

# REPORT

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## PROFILE 2018

### DEPARTMENT OF ENGINEERING

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RESEARCH  
TECHNOLOGY  
IMPACT



AARHUS  
UNIVERSITY



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## DAILY MANAGEMENT AND ADMINISTRATION 2018

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# Traits of an engineer



The future is technology.

The world is facing a huge number of colossal challenges, and addressing global problems requires a solid foundation in engineering science. No other discipline has such a strong link between a deep research-based understanding and an innovative and creative DNA. We build and invent technology to push problems aside: technology that not only benefits the individual or society, but the entire world.

Throughout its relatively short existence at Aarhus University, the Department of Engineering has focussed on three core areas: research, education and deep tech. We have aspired to a standard of excellence with a multidisciplinary focus anchored in deep engineering disciplines. This has enabled a rapidly increasing number of new research and innovation activities at both national and international levels.

In the past year, we have been involved in a record-breaking 16 new national Innovation Fund Denmark projects and 5 new EU-funded projects. Moreover, we have produced 401 peer-reviewed publications. This is a massive improvement on previous years, but growth doesn't stop here.

In 2018, we'll be starting a new series of exciting projects that could have an enormous impact on the grand challenges the world is facing today. Special focus is on digitalization that contributes to the fourth industrial revolution. These technologies

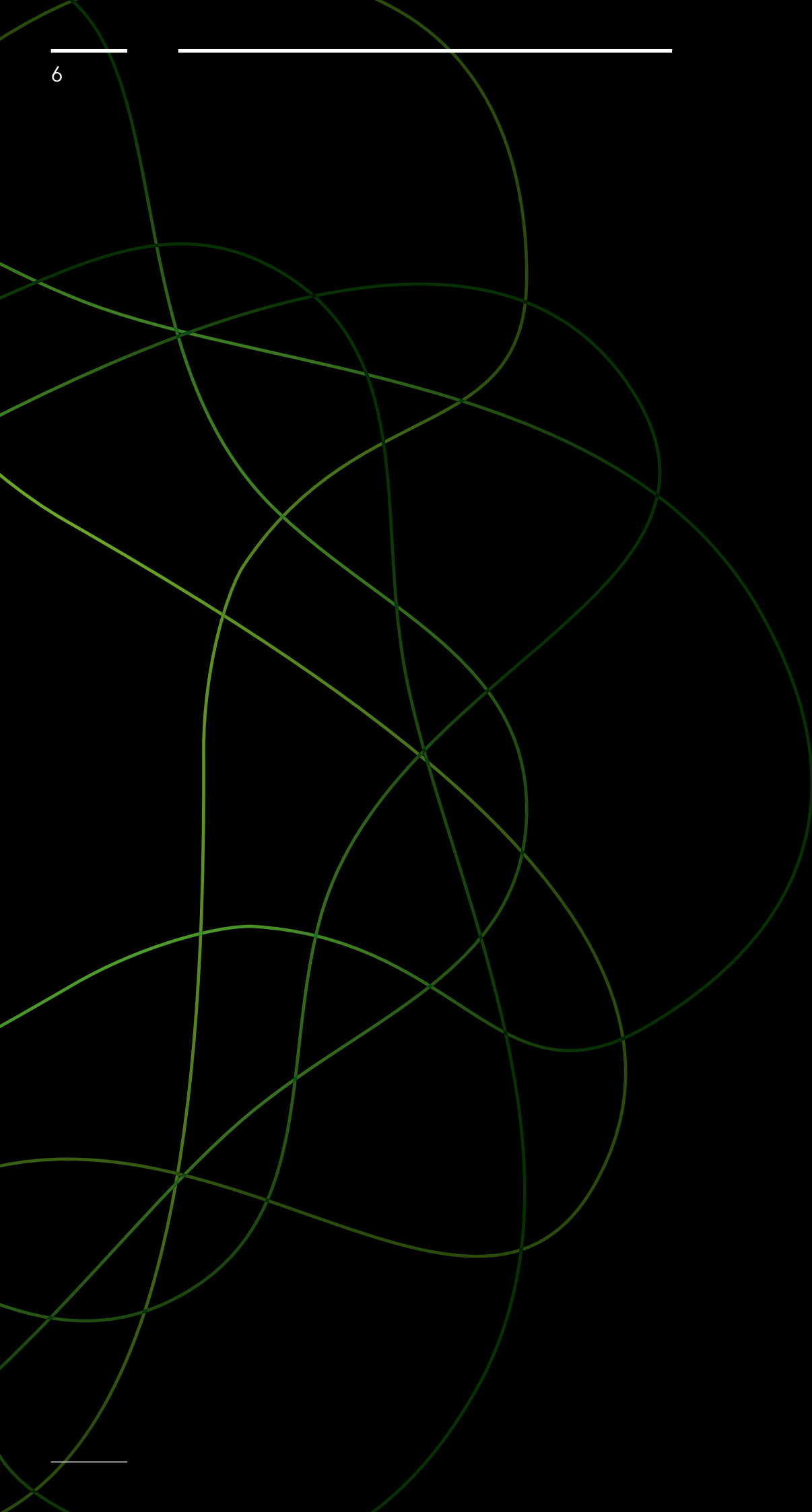
range from machine intelligence to the Internet of Things, cloud computing, Big Data analysis, cyber-physical systems, robots and nano-materials, and they will have untold implications for societies and a huge impact on business sectors like manufacturing, energy, healthcare and agriculture.

The future is disruptive, and change is placing unprecedented demands on engineering universities. Therefore, we're investing aggressively in new research facilities, more researchers and new educational programmes in engineering.

We invent. We innovate. We're dreamers, researchers and creators. These are the trademarks of engineers. And although we constantly strive for more commercial impact from our research, and for financially viable knowledge transfer to industry, most of all, we dream about creating the foundations for a better world.

I am proud to highlight some of our latest engineering projects and new research areas. All of these are examples of innovation that is at the heart of the global megatrends driving the transformation of society.

**Thomas S. Toftegaard,**  
Head of Department of Engineering  
Aarhus University



# ENGINEERING DISCIPLINES

- **Biological** Engineering
- **Chemical** Engineering
- **Civil** Engineering
- **Architectural** Engineering
- **Electrical** Engineering
- **Computer** Engineering
- **Mechanical** Engineering



AU Engineering, Campus Navitas, Aarhus





Photo: Lars Kruse

# NEW RESEARCH CENTRES

Interdisciplinarity is the native tongue of any engineer. Last year, many new strategic interdisciplinary centres emerged from Aarhus University. Each one combining the knowledge of researchers from a wide variety of fields. And each one with a heavy anchor point in engineering.

#### FACTS

The Aarhus University Centre for Innovative Food, iFOOD, is led by Professor Lotte Bach Larsen, Department of Food Science. The multidisciplinary work at the centre involves the participation of the following departments and centres at Aarhus University:

- Department of Engineering
- Department of Molecular Biology and Genetics
- Department of Chemistry
- Department of Agroecology
- Department of Animal Science
- Department of Clinical Medicine
- Department of Public Health
- Interdisciplinary Nanoscience Centre (iNANO)
- MAPP Centre – Research on Value Creation in the Food Sector for Consumers, Industry and Society

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**iFOOD**  
AARHUS UNIVERSITY CENTRE FOR  
INNOVATIVE FOOD

ENGINEERING  
THE FOOD  
OF THE FUTURE

The world is running out of land to produce enough food for its future double-digit billions of human inhabitants. New technology is needed and engineers at Aarhus University are already developing innovative solutions at the new strategic centre for food research.

Since the year 1800 the number of humans inhabiting the Earth has grown from 1 to 7.6 billion. And every single year, 83 million new faces are added to the pool. Though the population growth has stagnated, 11.2 billion people are still expected to inhabit Earth in the year 2100.

11.2 billion people living off the same resources as we are today. And while the demand for food products is rising even now, consumer confidence is on the decline. Clearly humanity faces an overwhelming challenge if we are to survive and thrive as a species on this planet, and engineers are going to play a vital part in securing sustainable solutions that will ensure food for everyone in the future.

On 25 September 2017 Aarhus University opened its doors to the strategic centre for innovative food research called iFOOD – a research initiative focused on solving important societal challenges and becoming a catalyst for growth and development in the food industry while encompassing the entire production chain from field to table.

#### **No fishy smell**

“We are fostering many new different technologies that could have a major impact on the food industry. For instance, we are trying to reduce waste by advanced integrated processing technology for agro-wastestreams. We are also working on increasing food shelf-life by developing new packaging solutions that could prevent the growth of bacteria, and

we are trying to enrich food products to maximize nutritional potential and make food healthier,” says Associate Professor Zheng Guo.



## **We are fostering many new different technologies that could have a major impact on the food industry**

Associate Professor Zheng Guo

He continues: “Take Omega 3 oil for instance, which is especially important for the elderly and new-born. Instead of extracting the oil from fish, we can get it directly from microalgae, where it actually originates from. By engineering the microalgae we are able to produce Omega 3 in a better quality and in greater quantities and even without the smell of fish.”

The Department of Engineering will contribute to the iFOOD centre throughout the entire food value chain, from cultivation of raw materials, identification of new

food ingredients and allergy assessment, sensor technology and production monitoring, to customer solution and packaging of end foods.

#### **From lab to pilot**

With the new centre, the engineers are – in close cooperation with other researchers and specialists – able to develop, implement and test new technologies from laboratory level to pilot scale and under upscaling conditions for both plant and animal-based foods, new packaging solutions and new production systems of raw materials. Furthermore, the centre will explore and validate the impact of new food technologies at consumer level.

Research and innovation in food products are key areas here, where unique expertise, excellent facilities, and good collaboration relations form a strong basis for highlighting Denmark even more clearly on the world map in an area with enormous commercial potential.

The centre is an interdisciplinary hub, where Aarhus University is bringing a number of skills and disciplines from several faculties together. Several departments at Science and Technology, the Faculty of Health and the MAPP Centre at the School of Business and Social Sciences will work together to address the complex issues of global food demand, creating a holistic picture of a situation with diverse challenges.

The Aarhus University Centre for Digitalisation, Big Data and Data Analytics is led by Professor Peter Gorm Larsen, Department of Engineering. The center is based on interdisciplinary collaboration between three departments:

- Department of Mathematics
- Department of Computer Science
- Department of Engineering.

