place. Not so long ago, but just as fascinating, is the story of the first female engineer at the Bandung Institute of Technology.
Luckily women engineers are no longer a rarity today. In the TU Delft Best Graduate Award, male and female finalists and winners have been relatively well-matched in recent years. And even if the immediate future holds much uncertainty, a future that is shaped in part by our best graduates of 2020 is a future I can face with confidence.

Professor Tim van der Hagen,
President Executive Board

PHOTO: SAM RENTMEESTER

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DELFT IN BRIEF

The QR codes refer to the longer articles. More science news on tudelft.nl and delta.tudelft.nl.

PHOTO: SAM RENTMEESTER

PHOTO: SAM RENTMEESTER

Diversity officer

On 1 September, David Keyson, professor of Smart Products and Environments, started as Diversity Officer. His remit is 'to promote diversity, inclusion and equality at TU Delft'. So why is he the right person for the job? "I was raised in a very progressive family", said Keyson in an interview in Delta Magazine. "My grandmother was already campaigning for black rights in 1930s New York. Dutch society is very open, but TU Delft is also very white. There aren't many minorities in senior positions."

The Night Watch scanned

IDE researcher Willemijn Elkhuizen recently scanned the surface of Rembrandt's painting The Night Watch. It's the first time the painting's relief has been studied in such close detail. "Consider this as a baseline measurement", says Elkhuizen. "By charting the height differences in the paint, we get a good idea of the painting's current condition and the effect of time so far on the painted surface. If we repeat this kind of scan in a decade or two, we will also be able to find out how and at what speed changes happen in the 3D surface."

Phone-dumping

When you buy a new phone, you are supposed to hand in the old one for recycling. But most people just throw them into a drawer, preventing a circular economy in precious metals from taking off. How can designers help to create a 'return culture', wondered Dr Flora Poppelaars (Industrial Design Engineering). To guide designers, Poppelaars devised ten principles in her doctoral dissertation *Let It Go. Designing the Divestment of Mobile Phones in a Circular Economy from a User Perspective*, that she defended in the ceremony in October.

Accolade for online course

Dr Andy van den Dobbelsteen, Eric van den Ham, Siebe Broersma and Tess Bloom (Faculty of Architecture and the Built Environment) made it into the finals of the 2020 edX prize for exceptional contributions to online education with their MOOC 'Zero-Energy Design: an approach to make your building sustainable'. The edX prize celebrates lecturers' contributions and innovations, emphasising the key and large-scale role that online offerings are playing in the development of education. The short film 'Energy Slaves' from the course also won the Gold Heron Award for creativity and innovation.

Three million online students

TU Delft has recorded its three-millionth enrolment for an online course on the edX platform. Enrolment reached a peak around the middle of March, the start of the first lockdown in many countries. The number of registrations for the MOOCs (Massive Online Open Courses) also tripled from around 6,000 to 20,000 per week.
Solar Energy was TU Delft's first MOOC, launched in 2013, and has attracted the highest number of enrolments until now: over 230,000. There are now more than 120 MOOCs, on subjects ranging from health to the energy transition and from quantum computing to sustainable cities and the circular economy. Want to know more about online courses and MOOCs ? Visit the website **online-learning.tudelft.nl/courses** or scan the QR code.

New partner for QuTech

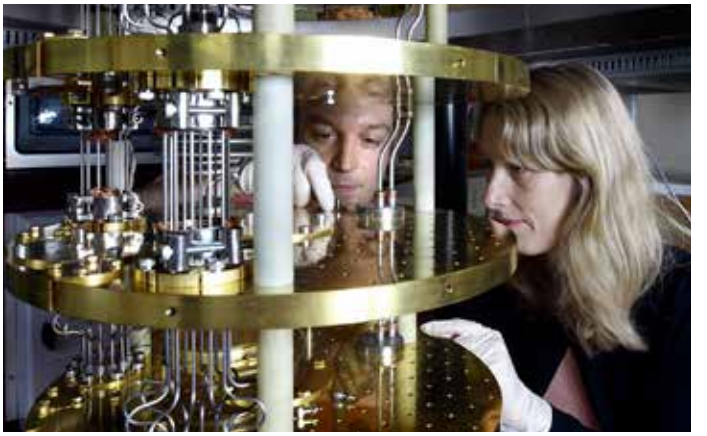

PHOTO: SAM RENTMEESTER

Following in the footsteps of Microsoft and Intel, Japanese electronics and computer manufacturer Fujitsu has now also signed a cooperation agreement with QuTech. QuTech is developing four different types of quantum bits (qubits). The development of superconducting quantum bits and quantum dots in silicon is receiving support from American chip manufacturer Intel. Microsoft has committed to the development of unfathomable Majorana particles as quantum bits. Thanks to the deal with Fujitsu, the fourth variant, spin qubits in diamond, now also has an industrial partner.

Flexible wing flies with feeling

PHOTO: SAM RENTMEESTER

An aircraft wing that can catch gusts of wind like a bird – that's probably the best description of AE alumnus Tigran Mkhoyan's SmartX-Alpha. When a bird lands, the angle of its wings increases relative to the wind, causing more friction and reducing lift. By sensing the prevailing pressure with its feathers and using its muscles to adjust the position of the feathers, it can respond to wind fluctuations. Mkhoyan's design achieves much the same. It contains pressure sensors, glass fibres as neural pathways and servo motors instead of muscles. Wind tunnel tests show that the active wing reduces the effect of sudden gusts by more than half.

Statuettes

PHOTO: SAM RENTMEESTER

From 1962 until 1982, artist Henk Zweerus (1920-2005) was Lector in Form Study and 3D Design at TU Delft. He had his own studio at the university. Johans Kreek (Alumnus from Architecture and the Built Environment) reminded the editorial team that the World Art Delft statue park on Rotterdamseweg features fifteen statuettes from his former studio. Zweerus wrote this about them: 'The studio in Delft enabled me to do a serial "rectangular form study" based on draft designs. I chose (white) concrete as the material to save money and make them last. Over the course of a decade, I applied this principle to compose seventy successive rhythmic variations.'

Barriers for cybercriminals

Are anonymous online marketplaces, like Silk Road and AlphaBay, sweet shops where cybercriminals can buy all kinds of tools and technologies for hacking and siphoning off money? Many experts fear that life is becoming increasingly easy for cybercriminals. Rolf van Wegberg (TPM) has spent years researching transaction data from eight of these anonymous online marketplaces. In his dissertation, defended in October, he concludes that there is no clear evidence of strong growth in this market and there are still huge barriers preventing aspiring cybercriminals from accessing what they need.

THEME *Hydrogen*

In August 2017, the sky blue Forze VII was a world first. For the first time ever, an electric hydrogen car battled it out with cars running on fossil fuels. The TU Delft student team that built the racing car did not win any prizes that year. But they did manage it two years later with the pink Forze VIII. This electric propulsion hydrogen car reached a top speed of over 210 kms an hour, beating most of the petrol driven cars and winning overall second place, emissions free, on the Assen circuit. Green hydrogen is the future and this theme is covered by Delft Outlook. However, there is still a long way to go to scale up production. TU Delft engineers are working on this in every conceivable way.

PHOTO: SAM RENTMEESTER

TEXT: JOS WASSINK ILLUSTRATION: STEPHAN TIMMERS

Green hydrogen brings electricity and gas together

Hydrogen is the ultimate CO_2-free energy carrier. TU Delft researchers are planning a future in which green hydrogen takes the lead as a source of both electricity and fuel.

Something strange is happening with green hydrogen (hydrogen that is produced using solar or wind power and so is CO_2 free); everyone wants it, but it does not actually exist.

The Government's view on hydrogen states: 'Industrial clusters and ports see hydrogen as an indispensable part of their future. For the transport sector, hydrogen is crucial for achieving emission-free transport. The agricultural sector sees opportunities (...). Cities, regions and provinces all want to use hydrogen.'

The reality contrasts rather poorly with this unanimous enthusiasm. A recent report (1) by the International Energy Agency (IEA) states that less than 0.1% of hydrogen is produced CO_2 free. The colourless gas hydrogen is accorded a wide range of colours in publications. The most commonly used type is the 'grey' hydrogen that is produced from natural gas by combining methane and steam under high pressure and temperature. If the resulting CO_2 is captured and stored, this hydrogen is classified as 'blue'. 'Green' hydrogen is produced by electrolysis (splitting water into H_2 and O_2) using solar or wind energy. When that electricity is generated in the Netherlands, this hydrogen turns 'orange'.

Grey hydrogen is currently the cheapest, while green hydrogen from electrolysis costs about twice as much (2). These prices fluctuate with the price of natural gas and the price of green power respectively. Over the next ten years, as electrolysis is scaled up, the price of green hydrogen is expected to fall by up to 60%. (3)

Balance, storage, capacity

Green hydrogen forms the link between electricity and gas. Electricity can be used to produce hydrogen by electrolysis, and hydrogen can be used to produce electricity in a fuel cell or as fuel in a gas turbine. The awareness of this reversible exchange between forms of energy brought together grid managers TenneT (electricity) and Gasunie (gas), resulting in a joint vision of the future (4). The Paris Climate Agreement requires emissions to be reduced by 95% by 2050. Gasunie and TenneT believe this will drive strong growth in solar and wind energy combined with large-scale conversion of electricity into hydrogen, the production of synthetic fuels and the development of energy storage solutions.

Gas offers solutions to the persistent problems faced by the greening electricity sector. For example, fluctuating electricity production from sun and wind makes it difficult to maintain the balance

between energy production and consumption. This balance becomes a lot easier to achieve when surplus production can be channelled into electrolysis plants.
Another problem is storage. Large amounts of electricity can really only be stored in reservoirs ('pumped hydro') which we do not have in the Netherlands. However, we do have salt domes large enough to store gas reserves for years.
Finally, capacity problems are to be expected when households switch en masse to heat pumps and electric cars, but hydrogen piped through a former natural gas pipeline has ten times more energy capacity than a high-voltage cable. A small hydrogen-fired CHP plant produces electricity and heat on site. By a lucky coincidence, the concerns of the electricity sector (balance, storage and capacity) are precisely the strengths of the gas sector.

Huge project

The fossil-free energy landscape of 2050 will rely heavily on immense offshore wind farms far out at sea. Hydrogen will flow from there into the country via pipelines. Ships will bring hydrogen from regions with cheap solar and wind energy to the ports on shore. Hydrogen pipelines from the west to the east of the Netherlands will supply energy for heavy industry, fuel for filling stations and heat and electricity to urban districts. Hydrogen will also support local energy networks.
But how do we get there? Offshore wind plays a key role. By early 2020, the Netherlands produced just over 1.1 GW in offshore wind farms (5). According to the central government's plan, this will have to increase to 11 GW by 2030 and 70 GW by 2050 to produce the required amount of green power. But that is far from enough to replace the remaining three-quarters of energy consumption in the form of fuel. So 'hydrogen professor' Ad van Wijk assumes that the Netherlands will import a substantial part of its energy requirements in the future, just as it does today, but then from areas with cheap solar and wind energy.
Electrolysis plants will also have to be scaled up enormously. There are currently an estimated several dozen megawatts of electrolysers in the Netherlands, mainly in chlorine plants where hydrogen is produced as a by-product. According to the Government's view on hydrogen, we will require 500 MW of electrolysers by 2025, 3 to 4 GW by 2030, and 10 GW offshore by 2040. Van Wijk has written a proposal (6) for 2 x 40 GW in 2030 as part of a European cooperation project. That plan has been integrated in the European Commission's hydrogen strategy (7).
Both offshore wind and electrolysis will therefore require unprecedented expansion in the coming decades. The routes to hydrogen are the 'Delta Works' of the energy supply.

> The routes to hydrogen are the 'Delta Works' of the energy supply

Starting point

According to Van Wijk, the gas platforms above the island of Ameland could be a good starting point. The natural gas can be converted on site into CO_2 and H_2, whereby the CO_2 is stored in an empty gas field and the 'blue' hydrogen gas can form the starting point of a fossil-free hydrogen network.
Hydrogen is more expensive than natural gas, says professor Kornelis Blok (TPM). "Just as with solar and wind energy, financial stimulation will initially be required to cover the excess costs." And it will probably stay that way. If green hydrogen becomes available in large quantities, it will reduce demand for natural gas, thereby lowering its price. So the success of green hydrogen will weaken its own competitive position. The hydrogen economy cannot get off the ground without subsidies or regulation. Ultimately, Blok expects that an energy system based on renewable sources will be comparable to, or perhaps 10% more expensive than, the current energy system.

1. IEA, The Future of Hydrogen, 14 June2019
2. Machiel Mulder, Peter Perey, José L. Morega, Outlook for a Dutch Hydrogen market, March 2019
3. Hydrogen Council, Path to hydrogen competitiveness, A cost perspective, 20 Jan 2020
4. Gasunie, TenneT, Infrastructure Outlook 2050, April 2020
5. NWEA, Nederland start inhaalrace offshore wind, 7 Feb 2020
6. Ad van Wijk, Jorgo Chatzimarkakis, Green Hydrogen for a European Green Deal. A 2x40 GW Initiative, 2020
7. European Commission, A hydrogen strategy for a climate-neutral Europe, July 2020

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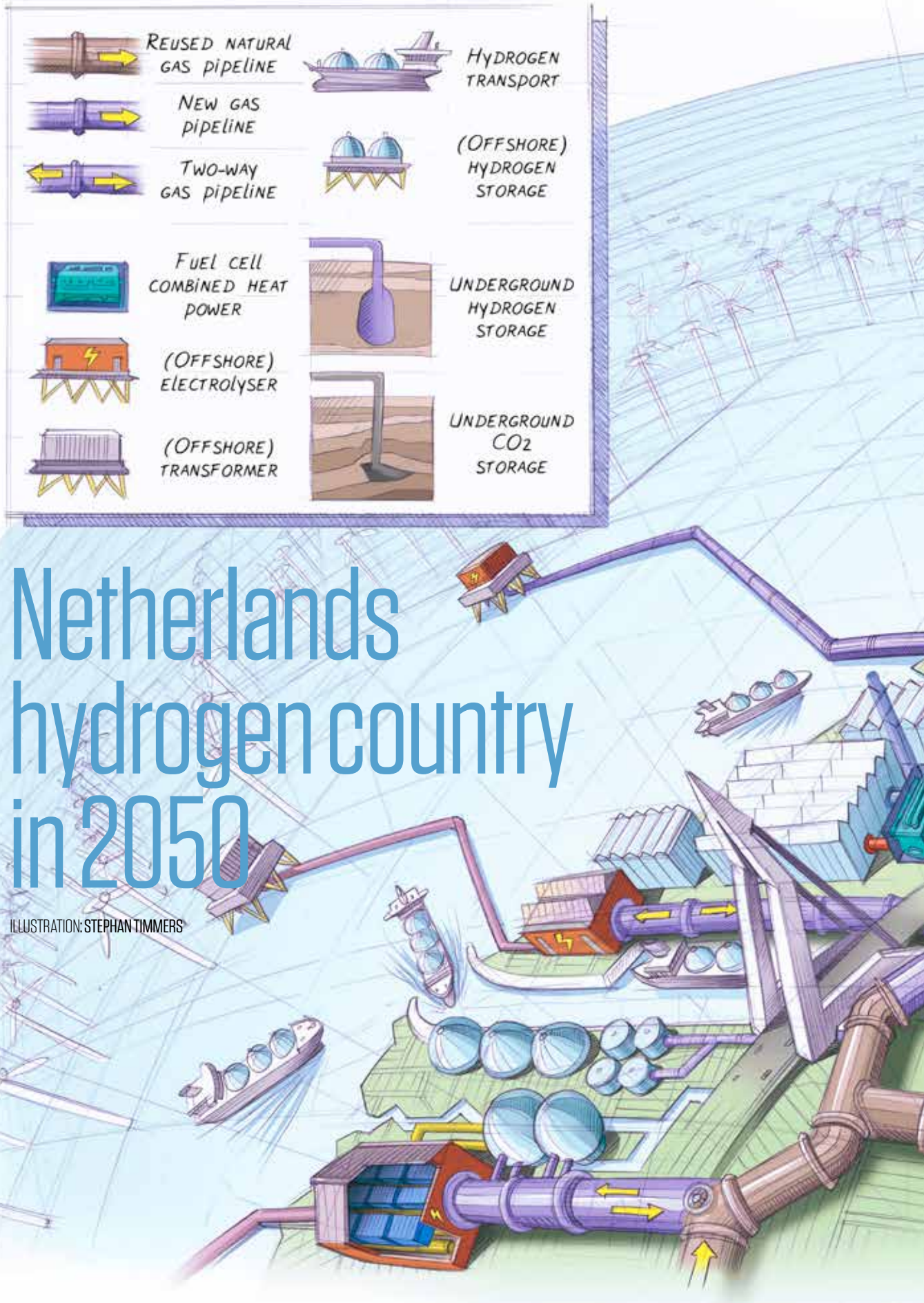


Netherlands hydrogen country in 2050

ILLUSTRATION: STEPHAN TIMMERS

Elektrolysis awaits scale up

The method of electrolysing water to create hydrogen is more than two centuries old. If hydrogen is to become a storage medium for renewable energy it will require gigantic installations. This calls for an efficiency boost.

Hydrogen is mainly needed for the production of fertilisers and explosives. In the last century, electrolysis plants of more than 100 MW were commonplace for the manufacture of these products. It eventually became cheaper to produce hydrogen from natural gas, and the last 100+ MW electrolysis plant closed in 1992.

Now that wind and solar energy is booming – with the associated peak supply – there is a demand for storage solutions. Batteries are an obvious choice, but they have drawbacks. Hydrogen is a good alternative: it is chemically stable and easy to transport. Because the production of natural gas causes CO_2 emissions, electrolysis is back in the picture, in a big way.

China aims to achieve a capacity of 5500 MW within four years, and the Netherlands aims to have 4000 MW by 2030, according to the Government's view on hydrogen which was sent to the House of Representatives in April. The view states that scaling up electrolysis should lead to a 50 to 60% cost reduction, which can only be achieved if it is made more efficient. TU Delft is involved in research to this end, whereby the battolyser, an innovative combination of battery and electrolyser, is well-known (see Delft Outlook, December 2018). But more fundamental research is underway.

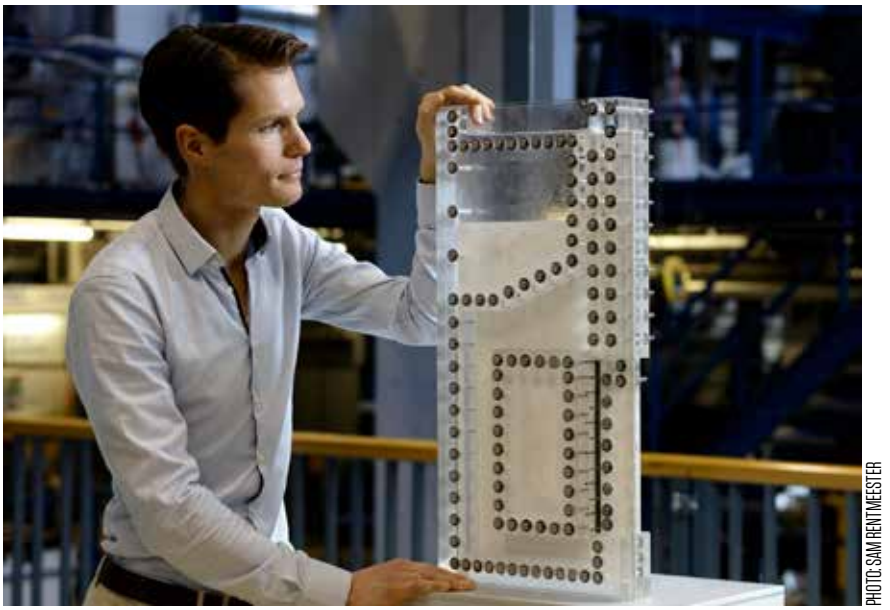


PHOTO: SAM RENTMEESTER

Dr Willem Haverkort with his test setup for electrolysis.

Explosive

In electrolysis, electrical voltage is applied to a saline solution. Hydrogen is subsequently released at the cathode and oxygen at the anode. These gas bubbles hinder contact between the electrodes and the solution, so they have to be extracted quickly. Ions also travel through the solution between the two electrodes. The process is more efficient when the electrodes are placed closer together, but then the gas bubbles also come closer together, and combined they form an explosive mix. So it is a puzzle to find the right combination of dimensions, materials, pressure, tension, temperature, etc.

"A typical 2 MW alkaline electrolyser is a tube with a diameter of almost two metres and a length of ten metres," explains Dr Willem Haverkort, who works at 3mE on the optimisation of electrochemical energy systems. "The tube contains plates that serve as electrodes, while separators prevent the two gases from coming into contact with each other. However,

these separators also impede the transport of the ions and so slow down the rate of hydrogen production."
Haverkort: "One of the solutions we are looking at is replacing the separator with a flow to drive the gas bubbles outwards. This could make the transport of the ions more efficient without the risk of the gases mixing."
Haverkort and student Pim van der Stigchel also designed an innovative electrode with a zigzag shape instead of the normal flat plate. This creates more electrode surface for the same volume. Much research still needs to be done, but they already have a patent.

Old discipline

"Electrolysis is an old discipline, but there still remains much to discover," says Haverkort. "The industry likely still has knowledge that has never reached the research community. In the 1960s, for example, the separator was often attached directly to the electrodes. When we try that today, it works for a while, but putting a very small distance between them still proves to work better. Old patent applications suggest that people knew this, but the knowledge behind this is unknown, at least to us at the university."