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**DIGIT**

AARHUS UNIVERSITY CENTRE FOR  
DIGITALISATION BIG DATA AND DATA ANALYTICS

MORE  
MUSCLE FOR  
DIGITALISATION  
RESEARCH

Most disruption happening to societies throughout the world is driven by radical innovations suitable for novel IT-based solutions. The new DIGIT Centre is significantly strengthening Aarhus University in its research abilities in the area of digitalisation.

Aarhus University is in the process of setting up DIGIT – a new research centre for digitalisation, big data and data analytics. DIGIT is a collaboration between the Departments of Engineering, Mathematics and Computer Science. The centre targets carrying out excellent and interdisciplinary research in a number of fields of crucial importance for the worldwide digital transformation of society.

DIGIT is built up around a strong collaboration with industrial partners, and it will enable researchers to apply new digitalisation technologies in very different contexts.

“Our collaboration with companies will give us opportunities to implement new knowledge in a commercial context at a very early stage. This will make the path from basic research to applied research and further into the real market much shorter. And speed is a decisive factor, if you’re aiming to set the agenda within digitalisation,” says Professor Peter Gorm Larsen.

Professor Larsen is the overall lead for the DIGIT centre. Among other things, this involves research into smart systems and cyber-physical systems.

#### **New collaboration with the European Space Agency**

For several years, software specialists from the Department of Engineering have researched in producing accurate models of software and its interaction with the physical world. The technologies are now so mature that it limits the needs for prototypes in the early design stages, paving the way for comprehensive digitalisation, for example in the manufacturing industry.

“We can build models of a relevant context and test software systems in a virtual context before they ever become reality. It’s clear that this kind of technology is extremely relevant, especially for companies that today spend huge amounts of money on developing prototypes. In the years to come, we’ll primarily be focussing on making it faster and more cost-effective to produce competent models,” says Peter Gorm Larsen.

He has previously used this technology in different industries (automotive, agriculture, railways and buildings), and now he is commencing on a new collaboration with the European Space Agency (ESA), and research applications for other application domains are also in progress.

“The intension is to use our modelling and simulation technology and combine it with the existing technologies used at ESA for the development of highly specialised equipment for space missions. Our great advantage is that we can simulate the dynamics of physical devices in space and test new equipment before investment is made on the actual physical development in the form of prototypes,” says Peter Gorm Larsen.

#### **A safeguard against digital terrorism**

Another important focus area for the research within the DIGIT centre is security. How can we protect data and algorithms that are crucial for society’s functions? For example, in the healthcare sector or in the transport sector, where data must be kept confidential and secure against hacker attacks.

“The more we digitalise, the more vulnerable we become to attacks including terrorism. We wish to have systems that

are sufficiently open to update remotely. However, we also need to minimise the risk of unauthorised access to both functionality and data. This is a great engineering challenge,” says Peter Gorm Larsen.

#### **Intelligent baggage handling at airports**

At DIGIT, researchers and companies will challenge the limits for what it is possible to teach a computer. Among other things, this will be exercised in a project to optimise baggage handling systems at international airports through machine learning.

The researchers’ goal is to increase the throughput of suitcases travelling from baggage check-in and out to airliners per unit of time. Therefore, they are training a computer to analyse the transport in airports’ baggage network, so that it can ultimately be able to predict bottlenecks and prevent breakdowns.

In principle, all data from the baggage is logged in all airports and this data is used to determine the optimum route for each individual suitcase. This is just an example of how research within digitalisation can very quickly move from the university and out to the real world.

“It’s extremely valuable for us to apply our research in real-life problems. We have a clear expectation that the knowledge we produce will be able to help solve problems in society and give the companies we work with a clear competitive advantage,” says Peter Gorm Larsen.

Researchers are developing the technology for baggage handling in close collaboration with Beumer Group A/S.

The Aarhus University Interdisciplinary Centre for Climate Change, iClimate, is led by Professor Jørgen Brandt from the Department of Environmental Science. The multi-disciplinary work at the centre involves the participation of the following departments and centres at Aarhus University:

- Department of Bioscience
- Department of Geoscience
- Department of Agroecology
- Department of Chemistry
- Department of Engineering
- Department of Animal Science
- Department of Food Science.
- DCE – the Danish Centre for Environment and Energy
- DCA – the Danish Centre for Food and Agriculture.

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**iCLIMATE**

AARHUS UNIVERSITY INTERDISCIPLINARY CENTRE  
FOR CLIMATE CHANGE

# CLIMATE CHANGE COMES INTO THE ENGINEER'S SPOTLIGHT



Denmark needs a solid knowledge base if it is to maintain its leading position within climate research and adaptation. Aarhus University's new strategic research centre, iClimate, will be making sure that this knowledge is in place; and there are more than enough engineering challenges to tackle.

The UN has pointed to climate change as probably one of the most important global challenges. Climate change affects everything from food and energy production, to public health, security policy, and how we organise our towns and cities, because everything depends on how people adapt to the new climate reality in the future.

In December 2017, Aarhus University inaugurated a new strategic research centre: the Aarhus University Interdisciplinary Centre for Climate Change, iClimate. The centre's ambition is to provide a solution-oriented approach to this highly complex area. Part of the centre is anchored at the Department of Engineering, where Associate Professor Rune Hylsberg Jacobsen is heading the engineering work:

"There's a huge number of engineering challenges in climate change, but some of the things we will be focusing on especially are managing and analysing data, developing mathematical models, making forecasts and determining consequences of possible scenarios. We hope that all of these can be used as a decision-making basis for governments in different parts of the world, for example," he says.

#### **Adaptation and mitigation**

In recent years, the Danish research community has had increasing focus on the climate issue. So far, much of the work has aimed at understanding and describing the changed climatic conditions and the related challenges, as well as the possibilities of limiting the effects of the anthropogenic changes. iClimate will have

greater focus on a more solution-oriented approach to the challenges, with a solid foothold in the knowledge accumulated.



**We can calculate the properties of new materials very accurately. We look at the geometry of the material structure and identify how it should look to perform a specific task**

Professor Henrik Myhre Jensen

Therefore, the engineering challenges at the centre of the issue are also about coming up with specific solutions for climate-adaptation and mitigation projects in connection with different climate scenarios - for example solutions to integrate renewable energy into the electricity grid. "In many places, including in Denmark, we're already well on the way to protecting cities from increasing water levels. But the climate knows no national borders, and we're working with global models. We want to zoom in on some areas that make sense for us - for example, the ag-

ricultural sector and the Arctic - and we want to develop our expertise within these areas in cooperation with industrial partners," explains Rune Hylsberg Jacobsen and mentions Greenland as an example:

"Climate change is often about adaptation and mitigation of future problems, but we must also remember to look at new opportunities. Here, Greenland is an obvious topic; for instance, should we develop agriculture in Greenland in the future? These are some of the opportunities that arise as a result of climate change, and they will be included in the analytical scenarios in our climate services," he says.

#### **A broad focus**

In addition to climate services, iClimate will be focusing on a number of points in relation to climate change. One of them is the 'climate-drivers' which, as the name indicates, spur climate change. There are as yet unknown factors here, for example the significance of the oceans, the importance of what is happening in the Arctic and the impact of the short-lived greenhouse components such as atmospheric particles, methane and ozone.

Agriculture and food production are also a focal point for the centre. The sectors will undergo fundamental changes in a changing climate, for example crop yields will change. Energy production and consumption, industrial production and the importance of cities will be included in the work at the new centre. Furthermore, research into atmospheric processes and modelling and other disciplines within air pollution will be included in the research portfolio.

# MATERIAL MATTERS

The Aarhus University Centre for Integrated Materials Research, iMAT, is led by Professor Bo Brummerstedt Iversen, Department of Chemistry. The multidisciplinary work at the centre involves the participation of the following departments and centres at Aarhus University:

- Department of Engineering
- Department of Chemistry
- Department of Geoscience
- Department of Physics and Astronomy
- Interdisciplinary Nanoscience Centre (iNANO)

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**iMAT**  
AARHUS UNIVERSITY CENTRE FOR  
INTEGRATED MATERIALS RESEARCH

Aarhus University has opened an interdisciplinary centre for materials research, iMAT. At the new centre, in close collaboration with industry, researchers will develop new materials within energy, construction, environmental technology and much more.

Humanity is facing huge challenges such as sustainable energy, climate change, water quality and food supply. The solutions to these challenges rely heavily on breakthroughs within materials research. The new Aarhus University Centre for Integrated Materials Research will integrate and bolster activities within materials science across the fields of chemistry, engineering, physics, nanoscience and geology.

"The cross-disciplinary approach to materials research offers completely new experimental opportunities for us, and this may pave the way to realising more theoretical modelling in practical manufacture," says Professor Henrik Myhre Jensen.

#### **A culture of interdisciplinarity**

Professor Myhre Jensen is responsible for the centre's engineering science activities and is highly specialised in theoretical and numerical modelling of the mechanical and functional properties of materials.

"We can calculate the properties of new materials very accurately. We look at the geometry of the material structure and identify how it should look to perform a specific task," says Henrik Myhre Jensen.

In this way, researchers can model the strength of materials, their deformation under load, and their response to fracture. This could be vital for the development of new composite materials and the practi-

cal application of knowledge in an industrial context.

"If we want to develop new materials, for example for the aerospace industry, it goes without saying that we need to be able to identify very precisely what happens if a wing breaks, and how long it takes from the first crack to final fracture," he continues.

Engineering-science materials research covers geomaterials, biomaterials, metals, polymers, composites and ceramics.

The Aarhus University Centre for Circular Bioeconomy, CBIO, is led by Senior Researcher Uffe Jørgensen, Department of Agroecology. The multidisciplinary work at the centre involves the participation of the following departments and centres at Aarhus University:

- Department of Agroecology
- Department of Bioscience
- Department of Food Science
- Department of Animal Science
- Department of Engineering
- Department of Chemistry
- Department of Molecular Biology and Genetics
- Department of Environmental Science
- Danish Centre for Food and Agriculture
- Danish Centre for Environment and Energy

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**CBIO**  
AARHUS UNIVERSITY CENTRE FOR  
CIRCULAR BIOECONOMY

DREAMING OF  
A BIO-BASED  
SOCIETY

There is an urgent need to find solutions that can enable the world's population to ensure sustainable management of biological and organic resources. The goal of a new interdisciplinary centre is to generate a knowledge base for a new bioeconomy and to demonstrate the commercial perspectives in using biomass to produce energy, food, animal feed and expensive chemicals.