> 'Electrolysis is an old discipline, but there still remains much to discover'

What they certainly did not have at the time were the extensive computer models that Haverkort now has at his disposal and which make the search for promising solutions much easier. However, it is presently impossible to say with any certainty whether the government's wish of a 50% efficiency increase will be feasible. CJ

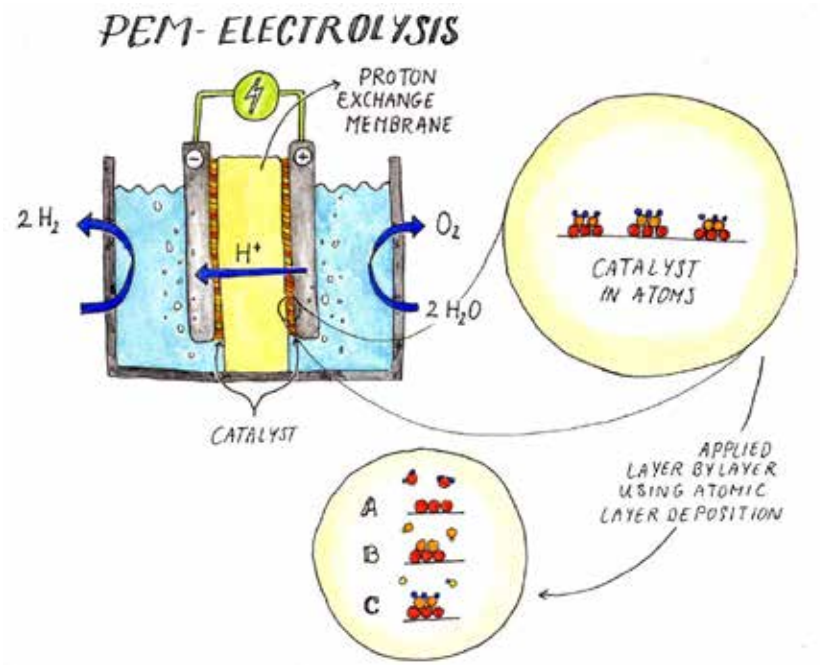
Marine life may benefit from hydrogen production

Hydrogen and oysters seem to have little in common at first sight. But if more offshore wind farms are built in order to produce the renewable energy required for hydrogen production, oysters may benefit. The seabed surrounding the foundations of offshore wind turbines must be hard to prevent sand erosion. The use of concrete foundations on which mature oysters are introduced produce a win-win situation. When the oysters reproduce they will form new oyster reefs. Renewable energy is produced and marine life flourishes!
It was with this in mind that civil engineering Master's student Victor van Rie started his internship at the Van Oord engineering firm. He designed a concrete structure to serve as a starting point for the development of oyster reefs. The European flat oyster (*Ostrea edulis*) used to form reefs that covered an area of the North Sea bed about half the size of the Netherlands. The reefs served as habitat for countless fish, crabs and lobsters. Diseases, overfishing and pollution have caused these oyster populations to virtually disappear. The hope is that the oyster reefs will regain ground with the help of projects such as this one. In October, a number of structures based on Van Rie's design were lowered to the seabed next to turbines in the Borssele wind farm off the coast of Zeeland. TvD

ILLUSTRATION: SIJA VAN DEN BEUKEL

Nanomaterials for hydrogen production

Ruud van Ommen is developing techniques to produce nanomaterials on an industrial scale. Expensive precious metals that serve as catalysts are the bottleneck for scaling up water electrolysis.



"Roughly speaking, there are two types of water electrolysis," explains chemical technologist Ruud van Ommen of the Faculty of Applied Sciences. "Alkaline electrolysis, a relatively old technology developed by the industry, and Polymer Electrolyte Membrane (PEM) electrolysis." The latter technique separates hydrogen and oxygen directly through a proton exchange membrane and looks to be the most promising method. Van Ommen: "The challenge with this technique is that it requires expensive precious metals to act as a catalyst."

Water electrolysis has an efficiency of between 60-75 and maximum 80%. "This efficiency has everything to do with the current density," explains renewable energy storage researcher Hans Geerlings (Applied Sciences). "If you force the electricity to flow slowly the efficiency increases; if you give the electrolyser a boost the conversion becomes less efficient. This must be factored in if you want to scale up." According to Van Ommen, there is little to be gained by increasing the efficiency of PEM electrolysis. "The key is to significantly reduce the amount of the catalyst iridium. We currently need 200 mg of iridium per kW, which must be reduced by at least a factor of 20."

Small clusters of atoms

Van Ommen is working on this step using Atomic Layer Deposition (ALD), a technique from the chip industry. The atoms of the catalyst are introduced in clusters, which increases the surface area and so requires less catalyst. This technique also works for catalysts of other energy applications, such as platinum in hydrogen cars and cobalt in electric cars.

Van Ommen's research has resulted in a spin-out company, Delft IMP (Intensified Materials Production). Delft IMP produces nanomaterials using ALD on a kilogram scale. The technology is still under development, but Van Ommen expects IMP to produce nanomaterials on a tonne scale within a few years. Geerlings expects water electrolysers to be scaled up quickly too. "Solar and wind energy are on the rise, and that requires good electrolysers. Within ten years water electrolysis will be carried out on a large scale worldwide."

Hydrogen in a solid carrier

The hydrogen carrier sodium boron hydride can be made to release twice as much hydrogen. This discovery by start-up H2Fuel could make hydrogen storage more practical. Klaas Visser (3mE) sees applications for the maritime industry.

Sodium boron hydride ($NaBH_4$) is a white powder that was previously used in detergents. In contact with water and with the help of a catalyst it releases hydrogen. Up until 2007, this generated no more than 30% of the bound hydrogen, but then Gerard Lugtigheid, a researcher at H2Fuel, discovered that purer water generates more hydrogen. The powder does not only release hydrogen, but also the hydrogen atoms from the water molecule according to the equation: $NaBH_4 + 2\ H_2O \rightarrow NaBO_2 + H_20 + 8\ H$. In other words, the hydrogen is doubled. This technical concept has been patented by H2Fuel. Klaas Visser, associate professor of maritime engineering (3mE), became interested in H2Fuel's technology around 2016. "The energy density of the powder (27 MJ/litre) is relatively high compared to other forms of hydrogen storage, and is close to diesel fuel (36 MJ/litre)," he explains. "Furthermore, with a flashpoint of 70°C, the powder is safer to transport and bunker than hydrogen in gaseous form."

Impression of the vessel that will sail on sodium boron hydride. (Image: Port of Amsterdam)

This means that sodium boron hydride meets three important conditions for zero-emission ships. "Not unimportantly, the water needed for the reaction with sodium boron oxide is available on a ship," adds Visser, "and with reverse osmosis and filters this can be purified to make ultra-pure water."
An important topic for research is how to make the process circular. Not only does the ship's tank become much heavier during the voyage due to the formation of the residual product sodium boron oxide ($NaBO_2$), it is also a challenge to regenerate the original sodium boron oxide using green energy and without producing waste. Visser: "The process is not yet circular, but TU Delft and the University of Amsterdam are working hard on this." These universities are designing a pilot reactor for regeneration. In 2021, the Port of Amsterdam will start the construction of a ship that will sail on sodium boron hydride in a pilot of the Interreg H2SHIPS project.

> The pilot plant has also been in operation for two years and has a capacity of 125 kW

"We learned how to separate the hydrogen from the carrier two years ago," says Frank Dobbelaar, co-director of H2Fuel. The pilot plant in Rotterdam has also been in operation for two years and has a capacity of 125 kW. Sodium boron hydride is currently purchased for this process. "This is too expensive for maritime applications." says Visser. "We really need to regenerate it ourselves." Visser won't yet say what specific chemical processes are involved in this regeneration. "The technique is proven on paper and we are already using it, but it can be made even more efficient," explains Dobbelaar.
A consortium of companies called Solid Hydro.Re.Gen is cooperating to develop sodium boron hydride as a hydrogen carrier. In addition to a number of maritime partners, railway infrastructure company ProRail also participates. Once all the techniques have been proven and have also been demonstrated to be economically viable, sodium boron hydride could be used on inland vessels, short-sea vessels, maintenance vessels and ferries, for example. "We expect to be able to start within the next five years," says Visser. SvdB

Floating blanket of solar panels

Researchers from TU Delft, MARIN, NIOZ and TNO believe that you have to think big if you want to produce hydrogen at sea. They want to build floating structures of thousands of square metres that can gently ride the waves. The structures are covered with solar panels and electrolysers that use the electricity to produce hydrogen. "They will resemble floating blankets," says Sebastian Schreier of the ship hydromechanics section (3mE). "We could also construct floating ports or even cities on the structures we envisage," he adds.

PHOTO: SAM RENTMEESTER

TNO tests floating solar panels on the Oostvoornsemeer.

The scientists have submitted an NWO research proposal to get funding to carry out their plans, but they hope to have a test version ready to experiment on in a towing tank even before they hear the decision. They address a wide range of questions: What forces are such floating islands exposed to? How can you build structures that are sufficiently supple and strong enough to withstand the waves? How do you attach the components to each other and what materials should you use? How will these structures effect marine life and how susceptible are they to fouling? The test version will hopefully be able to answer many of these questions.

Underground hydrogen storage

A huge amount of storage capacity will be required to get the hydrogen economy off the ground. Associate professor Hadi Hajibeygi of the Faculty of Civil Engineering and Geosciences (CEG) is studying whether underground cavities such as old gas reservoirs or salt domes can be used as 'batteries' for storing and recovering hydrogen.

The success of underground gas storage depends on how the gas flows through the rock and the reservoir. Hajibeygi is combining laboratory analyses with simulations and seismic measurements to find suitable locations for underground gas storage. He received a VIDI research grant from NWO for this research last year. The aim is to be able to designate a test site for the safe storage of hydrogen by the end of the five-year project.

"Hydrogen is the lightest molecule on our planet," explains Hajibeygi. "It is much more mobile than any other gas and it leaks easily. We need to find out whether it is safe to store hydrogen underground and recover it again in a cyclical process."

Scan the QR-code to read the TU Delft science story *The largest battery ever is just under our feet*

Integrating wind energy in the electricity grid

Wind turbines are getting bigger and bigger. According to professor Dominic von Terzi, offshore wind farms will need to diversify if they are to fit into the future energy mix.

PHOTO: SAM RENTMEESTER

Von Terzi used to work with General Electric, and his enthusiasm is still palpable when he talks about GE's prototype 12 MW wind turbine on the Maasvlakte. At a height of 260 metres, the HaliadeX is the 'largest machine ever built by man'. The HaliadeX was celebrated in Time Magazine as one of the 100 most sustainable innovations and is a candidate for future offshore wind farms.

But the wind farms of the future will also have to operate smartly to connect to the future electricity grid. At present, about 15% of electricity comes from wind power. That share is expected to grow to 40% or more by 2050. This means that the output of wind farms will have to be less variable than the wind itself.

"You need to increase your revenue," explains Von Terzi. Electricity generates additional revenue when demand exceeds supply, which causes prices on the energy market to rise. That is why it can be profitable to store energy in batteries when the price of electricity is low, so that when the wind drops and prices rise, it can be sold at a higher price.