In 2017, The Aarhus University Centre for Circular Bioeconomy opened at Aarhus University with some of the world's leading researchers within biology, agricultural sciences, food science and engineering.

Together, they will now be realising the dream of a bio-based society in which all of nature's resources are reused - carbon, nitrogen and phosphorus.

#### Value back to the ecosystem

It all starts in the field, where the challenge is to produce as much biomass as possible in a sustainable manner. Apart from this, the researchers' main challenges are primarily within engineering science. How do you convert biomass into high-value products? How can you transform a worthless residue into something that returns value to the ecosystem?

"We've been working for several years on a number of very promising refining technologies, and we're now in the process of their further development, with focus on full recycling. We want to convert biomass into completely new molecules that can

be combined in different ways: for example to become plastic polymers," says Associate Professor Lars Ditlev Mørck Ottosen.

#### Science at full scale

Together with his research team, Associate Professor Ottosen will generate knowledge to make it possible to transform agricultural waste into everything from clothes to proteins. And this won't just be petty projects in laboratories. The researchers want to build technology on a scale that can demonstrate its commercial potential in the real world.

"We're one of the few universities in the world that can create new knowledge at the same time as we're testing technology at full scale. This gives us a huge advantage in terms of innovation, and it'll benefit Danish businesses and the international community. Just think of the perspectives in making milk production sustainable throughout the entire cycle, or in using parts of fresh grass as nutritious protein feed for livestock to replace tropical soya," says Lars Ditlev Mørck Ottosen.



**We're one of the few universities in the world that can create new knowledge at the same time as we're testing technology at full scale**

Associate Professor  
Lars Ditlev Mørck Ottosen

The centre is working closely with major Danish and international companies such as DLG, Arla Foods and The Boeing Company.

The Aarhus University Centre for Water Technology, WATEC, is led by Professor Niels Peter Revsbech, Department of Bioscience. The multidisciplinary work at the centre involves the participation of the following departments and centres at Aarhus University:

- Department of Agroecology
- Department of Bioscience
- Department of Geoscience
- Department of Engineering
- Department of Environmental Science
- Interdisciplinary Nanoscience Centre (iNANO)

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**WATEC**  
AARHUS UNIVERSITY CENTRE FOR  
WATER TECHNOLOGY

# FLYING START FOR NEW CENTRE FOR WATER TECHNOLOGY

Clean water is one of the earth's most valuable resources, and Danish research will pave the way for new technology for cheaper and better water treatment. This is directly in line with UN Sustainable Development Goal number 6 on clean water for everyone around the globe by 2030, and the new centre has received an unprecedented donation from a private foundation to boost activities.

The new Aarhus University Centre for Water Technology, WATEC, opened in October 2017 with great ambitions to gather the university's scientific activities within water across departments and create an interdisciplinary research initiative with clear focus on application: How do we make the water cycles of the future sustainable? How do we secure high-quality drinking water for the burgeoning global population?

A few months after the centre opened, it received a DKK 40 million donation from the Poul Due Jensen Foundation, which has a strong philanthropic and commercial interest in making Denmark a leading nation in water technology.

"The university has a marvellous starting point for water research. Now we're joining forces to research into new technology that can generate value for the international community and create a basis for a considerable export potential for Danish companies," says Associate Professor Lars Ditlev Mørck Ottosen.

Together with the university's strategic funds, some of the money will be used to establish an advanced sensor laboratory, so that the researchers can monitor the chemical and biological processes in water during treatment at an unprecedented level of detail.

The researchers want to be able to control the micro-organisms in water treatment much better. This is crucial for achieving intelligent and automated monitoring and for controlling their growth conditions.

#### **Wastewater without waste**

The centre's engineering activities will focus in particular on technologies that make it possible to have cleaner and less expensive drinking water and, at the

same time, exploit optimally the residual products from wastewater treatment.

"We have to think big and innovatively about treatment. Historically, our focus has been almost exclusively on water quality. But now we'll start to look at how we can recycle the organic material in our wastewater efficiently enough to make it worthwhile. Cheap treatment and recycling technologies are the key to securing clean water for more people in the world," says Lars Ditlev Mørck Ottosen.

Today, we manage sludge residues from the water treatment process by burning off carbon and nitrogen. But this is an untenable strategy if we are to realise the sustainable development goal on clean drinking water and sustainable exploitation of resources, according to Mr Ottosen:

"We want to turn wastewater treatment into a profitable business in terms of energy accounts. And we've already developed promising technologies that make it possible to exploit waste from wastewater treatment plants."

#### **Sludge becomes aviation fuel**

Researchers are currently experimenting with various filtering technologies to collect and treat the valuable carbon in wastewater and subsequently convert it into high-value products such as chemicals, plastics and fuel.

All this is taking place at the world's most advanced pilot plant, which is based on a technology called hydrothermal liquefaction (HTL). By precisely controlling pressure and temperature, the plant converts the biomass into a thick oil similar to fossil crude oil. Researchers can then process the thick oil at a refinery and transform it into highly refined aviation fuel.

"In principle, we've already developed

the technology to produce sludge-based fuel for jet engines. This can replace fossil fuels and make long-distance travel by air as we know it today a climate-neutral and sustainable method of travel. The problem is that we're just working at experimental scale, and it's very expensive, even at this level. But we want to make the processes more efficient - and therefore more profitable," says Lars Ditlev Mørck Ottosen.

#### **Bacteria to eliminate environmentally hazardous substances**

Another major issue within water treatment is environmentally hazardous substances. These substances can be drug residues, endocrine disruptors, microplastics or heavy metals - all things we want to get out of our wastewater.

Wastewater is considerably contaminated today, but we have no effective method of removing these environmentally hazardous substances from the water. However, the researchers think that biological treatment could be the key to cleaner drinking water.

"Biological treatment requires detailed insight into the microbial conditions in the treatment process, and in this context sensor-based monitoring could give us a big advantage. Once we know how the micro-organisms behave, we can build the biotechnology that can help the right bacteria grow and attach themselves so that they aren't flushed out of the treatment plant," says Lars Ditlev Mørck Ottosen.

The researchers are also working on developing new biotechnologies to extract phosphorus from wastewater. Phosphorus is today a limited natural resource, and we will have exhausted our mines in the next 50-100 years.



AU Engineering, Katrinebjerg, Aarhus





Photo: Jesper Raas

# MACHINE INTELLIGENCE



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## Machine learning: solving a specific problem extremely well

Artificial intelligence is applied almost everywhere, and is already changing the way we live our lives. Not as the robots of science fiction movies though, but as computer technology that simply helps us solve problems.

In October 2017, Saudi Arabia became the first country ever to give citizenship to a robot. The robot, named Sophia, was built by the Hong Kong-based engineering and robotics company Hanson Robotics Limited. A month later, a Japanese artificial intelligence was the first ever virtual to be granted residency in a country.

It would seem the future of the various science fiction movies of the past has come to be. However, that is not the case. Both moves were attempts to promote the countries as places to develop artificial intelligence. And even though the visual impact of a robot giving a self-thought-out thank-you-speech at a grand event lingers, the actual level of artificial intelligence is nowhere near where you might fear.

“The public announcements and demonstrations work, but the idea of a “living” robotic citizen does not correspond to the reality of machine learning. We don’t have generic artificial intelligence that can combine multiple tasks and have superhuman power, and the abilities to destroy our world. That discussion – whether artificial intelligence will be good or bad for humanity – is due to a misconception of what the abilities of artificial intelligence is. Because artificial intelligence is not about building a new race. It’s about solving a specific problem extremely well,” says Assistant Professor Alexandros Iosifidis.

### Machine learning is everywhere

Alexandros Iosifidis, who has a PhD in computer science, is doing research in machine learning, computational intelligence, computer vision and pattern recognition – all related to the topic of artificial intelligence and all in an effort to better the standards of today. Because actually – although we now have robotic citizens – artificial intelligence is still in its infancy, he says:

“We need to solve machine learning problems in a better, more efficient and more reliable way than now, and we need computers to be able to do so with very limited computational power.”

The thing is, that although we’re constantly being presented to artificial intelligence as the futuristic idea of a superhuman robotic a ‘la iRobot or Robocop, machine learning is actually going on virtually everywhere. In reality, you have your own artificial intelligence solutions in your pocket. At your desk. In your refrigerator.

### Restructuring our lives

Machine learning is spreading to encompass virtually every gadget from household sensors to monitor temperature and humidity to kitchenware. That requires applications that do not need the latest and most expensive CPU on the market to be able to run.

“There are specific areas nowadays, where machine learning can outperform humans. Image processing for instance. What we try to do now is make the systems more reliable in their output, so we try to make better methodologies for training better models, such as powerful neural networks,” says Alexandros Iosifidis.

He continues:

“Today it is possible to have a genuine discussion with a machine, and you will not be able to discern whether you are actually talking to a human. Machine learning solutions are everywhere, and they are so well integrated in our lives that we might not understand what actually constitutes as machine learning. Take spam filters for instance. Those are actually machine learning solutions that work to make our day easier. In 5-10-15 years I think machine learning will have totally restructured the way humans think. The technology will be able to provide us with assistance in virtually every aspect of our lives, and even though we, as humans, are usually afraid of the future, and try to imagine the worst-case scenario to protect ourselves from what might happen, we already live side-by-side with machine learning, reaping its benefits every day.”



*Artificial intelligence is not about building a new race. Hollywood robotics are a misconception of what the abilities of artificial intelligence is. Because in reality it's all about solving problems in the best way possible, says Assistant Professor Alexandros Iosifidis.*

# Artificial intelligence provides new opportunities for architecture and design

Computer technology can help architects find precise answers to what good architecture and good spatial design is. This makes it easier to design buildings and rooms based on people's needs.

Architects design buildings that shape the human experience. They know how to make buildings feel cosy or spacious, inviting or confronting, stimulating or relaxing. And nowadays architects use computers during design. But there's a problem. Computers "see" building designs as only numbers – distances, coordinates, widths – and this poses a risk that the architect's vision can be completely lost.