Another option is to store energy in the form of hydrogen. An electrolyser can be built into the wind turbines or installed on a platform near a wind farm. Von Terzi's students are currently studying various options. One of these is the dual-use wind farm; an offshore wind farm that produces electricity when the market price is right, and hydrogen when the price of electricity drops. Such a wind farm will require both a power cable and a gas pipeline to the mainland. Won't that be too expensive? It depends, says Von Terzi. "If you have to build it from scratch, it probably will be, but pipelines lie all over the North Sea bed, and a dual-use wind farm could connect to these, if the authorities allowed it." JW

How the natural gas network is helping the energy transition

PHOTO: SAM RENTMEESTER

Hydrogen switching station at The Green Village on TU Delft Campus.

The extensive Dutch gas network could be an important asset to make green hydrogen available to a large public.

According to a recent Kiwa study commissioned by Netbeheer Nederland, this dense natural gas network of 136,632 kilometres and more than seven million connections is well suited to the transport of hydrogen gas. Could this gas be a suitable form of fossil-free heat for millions of older homes?

Electric heat pumps or heating networks based on geothermal or residual heat are often the preferred choice for CO_2-free heating, but not all homes are within reach of heating networks, and a heat pump is unsuitable in city centres, says Peter Luscuere, professor of building physics and services at the Faculty of Architecture and the Built Environment. "This is because heat pumps often work with a heat exchanger with a fan that makes noise all day," he explains.

Moreover, the electricity grid does not have the capacity to cope with a massive transition from central-heating boilers to electric heat pumps, even if the homes were to be adequately insulated. "The idea of 'everything electric' is completely insane," says Luscuere. "If you know how much effort it takes to increase the capacity of the grid by only 10%, you will understand why such a transition is impossible."

TU Delft alumnus Elbert Huijzer, strategic consultant for grid manager Alliander, estimates that this transition would require a much huger expansion. "If the electricity grid also has to absorb the peaks of the gas network, it will have to be expanded by a factor of six or seven."

This is why more and more people are calling for the natural gas network – the Netherlands' national treasure – to be reused as part of the transition to fossil-free energy instead of being decommissioned. Green hydrogen could reach millions of existing homes through that network.

New role

A forerunner of such a hydrogen network, the Hydrogen Street,

can be seen on the TU Delft campus. Grid managers Alliander, Enexis Group and Stedin commissioned the Green Village to create a hydrogen technology living lab that others can also use to test their hydrogen products. Lidewij van Trigt, Energy Project Manager of the Green Village, is seeking users for the facility inside and outside TU Delft.
The Dordrecht-based company gAvilar has been involved from an early stage. Their 'household gas pressure regulator' has been installed in almost every house and reduces the incoming gas pressure of 100 mbar to 30 mbar. The regulator works just as easily with hydrogen as with natural gas, explains TU Delft alumnus Lianne Mostert, project manager at gAvilar. The manufacturer is developing a small extension for the valve especially for hydrogen applications, which closes the valve when it detects a gas leak. gAvilar is one of the five partners in the H2@Home research programme which is supported by a grant from the Ministry of Economic Affairs' Energy Top Sector.
TU Delft alumnus Huijzer calls the test bed at the Green Village a 'Madurodam-sized gas network', referring to the miniature city. All materials and gas pressures commonly used in the national gas network have been brought together in a small area as a testing ground for hydrogen technology. Huijzer does not expect hydrogen to be available in the first households until 2030 – price and availability are a major factor. Currently, energy in the form of hydrogen is more than twice as expensive as natural gas. In Luscuere's opinion, fossil fuels need to be taxed more heavily and thus more fairly. "Only then will there be a transition and will you be able to start thinking about rolling out hydrogen in the Netherlands." JW

Hydrogen drone

Researchers from the micro aerial vehicle laboratory (MAV lab) have created a drone that runs on hydrogen and can take off and land vertically and fly for hours horizontally like an aeroplane. The drone weighs thirteen kilos, has a wingspan of three metres and is equipped with twelve motors and propellers. The researchers tested the aircraft on a Royal Netherlands Navy vessel while far out at sea. The drone can fly tens of kilometres, which makes it suitable for use as a forward observation post.
The battery that drives the motors and the hydrogen cell are geared to each other. This is because both propulsion systems have to be used simultaneously when the drone takes off, which is a highly energy-intensive operation. When the drone flies horizontally it switches completely over to the hydrogen cell.
As with hybrid cars, the battery recharges during flight. "Normally we would see the battery run down quickly during flight," says project manager Remes. "Now we have achieved the opposite."
Could civil aviation benefit from this development? "Taking off with passenger planes also uses an enormous amount of energy, and the extra power provided by batteries is therefore needed. But hydrogen cells could definitely take over once you are at cruising altitude. So yes, the technology we are developing is also of interest to the civil aviation sector." IVO

'Hydrogen cells could definitely take over once you are at cruising altitude'

Scan the QR-code and watch the video

‘Safety and security are part of almost every technological development’

He wants the Safety & Security Institute to make the Netherlands and the rest of the world safer, but why are safety and security so important to technology ethicist Behnam Taebi?

TEXT DESIREE HOVING PHOTOS SAM RENTMEESTER

Led by the Safety & Security Institute, TU Delft, TNO and the Netherlands Police are expanding their collaboration in order to conceive innovative solutions for national security issues. Behnam Taebi is the Institute's Scientific Director. PhD research is taking place on a range of topics, such as methods for making it easier to find people of interest in the huge amount of data available, and improved risk profiling using artificial intelligence (AI). Two large-scale research projects started earlier, one on the optimum deployment of available police officers in certain situations, such as riots or a fleeing burglar, and the other on using smart robots in dangerous situations.

Now the ink has dried on the letter of intent, what is the next step you will be taking in this collaboration?
"We want to expand the existing research projects and explore new research fields for collaboration. The police are offering some problems we can research jointly. At the same time, we see that TU Delft has new technologies and innovations for the problems of the future. We can examine security problems from various academic disciplines and only by working with important social partners can we find answers. The three-sided collaboration with the Netherlands Police and TNO is a result of this."

Do you dare predict what kind of questions the Netherlands Police will be asking in the near future?
"I think we can expect a huge diversity of questions. One hypothetical case is how drones can be used for security issues. Drones are being increasingly deployed for crowd control, and in some countries even for enforcing coronavirus measures. Drones can also be deployed in hard-to-reach areas or to help the fire service in firefighting. I can easily imagine that a drone like this gives rise to questions from citizens: can I check what exactly is being detected, are the images stored, can faces be identified on the images and what happens to the data? These are crucial questions that you need to answer during the development of technology and where you need to include ethical considerations."

What ethical considerations do you mean?
"The enormous possibilities opened up by artificial intelligence, for example. AI uses a huge amount of data in an intelligent way, without us knowing precisely how. This makes AI a lot like a black box; a lot of academic work is being done to open the black box and make AI applications explainable and transparent. That may be extra relevant for police work. Explainability – or being accountable for a conclusion – and transparency are central social values. Serving [the values of the rule of law] with vigilance is a motto of the Netherlands Police."

You have been Scientific Director of the Safety & Security Institute for a year now. Why were you invited for this position?
"I studied Material Science and Engineering and gained my PhD in the Philosophy of Technology. Since then I have focused on the long-term risks of energy and climate issues. How can we gain a better understanding and control of large-scale and long-term risks? I am also very interested in the social and ethical issues associated with technological risks. I think I was asked because of my interest in security, but also because of my background in engineering and philosophy."

> 'I can easily imagine that a drone like this gives rise to questions from citizens'

What is your intention for the Safety & Security Institute?
"The institute aims to make the Netherlands and the whole world safer and more secure, particularly in the area of technology development. Safety and security are multifaceted and complex issues; we need to take account of safety risks arising from an accident while at the same time making our technologies more secure against deliberate misuse by malicious parties. Within our institute we want to study safety and security as an integral entity."

Can you give an example of the different aspects of safety and security?
"The traditional task of engineering is of course to ensure safety. As technology has grown increasingly complex, so has ensuring safety and security grown more complex and challenging. In the last 50 years, thinking about risks has developed much further, particularly from a desire to prevent – or at least reduce the risk of – large-scale accidents such as in a nuclear power station or an airplane crash. This falls in the

CV

Behnam Taebi has been Scientific Director of the Safety & Security Institute since September 2019. He has worked as a technology ethicist in the Faculty of Technology, Policy and Management since 2005. Internationally, Taebi is a co-founder of the research field surrounding the ethics of nuclear energy. Together with Sabine Roeser, he put together the book The Ethics of Nuclear Energy: Risk, Justice, and Democracy in the Post-Fukushima Era. He is also the author of the book Ethics and Engineering for Cambridge University Press. Taebi is co-Editor-in-Chief of the journal Science and Engineering Ethics. He is a member of The Young Academy of the Royal Netherlands Academy of Arts and Sciences and a member of the OECD Expert Group on Transdisciplinary Research for Addressing Global Challenges. He studied Material Science and Engineering and the Philosophy of Technology at TU Delft.

category of safety risks. Security is about designing technology so that it can withstand sabotage and attacks from outside. In 2020 this is of course not a luxury but bitter necessity."

What aspect of safety and security particularly fascinates you?
"Scientifically speaking, I am fascinated by its multifaceted nature and complexity. For example the question: whose safety? We have long since stopped developing technology purely to ensure the safety of the user. And you sometimes see that solving problems creates new ones – that intrigues me as an engineer."

Can you give an example of a problem that creates a new problem?
"Among other things, the self-driving car was designed to reduce car accidents caused by human error. At the same time, you need to also give good thought to the infrastructure, the communication between cars and how a car makes ethical choices; who is responsible if there is an accident? This is my fascination for safety and security: they are part of almost every technological development. You must also consider the deeper philosophical question: How can you give technological shape to the interaction between man and machine in a meaningful way, and how do you regulate this interaction?"

Precisely how does the interaction between man and machine relate to safety?
"Here there is a strong relationship between safety and autonomy; how far are we prepared to hand over part of our human autonomy to the car? On the one hand a self-driving car does bring more safety, because there are statistically fewer accidents. Yet at the same time the car is dependent on the driver who needs to monitor the car's behaviour and intervene if the car makes a mistake. So it remains a man-machine interaction. How could you train the driver of a self-driving car to remain alert? And to what extent do we surrender autonomy to the machine? How can we meaningfully regulate man-machine interaction?"

Is this also something you work on at the Safety & Security Institute?
"In our institute we distinguish four themes. First, improved calculation of uncertainties and optimum understanding of risks; second, 'safe by design', in other words designing so that safety is seen as a core value; third, being able to reduce consequences; and finally, failure analysis. For this last point I can give another example from the automotive industry. TU Delft's solar-powered cars are world famous, particularly because of the cutting-edge technology used, and of course because our students win world-class prizes in them. But problems with technology have caused accidents as well. It is important to understand these problems and learn from them. We want to learn more often from accidents so we can design our technology better and make it safer. Our institute focuses on cyclical thinking about safety. On the one hand we want to prevent accidents, but on the other hand the world always becomes safer after an accident, at least, if we learn sufficiently from it. This is sometimes called the safety paradox."