"The question is – how can we translate human experiences into precise numerical measurements? The computer's inability to see anything other than numbers can be very expensive and dangerous and lead to total failures in building safety and function," says Assistant Professor Carl Peter Leslie Schultz.

Together with his research group, he is now developing artificial intelligence theories and software tools that break through the language barrier between

architects and computers.

"We are able to rapidly check a design at each step of the way, to make sure that the architect's vision is not lost as the design changes and evolves", he says.

The researchers have even developed systems that make it possible to create an exact numerical description of the geometry of a building while it is still on the drawing board. This provides architects with detailed insights in the early design phase, leading to healthier, safer and more exciting buildings.

## Architectural quality in a formula

A key breakthrough for the researchers is that computers should not only consider walls, doors, windows, furniture – but instead should think of buildings as the "shapes of empty space" between the walls.

This is where people live and work, and

this is a way of giving computers an understanding of human experience.

Using these new methods, it is now possible for architects to teach computers what human concepts mean such as near, far, bright, dim, all the way up to complex and rich concepts like spacious or cosy.

"When undertaking the task of design, architects imagine and anticipate the visuo-spatial and navigational experience of building users during the initial design conception phase. The ultimate goal is to ensure that the final physical built-up structure inherently performs with respect to function, preferences, behaviour and affordance," says Assistant Professor Carl Peter Leslie Schultz.

Assistant Professor Schultz has been working with artificial intelligence in architecture and design for many years, and he has implemented the technology in widely different contexts.



Photo: Melissa B. Kikeby Yildirim

Carl Peter Leslie Schultz is working on utilising the potential in artificial intelligence for modern architecture and he is aiming to create an entirely new understanding of the concept of empty space in buildings.

## project facts

### PROJECT 1:

#### TITLE

DesignSpace Group (research and consultation group)

#### SCHEDULE

2015-2018

#### PARTNERS

University of Bremen, Örebro University, M9 Management & Investmenti

### PROJECT 2:

#### TITLE

Project DesignSpace

#### SCHEDULE

2010-2014

#### FINANCIAL FRAMEWORK

Strategic Project in SFB/TR-8

#### PARTNERS

University of Bremen, Örebro University

### PROJECT 3:

#### TITLE

WP3 in its4land – Geospatial Technology Innovations for Land Tenure Security in East Africa

#### SCHEDULE

2016-2020

#### FINANCIAL FRAMEWORK

EU H2020 – Research and innovation actions

#### PARTNERS

University of Muenster

## Wayfinding at large hospitals

In a research project in collaboration with New Parkland Hospital in Dallas, Assistant Professor Schultz has completed wayfinding experiments in one of the largest hospital construction projects in the US.

He equipped 30 test subjects with eye tracking glasses and asked them to find their way to specific points on a map of the hospital. From his computer, he could monitor the subjects' eye movements and behaviour as they moved through the corridors and across the area.

"We obtained vast amounts of data based on video and eye movements. What were people looking at? What signs did they notice? What signs did they miss? When did they get lost? Was there a difference between the behaviour of young and older people? Women and men? The large

amounts of data enabled us to arrive at a basic definition of the idea of getting lost," he said.

The experiment at the hospital in Dallas was one of the first of its kind to use these artificial intelligence methods for wayfinding analysis.

"We've developed an intelligent system that makes it possible to identify patterns in the eye movements of test subjects in connection with the environment. A few years ago, scientists would have to watch hours of experiment video and manually identify when interesting things happened. Now, computers have the right language of human experience to automatically identify meaningful causalities that affect people's navigation abilities," he says.

## New ways of mapping the Maasai's use of land

Assistant Professor Schultz also uses artificial intelligence within the land administration domain in order to bridge the information gap between official land registration systems and local, cultural ways in which relationships on land are conceptualized.

Most of his current work in this topic has focused on the southern part of Kenya, where the Maasai live. The problem here is that the government lacks an overview of how the land is used, and this often leads to significant problems and disputes.

"Some Maasai are nomadic. These communities live on and use the land on the basis of a system that is deeply cemented in their culture. It cannot be recorded in current land administration systems, and therefore the authorities in Kenya are unable to see how governmental decisions on land administration impact the Maasai's use of land and way of life," he says.

In the approach used by Assistant Professor Schultz and his colleagues, researchers ask the Maasai to sketch hand-drawn maps of their movements, and these

sketched maps are used as sources of data for advanced computer analysis.

"The computer can recognise objects from the sketches - for example, the shape of a village, a water source, a particular tree or certain mountains. The computer then interprets how these hand-drawn objects are spatially related to decode distances, positions and orientations," he says.

The researchers' goal is to train the computer to find connections between the Maasai's sketches and satellite pictures to obtain a complete overview of how the indigenous people use the land, in a way that can be accurately registered in the government's land administration systems.

# Next generation social robots

Social robots are designed to engage humans in social interactions by presenting themselves—in appearance or behaviour—as intelligent social agents. However, the goal of building robots to participate in the space of human interaction raises new technological, empirical and normative questions.

In the intersection between technology, psychology, anthropology and philosophy, researchers across faculties and academic disciplines are working on an immensely ambitious project. They are creating a new methodology to develop artificial intelligence that will provide robots with situational awareness and make it possible for them to adapt to different contexts and users.

“Social robotics marks a new and very important relationship between engineering and the humanities. If we’re to succeed in creating robotic technology that can contribute positively to our future, it’s vital that we take our outset in what technology needs, but more importantly in the needs and values of people,” says Associate Professor Nicolas Navarro Guerrero.

He is coordinating activities in the university’s AU Social Robotics Lab, and he is also responsible for developing robots for several different social purposes.

## **New robots with situational awareness**

Assistant Professor Navarro Guerrero has been working with robots and machine learning for most of his academic career, and his goal now is to design new algorithms that can add a degree of artificial intelligence to robots so that they can understand and respond to the dynamics between the environment, people and other robots.

“The problem with the robots we know today is basically that they behave very clumsily. If we hope to integrate robots

into our social lives positively, we’ll have to understand people’s needs and values and teach robots to decode human norms and how to adapt to them. This requires highly specialised knowledge about hardware and software development. But it also requires an equally deep knowledge of the human and societal implications of such technology,” he says.

Researchers at the AU Social Robotics Lab have developed and are refining a methodological and theoretical framework whereby they can experiment with giving robots social intelligence in different contexts, and in parallel with the technological development, they are investigating the psychological and ethical implications. They have named the multidisciplinary scientific discipline “Integrative Social Robotics”.

“Since we can’t anticipate the long-term effects of widespread use of social robots, we need to envisage new forms of research organisation that will enable us to regulate social robotics applications from the start, and not, as currently, after the fact. Integrative Social Robotics is a new strategy for developing social robotics applications that includes strong focus on human interaction and value-driven design,” says Nicolas Navarro Guerrero.

## **Robots and social cognition**

Several of the interdisciplinary robot experiments involve recent research about the pre-conscious cognitive mechanisms. Our brain seems to process perceptual information about fellow human beings

## *project facts*

### **TITLE:**

INSOR – Integrative Social Robotics

### **SCHEDULE**

2016-2021

### **FINANCIAL FRAMEWORK**

Carlsberg Foundation

### **PARTNERS**

University of Copenhagen, New York University, University of Oslo, University of Southern Denmark, Hiroshi Ishiguro Lab, University of Washington, Harvard University, Technical University of Vienna, University of Helsinki and George Mason University

### **CONTACT**

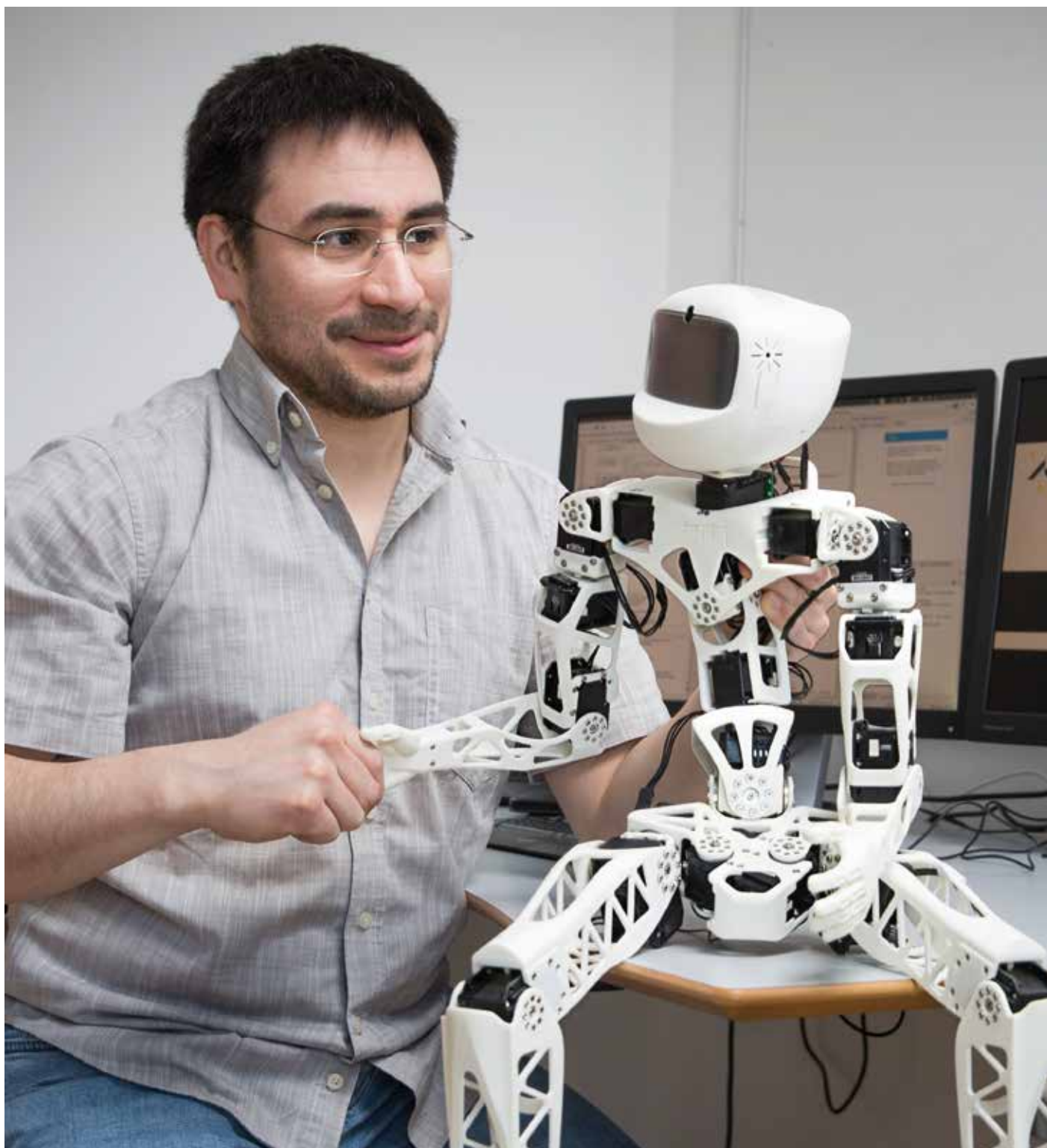
Assistant Professor Nicolas Navarro Guerrero; nng@eng.au.dk

in special ways, creating the distinctive mode of “social cognition” which involves emotional evaluations. Robots give us a chance to explore these mechanisms of “implicit social cognition” in further detail, since the design and movement of a robot partly do trigger such mechanisms and partly don’t.