In ten years' time, when would the collaboration with TNO and the Netherlands Police be regarded as successful?
"I would consider the collaboration a success if we succeed together in conceiving technological solutions that are well-embedded societally and ethically. In short: if we take an interdisciplinary approach to safety and security. And I hope that by doing this we can inspire the rest of the world to also take such a broad view of safety and security."

IN PERSON

Research funder NWO has made fourteen **recently graduated researchers** at TU Delft happy with a Veni grant of 250 thousand euros for three years of research. Scan the QR code.

NWO also distributed vidi grants of 800 thousand euros each to four Delft researchers: Dr **Doris van Halem** (CEG, Air as the driving force for drinking water treatment), Dr **Toeno van der Sar** (Kavli, QuTech, AS, How do electrons move through quantum materials?), Dr **Coen de Visser** (AE, Forecasting safe operating envelopes for autonomous robots) and Dr **Monique van der Veen** (AS, 'Nano heaters' to unravel catalytic reactions with ultimate time resolution).

Board member **Nicoly Vermeulen** will leave the TU on January 1st. The Vice President Operations will be temporarily succeeded by Professor **Theun Baller,** Dean of the 3mE faculty. Baller's task includes the financial-administrative management and personnel management of the University Corporate Office (UD) and the regular consultation with the office's subcommittee.

Delft students have won the second edition of the 4TU Impact Challenge. They will participate in the World Expo in Dubai at the end of next year with the **project ZED**, which develops batteryless applications for companies. In this way they want to contribute to both sustainability and better working conditions.

Together with **Floris van der Gronden** (Applied Sciences) alumna **Anne de Zeeuw** (Architecture) represents the TU Delft this year in the National ThinkTank 2020. This foundation brings together twenty (PhD) students each year to solve a social issue.

COLUMN

Everything becomes fluid under pressure

Quotes were being bandied about: 'Everything becomes fluid under pressure', 'Never waste a good crisis', Johan Cruyff's legendary 'Every disadvantage has its advantage', to name just a few. Whether relevant or not, optimists use these kinds of expressions to indicate that, as painful as it is to all of us, the coronavirus crisis offers us many opportunities. That now is the right time to innovate.

But is this really the case? There are entrepreneurs who are now learning the hard way a truth that every techie knows: not everything becomes fluid under pressure. If you have limited financial reserves and your turnover falls to almost nothing from one day to the next because you have to close your business while your overheads keep piling up, it is debatable whether creativity will get you out of it. You often do need financial resources if you want to innovate.

For those companies that have adequate resources and the many companies that are not quite as badly affected, it definitely is true that there is more room for innovation. Why? The reason is that two things that normally hold back innovation disappear during a crisis. The first is loss aversion, the tendency to prefer avoiding losses to acquiring equivalent gains. For companies, this means that they would rather safeguard their current turnover than put effort into generating new turnover. This aversion is heard in arguments such as 'That will eat into our existing turnover' and 'That new product has a low profit margin, which will lead to reduced profitability for the company'.

The second reason is the lack of urgency in times of economic growth. Until March 2020, many companies simply did not feel the need to innovate. 'Things are going well, aren't they?'

A radical crisis punctures this bubble. If your turnover collapses from one day to the next, loss aversion disappears in one fell swoop and there is a rapidly growing sense of urgency. This can unleash enormous powers of innovation, and teams can realise way more in a very short time than they could have imagined. Retail chains retrain their staff to become online sales advisors, producers of hard liquor start making disinfectants, producers of tents start making screens for protecting cashiers, organisers of festivals turn into production companies in online events, and 3D printing parks switch from commissioned work to producing Covid-19 test swabs themselves. The list of examples goes on and on. All because loss aversion has fallen away and been replaced by a sense of urgency.

Technically, it might not be true that everything becomes fluid under pressure, but for many companies things really do get going. A crisis can therefore be a breeding ground for innovation. Or, to quote Cruyff: "Every disadvantage has its advantage."

Deborah Nas is an innovation expert and part-time Professor of Strategic Design for Technology-based Innovation in the Faculty of Industrial Design Engineering. She studied Industrial Design Engineering at TU Delft.

THE FIRM

Predicting the harvest of fresh vegetables like broccoli using data and drones. That's what the company run by Kaz Vermeer (27) and Bas Nootebos (29) and Wageningen University alumnus Eric Verhoeff (29) does.

"Purchasing organisations only know how much broccoli they'll be getting when the lorries are unloaded", says Kaz Vermeer. "Harvests predictions are based on the grower's gut feeling. The actual harvest is almost always different. As a result, purchasing organisations don't find out if they can serve their customers until a very late stage. Because they can't build stocks, they have to do last-minute buying or selling, making that head of broccoli more expensive. It's the biggest uncertainty in the fresh produce value chain. VanBoven is changing all that."

'Developing in the winter and testing in the summer'

VanBoven uses accurate predictions of harvests to coordinate demand and supply, making transport more efficient and cheaper. In exchange for this information, customers take out an annual subscription. Vermeer: "In the time it takes a grower to check a dozen plants, we can use a drone to inspect thousands. Crop growth is highly weather-dependent. Currently, a set duration of growth is assumed, but the reality is always different. We process drone footage together with weather data, such as temperature and precipitation, into smart algorithms to predict when it's possible to harvest. We update this while the crops are growing, allowing us to predict harvest several weeks in advance and providing valuable time for action to be taken in the chain."

Kaz Vermeer: "We predict harvest several weeks in advance."

Company:	VanBoven
Product:	Harvest predictions for fresh vegetables
Founded in:	2018
Programmes:	Mechanical Engineering (Kaz) Aerospace Engineering (Bas), Hydrology and Geo-information Science (Eric).
Number of employees:	Three founders and six employees
Target group:	Fresh produce value chain
In five years' time:	"VanBoven's data-driven harvest predictions will be the new standard in the global vegetable market."

The alumni came up with the idea for their company thanks to Bas Nootebos' study on drone use in agricultural soil surveys. "This has potential, we thought", explains Vermeer. "Long story short: Bas and I were housemates, Eric a friend from school. We joined forces and, together with TU Delft's Faculty of EEMCS, successfully applied to the NWO for a Take-off Grant. We launched onto the market soon after."

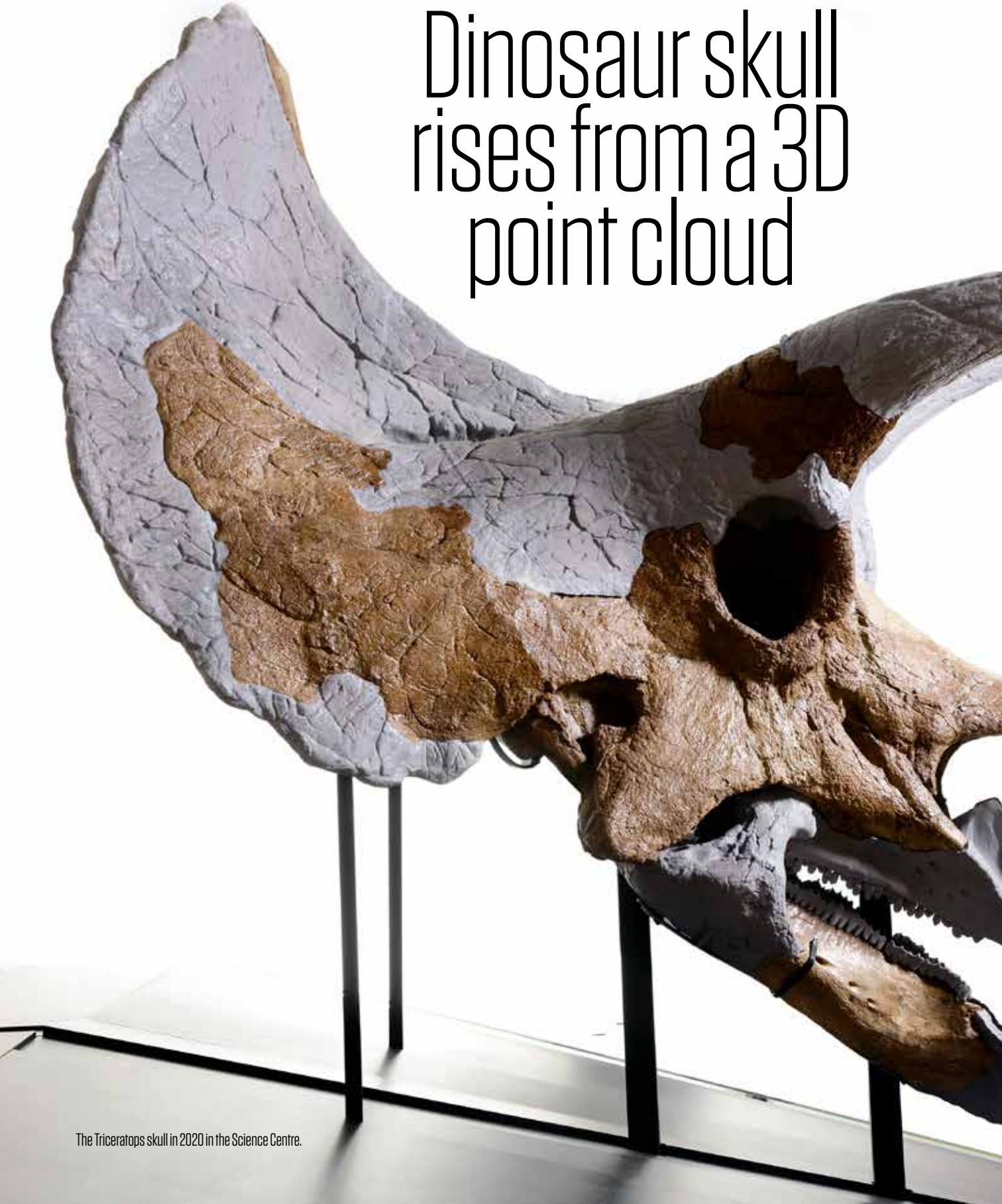
Like any start-up, VanBoven is still very much in the development stage. At the start of the harvest season, the algorithm was not working optimally. The dataset used to train the models was still too limited. Vermeer: "Some broccoli just looks different. Bigger, smaller, different lighting. Now, at the end of the season, we have a much broader dataset and a more accurate model. We also have to deal with growing seasons, developing in the winter and testing in the summer. That's more difficult than expected, because you can't test ideas quickly."

Vermeer and the team are now broccoli experts. "We've proved to four major growers and Bakker Barendrecht, the Albert Heijn purchasing organisation, that our technology works. Next year, we want to scale up to national level for the broccoli product group. We also intend to expand our range of fresh produce to include cauliflower and strawberries." EM

PHOTO: SAM RENTMEESTER

TEXT: JOS WASSINK PHOTO: SAM RENTMEESTER

Dinosaur skull rises from a 3D point cloud



The Triceratops skull in 2020 in the Science Centre.

The Triceratops skull is back in the Science Centre. The restoration combined 66 million year old bone fragments and today's scientifically modelled 3D prints.

Skull 21 has been through a lot, especially in the last 129 years. Some 66 million years ago, Skull 21 was the head of a large dinosaur in what would later become North America. It was about nine metres long, three metres high and weighed 13 tonnes. Triceratops prorsus, as it would later be called, was a stocky muscular colossus that lived off plants and shrubs. They worked these out of the ground with their nasal horn, grinding them with a long row of small teeth that worked like a shredder. Scholars are still divided about the role of the two upright horns and the neck shield. Were they the equivalent of a peacock's tail, or a defence against the predatory Tyrannosaurus rex, who also wandered these grounds at the time? Either way, at one point this colossus crossed the Styx, and left his skull and bones to fossilise. Even though at some point the skull was crushed between layers of earth, many millions of years later it surfaced again. In what is now called Wyoming, USA. In 1891, with 30 others, the skull was salvaged by a team from Yale University. It was given the catalogue number YPM 1832.

Broken bones

The trip to the Netherlands was, if possible, even more wondrous. The Delft palaeontologist Professor Jan Umbgrove was aware of the extensive Yale collection in the early 1950s and he wanted to have one item as a masterpiece for the Mineralogical Museum, the visiting card of the Faculty of Mining. In exchange, he offered a part (only doubles) of the so-called Timor collection - a collection of fossil shells that tell a lot about marine life in a particular period (Perm and Triassic). TH Delft, the later Delft University of Technology, had collected them in 1910 and 1916 on the Indonesian island of Timor.
To speed up the exchange, Umbgrove had already sent the shells out, says Science Centre director Michael van der Meer. If Umbgrove wanted to put the Americans on the block by doing this, his strategy succeeded. It was a pity that Umbgrove didn't live long enough to enjoy his success; he died in 1954 - two years before the skull he had ordered arrived in Delft.
The restored Skull 21 was put in a crate and shipped to the Netherlands in 1956. Unfortunately, the ship headed into a storm and the cargo was severely battered. Also, the delivery seems to have been less than gentle. Whatever the cause, when the curator of the Mineralogical Museum, Doctor Pieter Kruizinga, opened the crate, he saw more than a hundred pieces of debris. Kruizinga had retired five years previously, but he did what he had to do: he put the puzzle of his life together. The dinosaur skull was resurrected in his hands. For more than half a century it would be a showpiece of Delft's mineralogical collection. It remained there until the entire collection was transferred to Naturalis in Leiden in around 2014.

Naturalis

"There were some mistakes in Doctor Kruizinga's reconstruction," observes preparer Martijn Guliker of the Dinolab Naturalis. "The horns were standing upright on the skull like a young god, but that's not correct. Just like with goats, the horns first go upwards and later slant towards the front." To reconstruct it accurately, the Dinolab staff decided they had to go back to basics.

Read more on page 28

PHOTO: ARCHIEF TU DELFT

Triceratops in 1957 after the reconstruction by Dr Pieter Kruizinga.

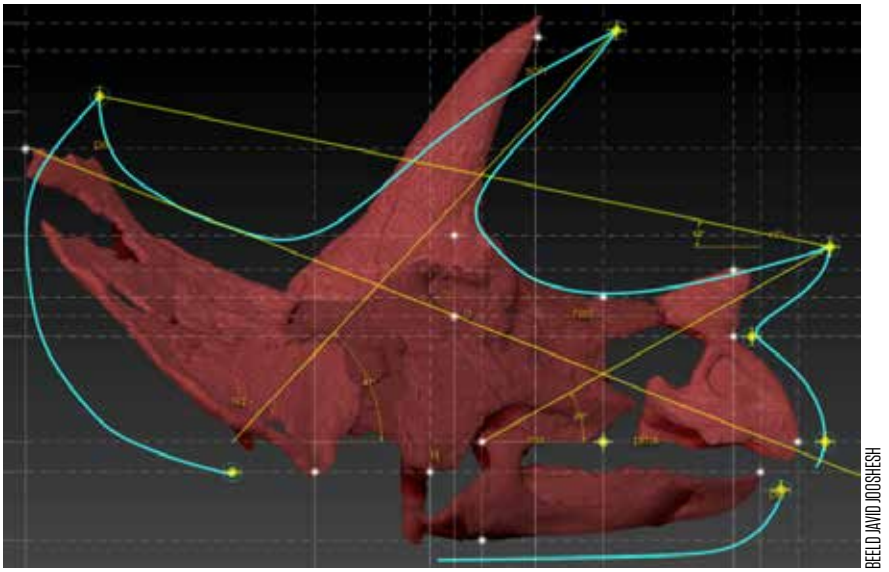
"I demolished it myself," says restorer Aart Walen, "with Martijn Guliker and Jan Hakhof. Martijn asked me to sandblast the pieces to see which bones were real and which not." After inventorying this, Guliker made a kind of blueprint of which piece belonged where by numbering the bone fragments. Then the work stopped

Kruizinga did what he had to do: he put the puzzle of his life together

for a while because the Dinolab had to process the findings of a Naturalis team in America. The most exciting dinosaur excavations ever, according to the researchers involved. Meanwhile, Science Centre Director Michael van der Meer saw the new acquisitions of Naturalis as an opportunity to bring Skull 21 back to Delft. Reconstructed using the best digital tools: 3D scanning, 3D modelling and 3D printing. The 21st century museum piece not only had to be an impressive historical piece, but also a showpiece of what digital 3D technology is capable of today. It had to be a marriage between palaeontology and 3D technology, between bone builders and model makers, between craft and data. That is what Skull 21 now stands for: an example of how knowledge and technology can resurrect a long extinct animal from bones and plastic.

Form finding

The reconstruction was a collaboration between restorer Aart Walen and 3D model maker Javid Jooshesh from Rotterdam. "We had to get used to each other's approach in the beginning," said 3D specialist Jooshesh. "While Aart was cleaning and sorting out the bones, I was working on 3D scans of the bones that I was putting together with the computer as a 3D Tetris." The first step was to find out how Kruizinga had reconstructed the skull, no matter how mistaken it was.
But what was the right shape? Jooshesh studied two smaller but comparable and fairly complete skulls from collections in Yale and Munich. He made optical 3D scans of them. "The scanner reads two million points



BEELD JAVID JOOSHESH

The Kruizinga reconstruction (red) with the calculated contour (blue).

per second, that's very precise. In the end, you have a detailed spatial model with a resolution of 0.3 millimetres."
In consultation with Naturalis' Dinolab, Jooshesh determined about 10 points on the skull between which he measured the distances and calculated the proportions of those distances. The TU Delft skull turned out to have strange proportions compared to those from Yale and Munich. The horns were 20 degrees too far up, the dorsal shield was too small and the snout too short. Jooshesh then adapted the 3D model of Skull 21 to the dimensions of the other two.
He still had to fill in missing parts – almost half the skull at TU Delft. This included facial features such as the horns, lower jaw, bridge of the nose, as well as a large part of the dorsal shield. Jooshesh did this 3D modelling based on the proportions of the other skulls and in consultation with Guliker at the Leiden Dinolab.
"Even then, I wasn't ready for printing," Jooshesh says. "Because then it would have looked like plastic." What was missing was the surface structure. Bone is not smooth; it is full of fine channels for blood vessels and nerves which branch out in various directions. Jooshesh collected 1,000 detailed shots of fossil bone structures as a basis for the surface structure of the 3D printed parts. "Combined with spatial design, this resulted in a detailed 3D model that was ready for printing and that would fit together like a puzzle," says Jooshesh. That puzzle is a compromise for the 3D printing technology, which is limited in size to about 50 centimetres. So 3D Printing Prototypes produced parts of the back shield and the horns in several parts.

Jooshesh collected 1,000 detailed shots of fossil bone structures as a basis for the surface structure of the 3D printed parts


IMAGE: JAVID JOOSHESH

Which piece where? The beginning of the reconstruction in 3D.

In the spotlights

In the Science Centre, Skull 21 is the centrepiece of a live presentation, supported by a light show. "These techniques have never been used in a museum before, and certainly not in palaeontology and archaeology," explains lighting designer Charl Smit. He built the light show that he designed with lighting professor Prof. Dr Sylvia Pont (Faculty IDE) and a team of students. At the entrance, the gigantic silhouette of the dinosaur skull moves over the projection screen surface using five different spotlights, as a guide explains the life of the Triceratops prorsus. Then Skull 21 stands, powerfully resurrected, in the coloured spotlights.
It is only when the spotlights fade and turn to white that the audience sees which parts are original and where the reconstructions are. This light trick is known as spectral tuning - the subtle tuning of LED spectra to the colour of the material, amplifying or eliminating colour differences.
"Our work complements that of Naturalis," says Science Centre Director Michael van der Meer. "At Naturalis you can see which dinosaurs there were and how they lived. Here we tell the story of the reconstruction of a skull. We show how the techniques have developed since the first reconstruction, and how restorers use them." <<

The Triceratops Skull 21 is on display in the Science Centre, Mijnbouwstraat 120 in Delft.

The Science Centre wishes to thank the sponsors of the Mineralogic Geologic Museum for their contribution to the reconstruction: Dietsmann, Shell, Dyas and Fugro.

Georgios Andreadis:

'Simply buying more servers is becoming irresponsible'

Georgios Andreadis is TU Delft Best Graduate. Every year the Delft University Fund presents the award to one of the eight best graduates of the faculties. Who are they and what do they do?

Rick Waasdorp - 3mE

We know that the brain sends a muscle a message before it moves. But we don't know precisely what happens next. Master's student Rick Waasdorp has come up with a swift, non-invasive technique for looking at exactly this. It is perfect for further research into muscular dystrophy. So Waasdorp's fervent wish to carry out research that makes a difference has been fulfilled. The project that started 18 months ago as a piece of fundamental research is almost ready for clinical trials on patients. In September, the mechanical engineering alumnus who specialised in biomechanical design, started an ambitious PhD research project, not about dystrophy this time, but still using highly refined measuring techniques. In the coming years he will be using ultrasound technology to map brain activity.

Amina Chouairi - ABE

For her Master's thesis, landscape architect Amina Chouairi took a dive into the tides of Venice. Her thorough research provided a basis for a unique design proposal for creating a natural flood defence. She also looked into creating a suitable environment for the much-needed recovery of the ecosystems of the Venetian lagoons. Her Master's thesis earned her a nomination for a place in the Archiprix pre-selection. In her research, Chouairi focused on an alternative form of 'slow tourism', and how you can refine local economic activities. Her main goal was to strengthen the cultural image of the Venetian lagoon; a unique horizontal and seemingly endless water landscape.