“Making the robot act autonomously and appropriately in a social interaction is an extremely complex technological challenge,” says Nicolas Navarro Guerrero. “There are a number of elements in social interaction that can be exploited to create smooth social interactions while at the same time playing with our pre-conscious mechanisms of social cognition. For example, if a robot, like a child, follows the gaze of a person, the person will receive the impression that the robot tries to understand and collaborate with the human.” Such research matters given in the course of the next two decades all of us we may come to directly collaborate with robots.

“At the moment we’re working on refining the robot’s tone of voice, and head and eye movements. Everyone knows how robots talk in a very monotonous tone and have a rigid, staring gaze without human characteristics. This is a really bad starting point for social interaction,” says Nicolas Navarro Guerrero.





*Is it possible to transform robots into artificial agents that interact with human beings in accordance with socio-cultural norms?*

*Nicolas Navarro Guerrero designs robots that can take part in meaningful social relationships with people. This requires advanced algorithms, but also a thorough understanding of psychological and philosophical dynamics in the user context.*

## INTEGRATIVE SOCIAL ROBOTICS

Integrative Social Robotics (INSOR)—A New Framework for Culturally Sustainable Technology Solutions

The production of robots with “social skills” or even “social intelligence”—drives a technological revolution of possibly unprecedented disruptive potential, both at the socio-economic and the socio-cultural level.

“Integrative Social Robotics” (ISR) is a new strategy for developing social robotics applications—it tightly integrates robotics research with a wide scope of research disciplines that investigate human social interactions, including empirical, conceptual and value-theoretical research in the Humanities,” Johanna Seibt, School of Culture and Society, Faculty of Arts, Aarhus University.

# COMPUTER TECHNOLOGY

Continued exponential growth within digital technologies like the Internet of Things, cloud computing, mobile internet, cyber-physical systems and Big Data is dramatically changing every aspect of the way our society works, from nano to mega-scale.

# Nanosatellites to revolutionise modern communications technology

Aarhus University is well on the way to launching its first satellite, Delphini-1. The satellite constitutes the foundation for what will eventually become an entire laboratory of small nanosatellites orbiting around the Earth.

A revolution is taking place in commercial exploitation of space. Traditional satellite communication, based on large, geostationary satellites around 36,000 km above the equator, is about to be replaced by huge constellations of much smaller satellites in lower orbit. From 400 to 1,000 km above the Earth's surface, these nanosatellites will float around in constant communication with each other and the Earth.

In a major new project Aarhus University is helping to start this revolution. Therefore, in 2018, the university will be sending its first satellite into orbit around the Earth. The launch will be a milestone for the university and Danish space research, and the aim is to create a unique laboratory that will generate previously unthinkable possibilities.

"The plan is to create an entire network of satellites outside the atmosphere. Satellites that can be used to study a wide range of different areas. It's amazing that building a laboratory in space is becoming so cheap that now even a university can do it. That we can have our own equipment out there and study and make measurements without atmospheric disturbance. This was entirely unthinkable just a few years ago," says Associate Professor Rune Hylsberg Jacobsen.

## Probing the unexplored

The project will examine the potential for networks of small satellites, and it goes under the name of MegaMan, an abbreviation of Mega-Constellations Services Management. It has a total budget of DKK 11 million and the plan is to create a platform that can monitor hundreds of small satellites in one single mega-constellation.

Such constellations can be used for space exploration, climate research and geological surveys, but their many sensors and communications mechanisms could also open up for a range of opportunities within many different sectors such as agriculture, shipping, aviation and land transport. Mega-constellations could also bring the internet and mobile coverage to the Earth's remotest regions as well as new and exciting perspectives for the Internet of Things.

"There is much unexplored territory in the possibilities of mega-constellations of nanosatellites. The much lower orbit of the satellites offers completely new opportunities compared with traditional satellites, which means that we can observe and communicate in completely new ways," says Rune Hylsberg Jacobsen.

## The next major revolution

Denmark has made a very good start in

## project facts

### TITLE

MegaMan – Mega-Constellations Services Management

### SCHEDULE

2017-2019

### FINANCIAL FRAMEWORK

DKK 11 million. Innovation Fund Denmark

### PROJECT PARTNERS

Zoperate A/S  
GomSpace A/S

### CONTACT

Associate Professor Rune Hylsberg Jacobsen; rhj@eng.au.dk

the race to lead commercial exploitation of mega-constellations. Both Aalborg University and DTU have similar satellite programmes, which means that Danish engineers, physicists, and geologists can develop unique competencies within the space industry.

And there are plenty of challenges to take up. One of the biggest is that the many small satellites have to be monitored, and errors must be identified and rectified. By re-using concepts and standards from operating mobile networks, over the next two years the project partners will develop the world's leading monitoring platform for operating mega-constellations.

The shorter distance to the satellites makes the delay in conversations much smaller, for example, and at the same time coverage of the entire globe can be significantly improved - also in the open ocean and over the polar regions. Mega-constellations are also easier to build up as required over time, because capacity can be increased by launching ever more satellites in the same constellation.

Implementation of mega-constellations is still at the beginning stages, so there is enormous potential to be part of the next major revolution in the satellite industry.



Space: the final frontier. Associate Professor Rune Hylsberg Jacobsen standing next to the antenna that will allow communications with the nanosatellite once it enters orbit.



A team of Aarhus University students building the satellite, that will enter Earth orbit in 2018.

# Building a computer like a human brain: a technological revolution

For decades computers have been growing exponentially in computational power. However, the current technology is nearing a threshold: computing simply requires too much power.

In March 2017, the local TV station Mid-West reported that, once completed, Apple's new data centre in Viborg, Denmark, will use so much power that it corresponds to three per cent of the entire electricity consumption in the country.

Three per cent. One single data centre. That is a lot of power to run servers and keep them cool. In fact, power consumption is becoming a rapidly narrowing bottleneck in developing new hardware: too much power is wasted on cooling. Why? Because the technology behind modern computers generates heat.

Imagine for a moment that computers worked like the human brain. No excess heat there. If our brains were to heat up when thinking, we would have a huge problem. We would in fact die. But instead our minds are capable of monumental computational tasks without even breaking a sweat.

## A lot of work for nothing

Building a computer just like the human brain is actually what a team of engineers are working on with a project at Aarhus University. The project is entitled PHOTON-NeuroCom, and it focuses on mimicking the brain, which works in an analog way – not digital.

"When it comes to image and video processing, the human brain is far superior to any supercomputer of today in terms of energy efficiency. Once I have met a



**Current computers will not work in the future because the power consumption required to deal with the exploding big data industry will be too great**

Associate Professor Farshad Moradi

person, for instance, I can easily identify the same person in a crowd without too much energy consumption. The person has been imprinted on my memory. For a computer, the same task is not that easy. A computer has to process and categorise every single feature on every single face in the crowd in order to identify the object. The computer gets inputs, converts them to 1s and 0s, does the signal processing and then the detection, which may turn out to be negative in many cases. A lot of work and energy for nothing," says Associate Professor Farshad Moradi.

## Extreme amount of energy

There is a huge gap between the energy consumption in the brain and the energy consumption of a single computer. Since a very large part of the Internet is concerned with image and video processing, an extreme amount of energy could be saved with more 'brain-like' computers.

"If you tackle the problem of the large amount of energy consumption involved in image and video processing by using new hardware to fill the gap between the power density of the brain and the existing processors, you are probably in good shape to develop a next-generation, power-efficient and brain-like computer," says Associate Professor Moradi.

"The current von Neumann computers will not work in the future because the power consumption required to deal with the exploding big data industry will be too great. In this project, we have started a journey to construct a cognitive computing system as a proof of concept, using special very low-power nanoscale devices called spintronic nano-oscillators, which will function as neurons in the brain-like computers of the future," he continues.

Non-von Neumann 'brain-like' computers are currently built in research labs for basic cognitive computing, but they are on their way to revolutionising the global tech industry.

## project facts

**TITLE**

PHOTON-NeuroCom

**PARTNERS**

Aarhus University & CEA/SpinTEC

**BUDGET**

DKK 1.58 million

**CONTACT**

Associate Professor Farshad Moradi;  
moradi@eng.au.dk



Photo: Lars Kruse

*The human brain is far superior to any supercomputer of today in terms of energy efficiency. That is why Associate Professor Farshad Moradi is working on building a whole new generation of power-efficient and brain-like computers.*

## project facts

### TITLE

Industry 4.0 R&D Programme

### SCHEDULE

2017-2019

### FINANCIAL FRAMEWORK

DKK 25 million

### CONTACT

Head of section Andy Drysdale;  
adr@eng.au.dk

# New knowledge will get companies to take part in the fourth industrial revolution

Aarhus University will use a new programme to ensure that knowledge about digitalisation and materials technology will benefit Danish companies. This will prepare them for developing smarter products and production methods, so they can ride the Industry 4.0 wave.

With a large amount of regional business development funds from the Central Denmark Region and the European Regional Development Fund, it will be possible for small and medium-sized enterprises (SMEs) in Denmark to gain access to knowledge about new technologies, and help to implement these in their products, services or production systems.