Frans Liqui Lung - CEG

It's a huge chaos in the atmosphere, but we don't see much of it. To better map out atmospheric processes close to the ground, Frans Liqui Lung developed a digital simulation model that can show the influence of wind on sand and sand on wind on a small scale. Anyone walking on the beach or in the dunes will recognise the wavy structure of the sand surface. The ripples are formed by the wind transporting grains of sand over short distances. At the same time, the sand ridges influence the wind, says Lung. "The movement of the sand is accelerated by the wind, but once a ridge has been formed, this same sand slows the wind down."

Georgios Andreadis - EEMCS

Just like the roads they are on and the dykes protecting them, cloud data centres are an essential part of our national and the global infrastructure. Georgios Andreadis' graduation research was on the capacity planning of these data centres. "Simply buying more servers is becoming irresponsible", he states. Thanks to his research, in the future data centres will be able to meet the increasing need for computational power more cheaply, efficiently and sustainably. The final result of his Master's research in the @Large Research group is the Capelin tool, that supports capacity planners who are working on new hardware. Many organisations, from industry to academic institutes have shown interest in the tool as soon as the software becomes available.

Chen Chou - IDE

It is hard when someone you care about is admitted to hospital. But it's even harder when you can't visit them because of a pandemic. Chen Chou developed a way for people to maintain contact using music. Her research project CareTunes for Families converts information such as the heartbeat, brainwaves and movement of a patient into a soundtrack that their loved ones can listen to. Chou feels that industrial design can add much value to the progress of medical care. She started her Master's programme in 2018, long before anyone had heard of the coronavirus. But the outbreak of the disease soon showed the importance of and the need for her work.

Wouter Schaberg - AE

Solving a 25-year-old aviation problem? No problem for Wouter Schaberg (Aerospace Engineering). He improved part of the Modified Voltage Potential (MAP) algorithm that is used to prevent aircraft coming too close to each other following an averted conflict. The skies have grown increasingly busy in recent years. In 2019 the average number of aircraft in flight at any one time was 11 thousand, twice as many as ten years ago and making central air traffic control work overtime. A possible solution may lie in more decentralised flight control, where the aircraft determines its own flight route using algorithms. It is questionable whether this will ever happen, as all the safety risks mean the aviation sector is very conservative.

Maria Chiara Mazza - TPM

Chatbots on eHealth apps may help support people suffering from anxiety and other mental health problems. Maria Chiara Mazza (Technology, Policy and Management) investigated how recognising someone's linguistic patterns and personality can help to improve personalised chatbots. As many as one in four people in the world suffer from anxiety or other neurological disorders. The problem is that sufferers are also likely to be afraid of enlisting help, says Mazza, who graduated in July. Mazza gave 142 students of different nationalities a survey to complete plus a written assignment. Forty percent of the participants turned out to be suffering from an anxiety disorder. The texts showed that people with such a disorder have a different language pattern.

Teun Huijben - AS

Teun Huijben's research is about particles so small they are invisible to the naked eye. In fact, they cannot even be seen through an ordinary microscope. You need a special instrument to observe these tiny particles, such as proteins in a cell. To study and find cures for many kinds of disease, it is important to be able to scrutinise small, individual parts of cells separately. Huijben has developed a smart algorithm which makes this possible.
He created a calculation program that can distinguish between the shapes of an "apple" and a "pear". The algorithm divides images into different categories, in such a way that you can now tell them apart.

The first woman engineer in Bandung

'That woman was my grandma', wrote a reader in response to the article on 100 years of the Bandung Institute of Technology (Delft Outlook, July). Who was this woman in the first cohort of civil engineering students in the former Dutch East Indies? Granddaughter Annette Lievaart tells the story of her grandmother Lies Odenthal.

"Her name was Elisabeth Antoinette Odenthal (Lies to her friends). She was born on 27 April 1902 in Surabaya and died on 16 January 1984 in Roosendaal. My grandma was born and raised in the Dutch East Indies, where her forefathers had lived for many generations. She was a Dutch national and clearly had Indonesian heritage. Encouraged by her parents, she decided to study civil engineering in Bandung. She would rather have studied mathematics, she told me later, but that wasn't possible in the Dutch East Indies and she certainly didn't want to travel to the distant Netherlands.

My grandpa – Adolf Petrus Frederik Kist – also started in the first cohort. As my grandma finished studying a year before my grandpa, she took a job as a science teacher at a convent school in Bandung. They were married in Surakarta on 22 May 1926. My grandpa was already working as an engineer for the Provincial Public Works Department in Bandung and my grandma was a housewife, as was usual back then. The family story goes that if my grandpa had to calculate a new project, he took it home for my grandma to help him.

Right at the start of World War II my grandpa was interned as he was a reserve officer, leaving my grandma to care for three children. She went to live in a house together with a second cousin and all the children. The cousin gave singing lessons, which was not allowed, but according to my grandma, the Japanese were so charmed that they allowed her to continue. As there was already so much coming and going in the house, my grandma decided to give private maths lessons. The schools and university were already closed and what she was doing was forbidden, but her students blended in with all the music students. This enabled her to earn something of a living, even though she did it more on principle than for the money. She also refused to bow to the Japanese she met on the street.

After the war, they tried to pick up the pieces of their lives. Despite the start of the military actions, my grandpa became head of the Java district Public Works Department. In 1948 he was also appointed extraordinary lector in road construction at the ITB. In 1949 he was able to take leave and travel to the Netherlands. On 26 July 1949 they set sail on the Willem Ruys and arrived in Rotterdam on 15 August. My grandparents planned to get my aunts settled and then return to the Dutch East Indies with my mother. Unfortunately, they were forced to change their plans as the transfer of sovereignty took place while they

'During the war, my grandma decided to give private maths lessons'

PHOTO: ANNETTE LIEVAART

Grandma Elisabeth Odenthal is clearly recognisable in the graduation ceremony of the first cohort of students on 1 July 1924. Grandpa Dolf Kist is the second student on the left of the beadle.

were in the Netherlands and a return to Indonesia was no longer an option. Even though my grandpa worked for the Dutch government all those years, he was now unemployed and left to sort things out for himself. One of my aunts said this was partly because my grandparents knew President Sukarno from their student days and Sukarno even fancied my grandma a little. People from my grandpa's circle explicitly asked him to return to his old position, in which case the family would be given Indonesian nationality. My grandpa turned down the offer. He eventually found work in the Water Cycle Laboratory in Delft and taught at the Institute of Technology, specialising in Road Technology. In 1955 he took up a post teaching Civil Engineering at the Royal Military Academy in Breda. Here he trained Military Engineering cadets and founded the Military Engineering Laboratory. He worked in Breda until his retirement. The desire to teach continued, and for the remainder of their lives my grandparents helped the neighbourhood children with their science homework. When I took my pre-university school-leaving exams, my grandma was very interested in the maths and physics assignments, although less impressed by probability theory and statistics. Fortunately she was still around to see me enrolled as an Applied Mathematics student in Delft, and to see I had a boyfriend who also studied in Delft. Now we've been married nearly 30 years and we are both engineers. In November 2019 our eldest child graduated in Aerospace Engineering. For this occasion we instituted a tradition that our children should be given a book from my grandparent's collection of textbooks. But I'm keeping the lecture notes on integral and differential calculus and geometry by Boomstra for myself. By the way, I saw my grandma mentioned in a biography on Sukarno by Lambert Giebels (*Sukarno: a Biography*). My grandma said that Sukarno received equal treatment as a student until he began his propaganda campaign for independence in earnest. That he never forgot my grandma can be seen from when he was introduced to a cousin of my mother who looked a lot like my grandma, and he said: "Lies, is that you?". When my grandma heard this she said: "Did that nutcase think I stayed forever young!" <<

'Sukarno even fancied my grandma a little'

Two mini-exhibitions, on Delft Civil Engineers in the Dutch East Indies and Architecture in Bandung, can be seen in the hall of the TU Delft Library until March. From the start of 2020 they can also be seen online at erfgoed.tudelft.nl.

‘Total online education is difficult to sustain’

After almost nine months of online education, the end is not yet in sight. How can we monitor students’ well-being if we hardly ever meet them in the flesh? Alumnus Dirk van Gameren, Dean of the Faculty of Architecture and the Built Environment, has been focusing on this issue since the start of the corona outbreak.

A recent survey of students showed that they themselves are not so dissatisfied with the teaching. “We see that the transfer of knowledge is no problem”, explains Dirk van Gameren. “Online, it’s also really easy to call on people from within and outside the university to give a presentation or join a discussion.” But studying should be about much more than just transferring knowledge. Building a network, gaining an all-round education and just having the time of your life – there is currently hardly any scope remaining for these aspects. Hardly surprising then that 30% of students admit to being poorly motivated. “Total online education is difficult to sustain. Students miss meeting each other and collaborating. That’s a major issue. Another problem is the lack of a good workspace. No wifi, no space, no peace or quiet”, explains Van Gameren.
He chairs the taskforce established in the spring. It is now part of the Study Climate group, in which the Executive Board, Education & Student Affairs and the Study Climate programme are focusing on student well-being in the time of coronavirus. “Study Climate used to be about study workload. That has a lot to do with student well-being, but there are now new, coronavirus-related issues for the group to deal with. There are also numerous student initiatives focusing on student well-being. We try to keep track of them all, identify any gaps and fill them.”

Initiatives

All this is happening in close collaboration with students. “I think they know best what works for them, so it’s important that they organise it themselves. Our role is to ensure the organisation supports their initiatives.” He sees that they’re doing this in a really responsible way in his own faculty. “They arranged a registration system so that students could go to the Bouwpub, in accordance with the rules. It was a very positive sign that we’re making concerted efforts to enable social activities like that to continue.” Unfortunately, the reality of coronavirus is unpredictable and

PHOTO: TU DELFT

Dirk van Gameren: “We need to ensure that students can continue to share their concerns and problems.”

the Bouwpub had to be closed again at the time of writing, although the pub quiz is continuing online. Since September, students are allowed back on campus in small numbers, partly in response to urgent recommendations from the taskforce, with priority given to first-year students. “It’s important for all students, but first years don’t yet have a network and may be sitting alone in a room at home. They can easily become isolated”, says Van Gameren. The same applies to international students. “They also have additional worries about their health, because the Netherlands often adopts different measures than other countries. Coping financially is another issue.” Dutch students also face financial problems, with the loss of many part-time jobs.

Support

Although the group cannot solve every problem, there is a lot of practical and emotional support. “For students struggling to work at home, there are safe workspaces, such as in the Library. We plan to extend this, enabling students also to come at other times.” In addition to extra space, another key priority is the availability of psychologists and academic counsellors. “We need to ensure that students can continue to share their concerns and problems. That way, they know the right way to find professional help and can also support each other.” All of this starts with effective communication. “The information provided must be clear and comprehensive, otherwise people no longer read it. That’s another priority.” The website now features all relevant student welfare information in a single place.

PHOTO: DALIA MADI.

First-year students can easily become isolated.