“Technological development is radically changing the innovation conditions for the business sector at present. Especially digital growth technologies and new production methods have started a rapid race for development in virtually all branches and, in this context, knowledge is a crucial fuel for the companies. As a university, we have considerable responsibility to ensure research and education with a high degree of social relevance,” says head of section Andy Drysdale.

### 30 new business adventures

The aim is to increase the number of companies that can turn technology into new business opportunities, and thereby

achieve an industrial competitive edge in global markets.

“Many companies can create a significant head start by implementing new growth technologies in their development activities, and many of them simply have to do this to survive tomorrow and in the long run. Industry 4.0 transforms the business sector’s framework conditions, and paves the way for completely new business models,” says Andy Drysdale.

He is the project manager for the new programme, which will implement ten new innovation collaborations with a total of 30 companies during the years to come.

### Science, productivity and export

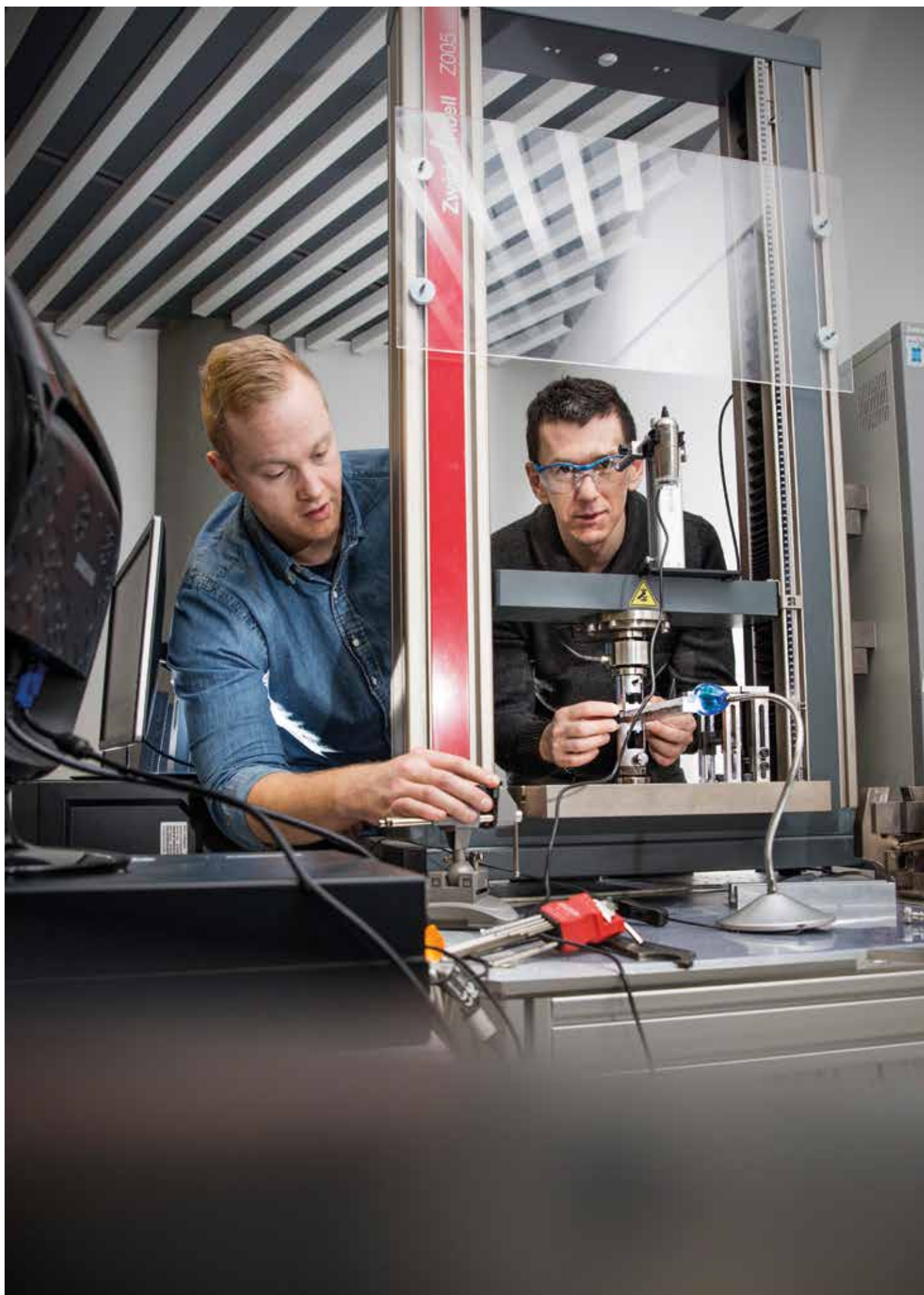
In principle, the programme targets all SMEs with a need for technology-based innovation. The companies participating in the programme will collaborate on a specific project in a small consortium with two other companies and a knowledge institution.

In this connection, Andy Drysdale points out particular research areas that are significant for industry’s adaptation to the Industry 4.0 wave.

“Advanced, smart materials, smart products and processes, and artificial intelligence are growth technologies that can be seriously important for business development in the coming years. The knowledge created by the universities in these areas radically changes production conditions. Industry 4.0 is basically about machines and products becoming intelligent and self-learning, and able to exchange information in real time. It’s clear that companies that are good at spotting opportunities in scientific progress and creating new forms of collaboration concerning innovation will gain a considerable competitive edge,” he says.

In Denmark, it is well documented that new knowledge and technology boost a company’s productivity and export capacity.





*With a new Industry 4.0 R&D Programme, companies and researchers have an opportunity to intensify their collaboration regarding technology-based innovation. Pictured here are Assistant Professor Michal Budzik and PhD Student Simon Heide-Jørgensen. They are developing a new molecular adhesive for bonding of rubber to metal surfaces in the food industry.*

# A Changing Internet

The Internet is undergoing a degree of change that only few can imagine. The flow of information is in explosive growth, and this places extreme demands on the way we compress and store data. Researchers are now getting started on the creation of completely new conditions for communication between humans and things in the network.

There are currently around 12 billion devices connected to the Internet. Researchers believe that this figure will increase to close to 500 billion during the course of the next decade. We are thus well on the way to the future Internet of Things (IoT), where all things possible will use sensors to find their way to the Internet and communicate with each other.

This development will obviously lead to a colossal growth in data traffic and increase our storage requirements dramatically. It is therefore necessary to find new methods to compress, send, index and store data.

"The next few years will bring with them sweeping changes on the Internet. Our proposed concepts will make it possible to pack data so that it fills 10 to 100 times less space than it does today. This is a dramatic reduction based on a complex mathematical theory that we are developing and getting ready to implement in practice," says Associate Professor Daniel Enrique Lucani Rötter.

Associate Professor Rötter expects that, in the longer term, his method will reduce

our need for hardware and electricity consumption for cooling at datacentres.

He is one of the world's leading Internet and Cloud technology experts, and in just ten years he has been responsible for several scientific breakthroughs, started one company, and taken out eight commercial patents and licensed them to three companies so far.

## Preparations for the Super Internet

Denmark's national elite research programme, Sapere Aude, has invested huge sums in Associate Professor Rötter's research. The funding will help solve some of the major challenges facing the Internet: lack of storage space and efficiency.

"We'll build on our existing scientific work and develop new concepts for the Internet of Things that make it possible to store data more efficiently to an extent we can't even imagine today," he says.

What is special about the Internet of Things is that it is partly composed of sensors that generate a flow of dynamic data that is difficult to predict. This requires the

## project facts

### TITLE

SCALE-IoT – Scalable Systems for Massive IoT

### SCHEDULE

2019-2022

### FINANCIAL FRAMEWORK

DKK 6 million Independent Research Fund Denmark and

### PARTNERS

MIT, TU Dresden, U. Neuchâtel, Kamstrup

### CONTACT

Associate Professor Daniel Enrique Lucani Rötter; Daniel.lucani@eng.au.dk

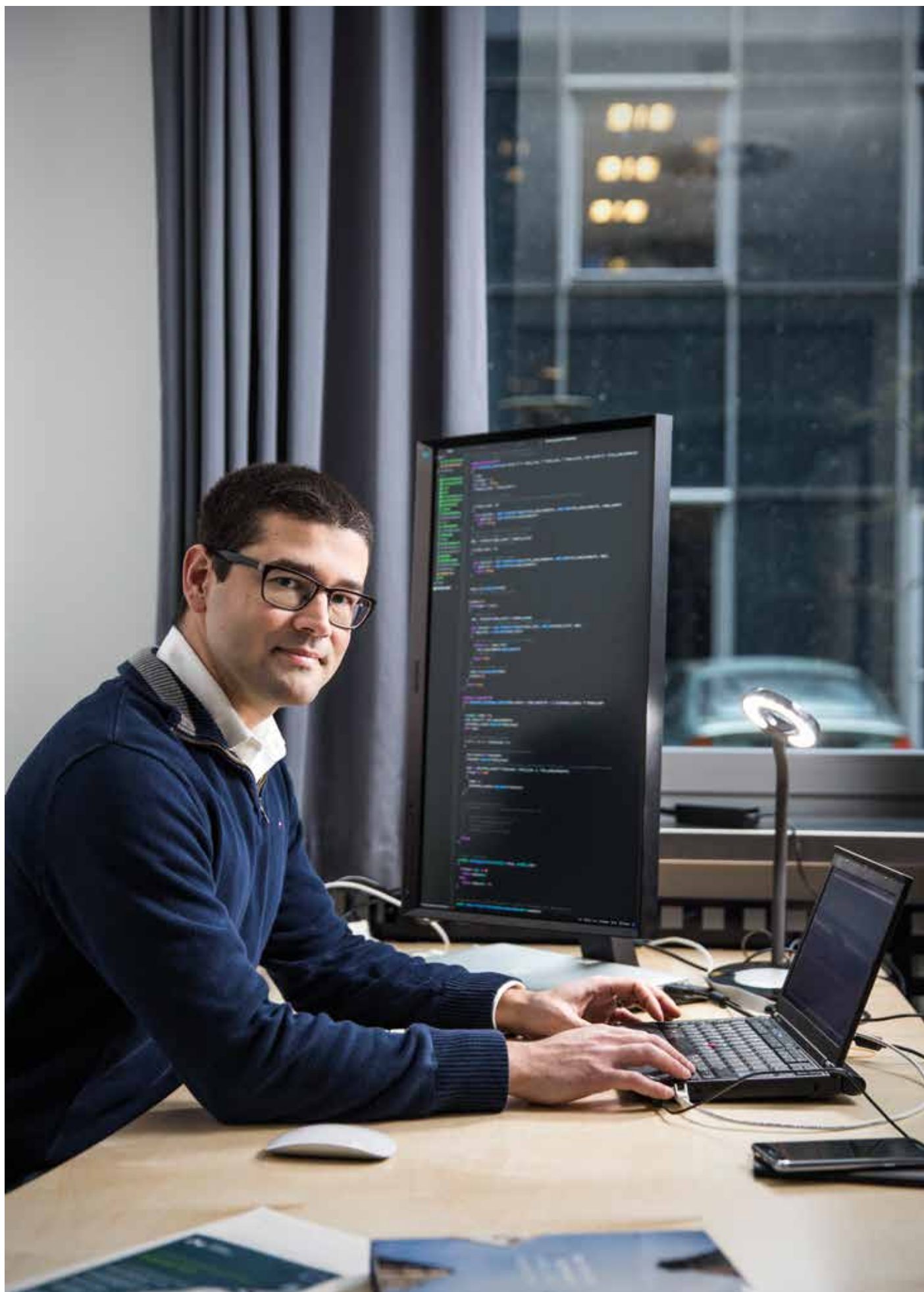
system to make multiple updates, and therefore, an agile compression of the data that allows us to perform swift updating is crucial in the future.