First-year students remain a cause for concern. “It is just really difficult for them. How do you create a new life for yourself in this situation? You want to get to know people and there are only limited opportunities for that in classes. As a result, first years are now extra eager to join study and sports associations, which also have limited capacity. Imagine: there’s no place for you and you feel rejected again.” Graduating students are also struggling. “It’s a difficult time to find work and imagine a life after your degree. Alumni could definitely play a useful role in that”, believes Van Gameren. “We also need to arrange more internship positions. I’m a partner at Mecanoo. Even there, a lot of people are working at home, but we offer graduating students and interns a safe place where they can work together and get support.”

Students miss meeting each other and collaborating

A new lockdown is now looming. “What happens if we have to close again? We could possibly organise some workspaces. We may be able to keep the buildings open, but teach online. We no longer need to work out from scratch how to do it. But lecturers just prefer teaching in person.” <<

As an alumnus, you can do something to help students. Students Job Vlak and Thijs de Jongh are calling on people to facilitate study places in the Delft area. You can find more information at **alumni.tudelft.nl/studieplekken**.

TEXT: AGAATH DIEMEL PHOTO: JOSÉ ÁNGEL MOLINA/COMILLAS PONTIFICAL UNIVERSITY

'Don't be afraid to go back to academia'

Timo Gerres: "I also have met a lot of alumni professionally."

Timo Gerres has interspersed his academic career with periods working in industry. Now in the final stages of his PhD, it is time for the next step. Continue his research or return to industry to put his academic insights to practice?

Timo Gerres first came to the Netherlands for an internship with Eurodev, just across the border in the Netherlands. "My job with the industry division was helping US companies to get a foothold in Europe. I enjoyed working with my Dutch colleagues. They are very straightforward, and the atmosphere is less hierarchical than in Germany. That suits my character."
After his first step into the business life, in a pattern that was to repeat itself, he embarked on a Master's degree in SEPAM (System Engineering, Policy Analysis and Management, now known as CoSEM) at TU Delft's TPM Faculty. "In Almelo I had worked with oil refineries, the dirty side of the energy sector so to speak. Now, at TPM we were looking at renewable energy from a systems perspective. How do you integrate fluctuating renewable energy sources to the electricity system? How do you create investor interest in new technologies? And how can government regulation stimulate this? Those kind of questions really sparked my interest."

After working for a few years on offshore wind projects at TenneT in Germany, he is now a PhD researcher at the Institute for Research in Technology (IIT) at the Comillas Pontifical University in Madrid. There, he has turned his attention to the next-level challenge: the decarbonisation of (heavy) industry and its effect on our energy systems, "Many people don't realise that for every tonne of cement produced, you emit roughly one tonne of CO_2, not only because of fossil fuels being burned, but also due to the chemical reaction taking place inside the kiln."

> 'I have been organising these events-in-a-box twice a year since then'

Staying in touch

Throughout the years, Gerres has stayed in touch with TU Delft "On the personal side, I have a circle of friends dating back to my years in Delft. Normally we see each other at least once a year, but corona has temporarily put a stop to that", he says. "I also have met a lot of alumni professionally. As it happens, when I applied for my current position, I got interviewed and hired by an ex-colleague from Delft. One of the reasons I ended up in Spain is that we knew the same people. My current boss is also an alumnus. Our links at academic level remain also quite strong. We collaborate well, and we also recruit from TU Delft." Gerres has also been a loyal visitor of alumni events, both from the Dutch Engineers Alumni Network (DEAN), where he made good friends among alumni from both Eindhoven and Delft. It was at the first DEAN event in Madrid that he met Janneke Hermans of TU Delft Alumni Relations, who was looking for volunteers to organise future events. Timo happily volunteered. "I have been organising these events-in-a-box twice a year since then. You get a box containing traditional Dutch treats like 'pepernoten', but also things like games you can play to break the ice. It creates a nice atmosphere and you always get to meet new people." In the past year, Gerres has also been an occasional coach at the online Career Cafés, set up by Alumni Relations and the Career Centre. Here, alumni share their experiences in the job market and coach students and recent graduates.

Life after PhD

Three and a half years into his PhD, he is thinking about a next step. "I have to decide soon. It is a bit of a dilemma: on the one hand, there are still a lot of loose ends I want to tie up and the IIT is great place to work. We do a lot of technical consulting projects and additional work on academic projects, and that really suits me. On the other hand, maybe I will return to industry, to put in practice what I have been researching", he ponders. "In academia you sometimes live in an ivory tower. That is a nice place to be to understand the greater picture, but if you sit up there too long, you lose touch with the real world. However, you should never be afraid to return to academia if there are open questions in your field of work, because academia is the ideal place to find the answers. I would encourage everybody who has worked in industry for a couple of years to reflect on that from time to time." <<

Read the longer article on the website: alumni.tudelft.nl

Are you inspired by this story? And do you want to explore the possibilities to explore involvement in TU Delft? We would like to get in touch with you. Send an e-mail to alumnirelations@tudelft.nl.

Alumni activities

TU Delft FOR LIFE SINCE 1842

From online events to career coaching, to lectures on campus. If you want to participate in an event, the information offer can be found on the alumni events page: Alumni.tudelft.com/events

11-15 January
Week of Resilience - Celebration 179th Dies Natalis TU Delft

12 January
DEAN-lecture Koen Klompe

19 January
Lecture alumna Nadine Bongaerts

28 January
Alumni event – San Francisco

Get in touch:

Questions, comments or ideas?
Email: alumnirelations@tudelft.nl
Website: alumni.tudelft.nl
Community: tudelftforlife.nl

'TU Delft for Life' is the online community for all TU Delft alumni. Expand your network, meet your old university peers and stay up to date on the latest news and events. Sign up on **tudelftforlife.nl**. You can also change your contact details and communication preferences there.

TEXT: JOS WASSINK PHOTO: PIET VAN NOORT

A mysterious beach-phenomenon

Why do shellfish reefs wash up in wave shapes on the beach, asked a beach photographer. Dr Matthieu de Schipper has an explanation.

Beach walker Piet van Noort regularly Twitters about coastal defence, the beach, sea and dunes. Last spring, he photographed wave shaped beds of shellfish on the beach. He asked on Twitter if anyone could explain the regularity of the shapes along the coast.
Delft Outlook asked coastal engineer Dr Matthieu de Schipper (Faculty of Civil Engineering and Geosciences). De Schipper became well known for his methods to take measurements by jet ski. He pointed us to an article entitled , the popular science website. The article's author Kaushik Patuwary explains that wave shaped shellfish beds – called beach cusps – are a worldwide phenomenon.

The regularity of the cusps illustrates the chaos theory.

Self-organisation

Wave action is the driving force behind the shellfish beds' shapes, that is clear. But how do the waves do it? The start of the process is unclear, but once the shellfish beds start to form, it turns into a self-reinforcing process. A wave rolls over the top of a cusp and breaks to the sides, allowing the large sediment to sink into the bed, which continues to grow. The water flows along the sides of the bed further up the beach, picking up finer sand and meets the water from the adjacent bed in the middle. As the water flows back to sea, it quickly meets the next wave. The shellfish beds then grow while the beach between them are cleared. Most of the shellfish beds are a couple of metres long, but beds of 60 metres have been found.
But how the formation actually starts is still unknown. Why the cusps are so neatly arranged at the same distance? De Schipper explains that researchers originally believed that the distance was determined by the wave patterns at sea. But since the arrival of the chaos theory in the 1970s, experts are tending towards self-organisation as an explanation. "The length between the cusps is determined by the characteristics of the sand and water," says De Schipper. There are always small irregularities that spontaneously grow into clear patterns under the right circumstances. Wave shaped cusps share this phenomenon with regular cloud formations in the sky and the hurricane caused by the butterfly.
Paradoxically, the regularity of the cusps illustrates the chaos theory in practice. At least until the wind and current changes the wave pattern and everything flows into each other again.
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DELFT RESEARCHERS AND STUDENTS HELP TO COMBAT THE CORONAVIRUS

In March 2020, Delft University Fund established the TU Delft COVID-19 Response Fund. And with success. Thanks to the support of more than 1.600 TU Delft alumni, the fund has now been able to allocate €375.000 to 27 Delft research projects. These projects make an important contribution in combatting the virus and improving health care for patients. Below some projects highlighted. For a complete overview of the funded projects, please visit **www.universiteitsfondsdelft.nl/supportedprojects**

EXTEND LIFETIME FACE MASKS
€ 3.300

THE EFFECT OF UV-C LIGHT ON THE VIRUS
€ 25.000

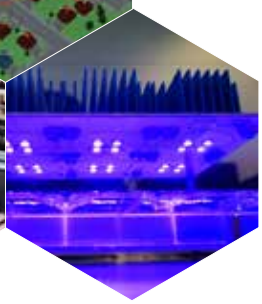
REDUCE RISKS ABDOMINAL SURGERY CORONAPATIENTS
€ 10.000

INSIGHTS ON HOW CULTURE INFLUENCES PANDEMIA
€ 7.200

BREATHING DEVICE THAT EVERYONE CAN COPY
€ 20.000

FORECAST EVOLUTION OF THE CORONAVIRUS
€ 10.023

TECHNICAL ADVICE HEALTHCARE INSTITUTIONS FOR CARE AND SCREENING PATIENTS
€ 23.976



1600 alumni

13 Projects completed

14 Projects ongoing

€ 375.000 granted

Workshops
Materials
Websites
Test setups
Machines
Prototypes
Toolkits
Additional researchers

27 Delft projects

THANK YOU

On behalf of all researchers and students: thank you! Thanks to your financial contribution, our researchers and students could execute their research immediately and no valuable time was lost. You support is still very welcome for several corona-related projects. Check: **www.universiteitsfondsdelft.nl/coronavirus**

TU Delft | Universiteitsfonds

TEAM UP WITH **EXCELLENCE**

ALL IN THE FAMILY

The Le Mahieu family

Some families have several generations who all study at TU Delft. In this series, parents and grandparents discuss their student days with their children and grandchildren. Read the full version at:

After completing his studies Mechanical Engineering, Grandpa Rinus le Mahieu has seen plenty of his descendants at TU Delft. First his daughter Marie (Architecture) and now grandchildren Maurice (Industrial Design) and Lauranne (Clinical Technology). Grandpa Rinus found a room through his sister who was already living in Delft. He later moved to Duivelsgat, barracks along the Schie close to Paardenmarkt. Marie lived in an attic room close to the church while she was studying. She answered an ad in the Delftse Courant. The landlord had drawn her name out of over 500 applications. When she thinks back to her room, she shivers. Literally, as it could be very cold. "That cold that my duvet froze in winter. When the snow started blowing in, I fixed insulation to the roof." Maurice and Lauranne remark that even in their aunt's time at TU Delft, there was a shortage of accommodation. "Maybe it wasn't as bad as now as it took me six months to find a room," says Lauranne. Maurice was luckier. He found a great house through his cousin and could even choose his housemates. He moved to the Koornmarkt this year. "It's exactly across the road where Grandpa used to live. The circle is closed." MvdV

PHOTO: SAM REINTMEESTER