## The art of storing data in packages

As a newly appointed research leader at Aarhus University, Associate Professor Rötter will be developing a new method to store billions of files on the Internet.

"We're working on a promising method that can make it possible to compress data in a significantly more efficient way by indexing and identifying similarities in data fragments. It's basically about getting away from compressing individual files to compressing across multiple files from different users and devices," he says.

Researchers at Aarhus University are collaborating with Massachusetts Institute of Technology (MIT) on the project, and the knowledge generated from their activities will help ensure that Danish engineers possess competitive skills within the Internet of Things and Cloud technologies.



*Moving advanced mathematical theories into the laboratory to become new solutions for the Internet of the future demands heavy equipment. Researchers have set up a datacentre with several servers to study storage capacity and energy efficiency. The photo shows Associate Professor Daniel Rötter.*

**CONTACT**

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## Lightning fast computer vision to make train travel safer

Every year, railway operators all over the world spend vast sums on maintaining rail systems. Researchers from Aarhus University are developing a new system to quickly and easily detect irregularities in the rails that would otherwise be extremely costly to discover.

When you're standing on the platform at Aarhus' newest mode of transport, the Light Rail Transit, and you look down the line, at first glance it appears that the rails are completely straight and parallel, and they're flat as a mill pond.

But they're not. Tiny bumps and bends are impossible to avoid when the rails are laid and the ground settles. Furthermore, daily wear and tear will cause larger and larger irregularities in any rail system. These cause vibrations in carriages, they make passengers' journeys uncomfortable, and they increase the risk of derailment.

Therefore, Associate Professor José Escalona is currently working on a project that could greatly improve the chances of railway operators in Denmark and the rest of the world to discover irregularities and rectify them to make journeys more comfortable, and to reduce the risk of fatal derailments.

"The vibrations you feel when you travel by train are primarily due to irregularities in the rails. The rails should be straight, but

they're not. The irregularities must therefore be kept to an absolute minimum, and this applies in particular for high-speed trains," he says.

### Testing at normal speed

José Escalona came to Aarhus University on 1 August 2017. He has researched trains and rail systems since 2001 in both Spain and the US, and the plan is to develop a solution that could provide considerable savings in annual rail maintenance, which is very costly for society.

"Today, we measure irregularities with specially designed trains that move very slowly and therefore interfere with normal train operations. The system we're working on can be used on a completely ordinary train to measure irregularities on any rail system in real time and at normal speed," he says.

This means you don't need the special, expensive trains which disrupt timetables. Instead you can make measurements with ordinary train units in daily operation, and the railway operator can obtain an overview of wear and tear, where there



## The system can be used on to measure irregularities on any rail system in real time and at normal speed

Associate Professor José Escalona

are problems, and where it is necessary to make repairs or at worst stop the train because of the high risk of derailment.

The system works using lasers and special video cameras, and by measuring how carriages respond to irregularities, José Escalona has developed a system that can calculate and use graphs to display the current level of comfort and the risk of derailment.



Photo: Lars Kruse

*Train rails aren't as straight and perfectly regular as they might seem. Associate Professor José Escalona, here in front of Aarhus' newest mode of transport, the Light Rail Transit, is developing a new system to quickly and easily detect rail irregularities. A system, that could provide considerable savings in annual rail maintenance.*



Navitas Campus, Aarhus

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# ADVANCED MATERIALS



New materials with properties that we hardly dare dream of today will see the light of day in the near future. We are on the threshold of yet another industrial revolution where technology will pave the way for completely new inventions and advances in a considerable number of areas. Examples are space, healthcare and manufacturing through e.g. 3D printing.

**CONTACT**

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 aghababaei@eng.au.dk

# Solving the long-standing mystery of friction and wear

Leonardo da Vinci was probably the first to study friction and wear. Despite the passage of more than five centuries, our understanding of these phenomena still remains empirical and is therefore very limited. Now, a group of researchers is trying to further understand the origins of friction and wear at different scales, ranging from atomic to macroscopic.

Friction and wear are probably not topics you would dwell on for too long, except maybe when the time comes to change the tyres on your car, but for many industries, they are indeed of great interest. Nowadays, friction and wear are part of a wider branch of the science of interacting surfaces in relative motion, referred to as “tribology”.

“Friction and wear occur everywhere – all around us we have contacting surfaces in relative motion. From an industrial viewpoint, friction and wear are a waste of energy and material. Friction transfers mechanical work into wasted heat and, as a direct result, wear causes material degradation and eventual failure of mechanical parts. Tool wear for instance is one of the biggest challenges for metal and composite manufacturers, and for decades industry has strived to reduce wear in order to optimise production,” Assistant Professor Ramin Aghababaei explains.

## Monumental industrial problems

Scientists and engineers have been studying the friction and wear phenomena for decades. And with good reason, since – aside from the societal woes, - friction

and wear are still monumental problems for industry, as Assistant Professor Aghababaei adds:

“Regardless of scale, the process is always the same: two surfaces – the gears of a watch, brake pads against their discs, an artificial joint against its socket – rub against each other. Short-ranged atomic forces acting between the surfaces, known as van der Waals forces, locally stick the surfaces to each other (i.e. friction force). If the stickiness is strong enough, small fragments of one of the surfaces can peel off, eventually leading to the formation of tiny particles, referred to as wear debris. Despite this deceptive picture, predicting the magnitude of friction and wear is one the most challenging problems in mechanics and physics.”

Up to now, our knowledge about material wear has been empirical and derived from trial and error. Now, along with a team of researchers, Ramin Aghababaei is trying to bring a more fundamental understanding into the field in order to predict how surfaces of materials react and eventually degrade in relative motion.

## Breakthrough studies

Before becoming head of the Surface Mechanics group, Assistant Professor Aghababaei was the leading scientist in a group at EPFL, the Federal Institute of Technology in Switzerland, who was the first to reproduce the material detachment mechanism using computer simulations. These breakthrough studies, which are published in Nature Communications and PNAS journals, laid the groundwork for a new field of study in the broader science of tribology. Now, at the Department of Engineering at Aarhus University, the Surface Mechanics group is designing systematic sets of experimental and computational setups to further understand the microscopic origins of friction and wear at various scales.

“There is a big gap between the science of adhesive wear and its application in industry, so we’ll be trying to fill this gap as much as we can over the coming years. The dream is to develop a simple and predictive model to predict friction and wear between surfaces under different working conditions,” Ramin Aghababaei says.

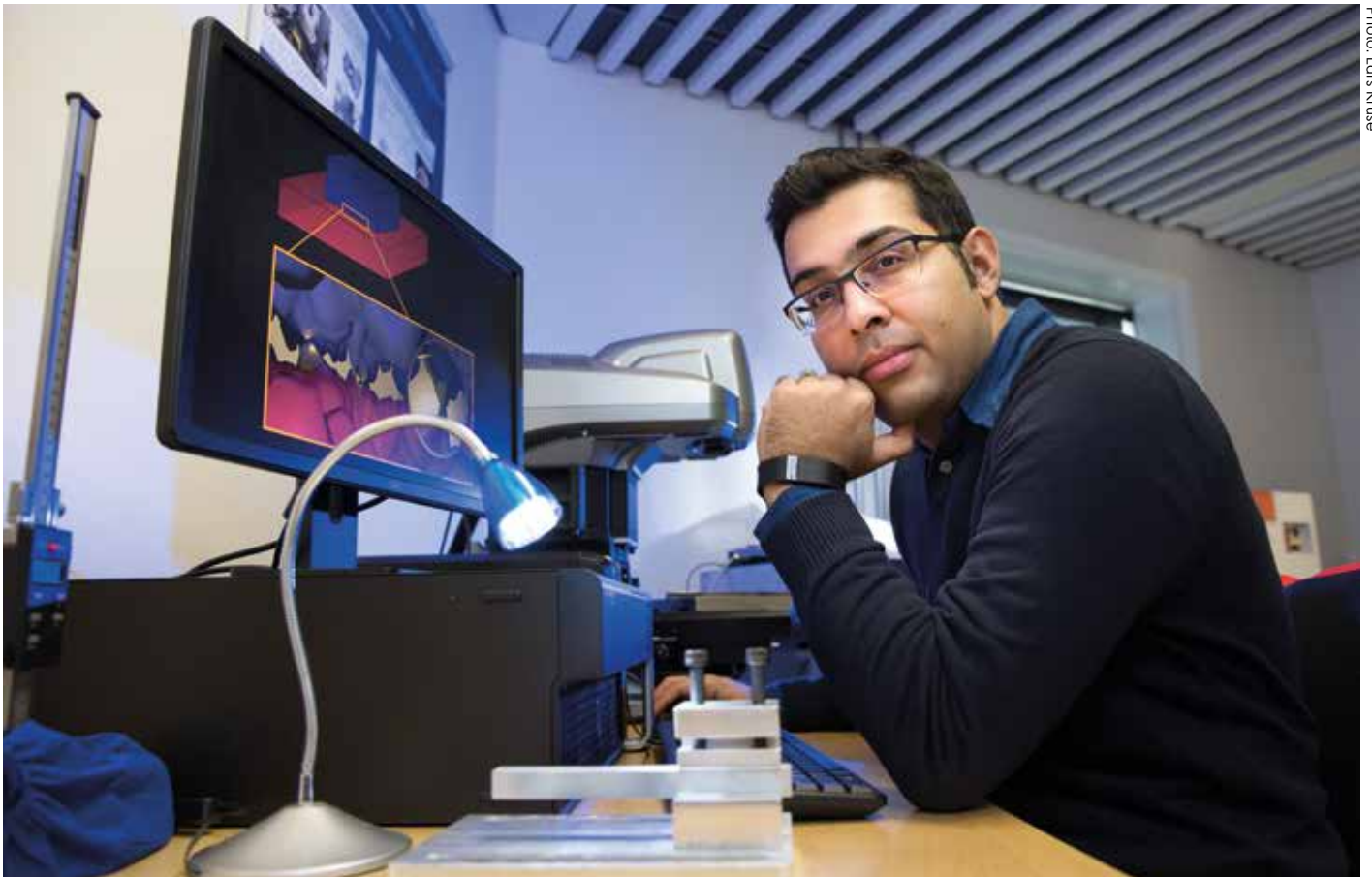


Photo: Lars Kruse

*Wear occurs everywhere and all the time. And though friction is a very simple problem, it is still one of the least understood and most complex areas in mechanics, Assistant Professor Aghababaei says.*

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**CONTACT**

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## Centuries-old art form generates completely new materials

Origami. For many people, the word means not much more than skilfully folding paper to resemble swans, frogs or other animals. But origami is much more. There are examples of origami throughout the modern world, but it's likely that you won't notice all the things that are in fact inspired by this old 17th century Japanese art form.

In 1985, the Japanese astrophysicist Koryo Miura revolutionised the satellite industry using origami. He introduced a simple system for satellites that made it possible to fold solar panels so that they physically took up very little space but they could easily unfold to full size when the satellite was in space. The system is called the Miura fold. Since then, origami and its sister technique, kirigami, have won an increasingly strong footing in technology.

Someone who works with origami and kirigami in the realm of mechanics is Assistant Professor Marcelo Dias. By studying this old art form, he is researching so-called mechanical metamaterials, which are used as mechanical actuators, for example.

"Take a completely ordinary material such as a piece of rubber. If you pull on both ends in a longitudinal direction, the transverse dimension is shortened as you pull. Similarly, the transverse dimension expands if you push the two ends together. If this happens, it means that the material has a positive Poisson value, and this applies for by far the majority of materials. I research structures where a well-

thought-out geometrical design results in materials with a negative Poisson value," Assistant Professor Dias says.

### Castles and dragons

In principle, it's about changing the properties of the material by folding and cutting in the right places - just as with Miura's solar panel technique.

It is also well-known from children's pop-up books: You turn the page and up pops a castle with a princess at the window, guarded by a dragon.

The technique can be used on many other materials than paper, and the advantage of crafted material property is that it requires very little energy to make the deformation, so you can add unique structural properties to the material.

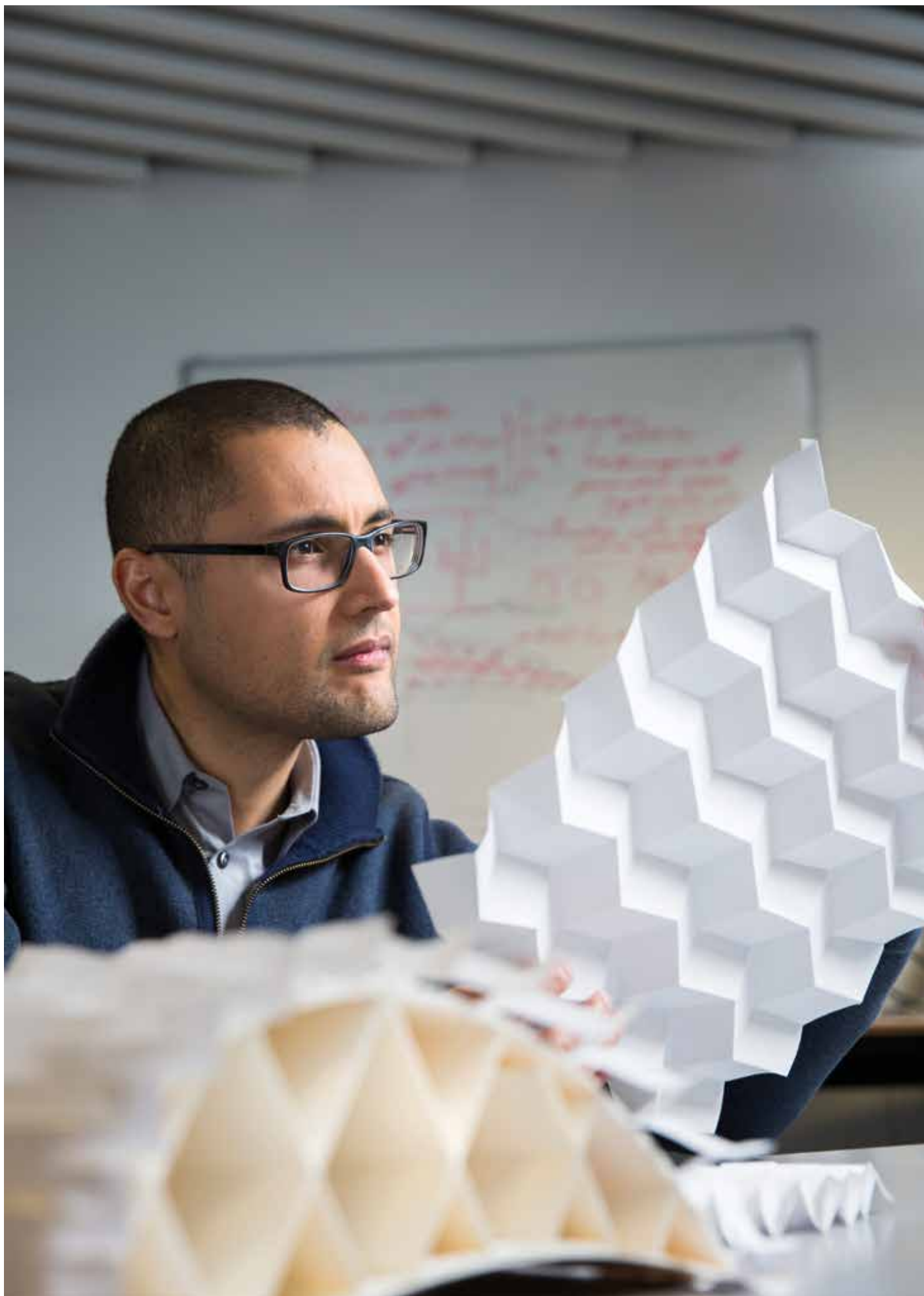
"You change the material's structural properties by changing its geometry. The idea is to find an intelligent way to design folds and cuts to generate the reproducible movement you want. There are many ways to make use of these techniques in the real world, from large-scale down to micro-scale," he says, pointing to flexible

solar panels, for example, as well as prefabricated buildings and flexible electronics, right down to Micro Electro-Mechanical Systems (MEMS) and nano systems.

"Before long we'll be wearing our electronics - just like clothes. This'll require that the electronics can move with our body and skin, but how is it possible to combine the suppleness of biological tissue with the rigidity of metals? This is a conundrum we're working to solve by borrowing techniques from these old art forms," he says.

Marcelo Dias has been working with the Japanese art form since 2010, and he holds a PhD in the mechanics of origami from the University of Massachusetts.

"I've always worked with this. Ever since my PhD, I've been interested in manipulating geometry to improve the material and give it extraordinary properties. It's all about improving the materials already found in nature; cutting them and folding them. It's quite remarkable that kirigami can provide us with so many possibilities within materials science."



*Much can be learned from the ancient Japanese art form origami, when it comes to designing modern metamaterials.*

# CLIMATE & ENERGY



## Encouraging the optimal energy system

In the near future, renewable energy technologies will be the primary source of power for the European electricity grid. In order to build the optimum power infrastructure, researchers are working on how to allocate the cost of future energy systems in the most efficient way.

In accordance with the European Union's 2030 climate and energy framework and the Paris climate agreement, the European countries have all committed to reducing their carbon emissions by 40 per cent compared to 1990 levels.

To reach this ambitious goal, the entire European energy system has to undergo a massive change in which the number of conventional centralised fossil fuel power plants is reduced in favour of various renewable technologies.

Such a shift towards a sustainable, clean energy infrastructure is strongly dependent on the system integration of renewable sources, such as wind and solar energy. For the system to function at its best, the grid infrastructure must be flexible enough to pool resources over large geographical areas, as the best wind and solar power resources are usually located far from population centres.

### The big picture

This requires build-up of a complex energy grid able to sustain increasingly long-range transmission, while at the same time, developing a cost allocation model for the corresponding usage associated with power import or export by the involved countries or agents.

"To design a future system where most of the electricity derives from renewable energy sources, it is best to look at the European Union as a whole. Then, when we know what the optimal system would look like, we can develop a method for cost allocation based on flow-tracing techniques, which allocates system costs based on actual usage of the grid infrastructure. This means, for example, that if windfarms are built mainly in the north, but most of the power is exported to the south, the southern countries would be sharing the investment costs. This is the system we are currently modelling," says PhD Student Bo Tranberg.

Bo is working on modelling the future European power grid in a way that encourages involved countries or agents to contribute to building the optimal energy system:

"We'll be exploring which economic incentives should be in place for investments in renewable generation and transmission capacities to build on the current layout and reach a future highly renewable energy system based on the already known political goals for reduction of CO<sub>2</sub> emissions. In other words, what is the optimal market design in this transition period until a fully renewable electricity system is reached?"

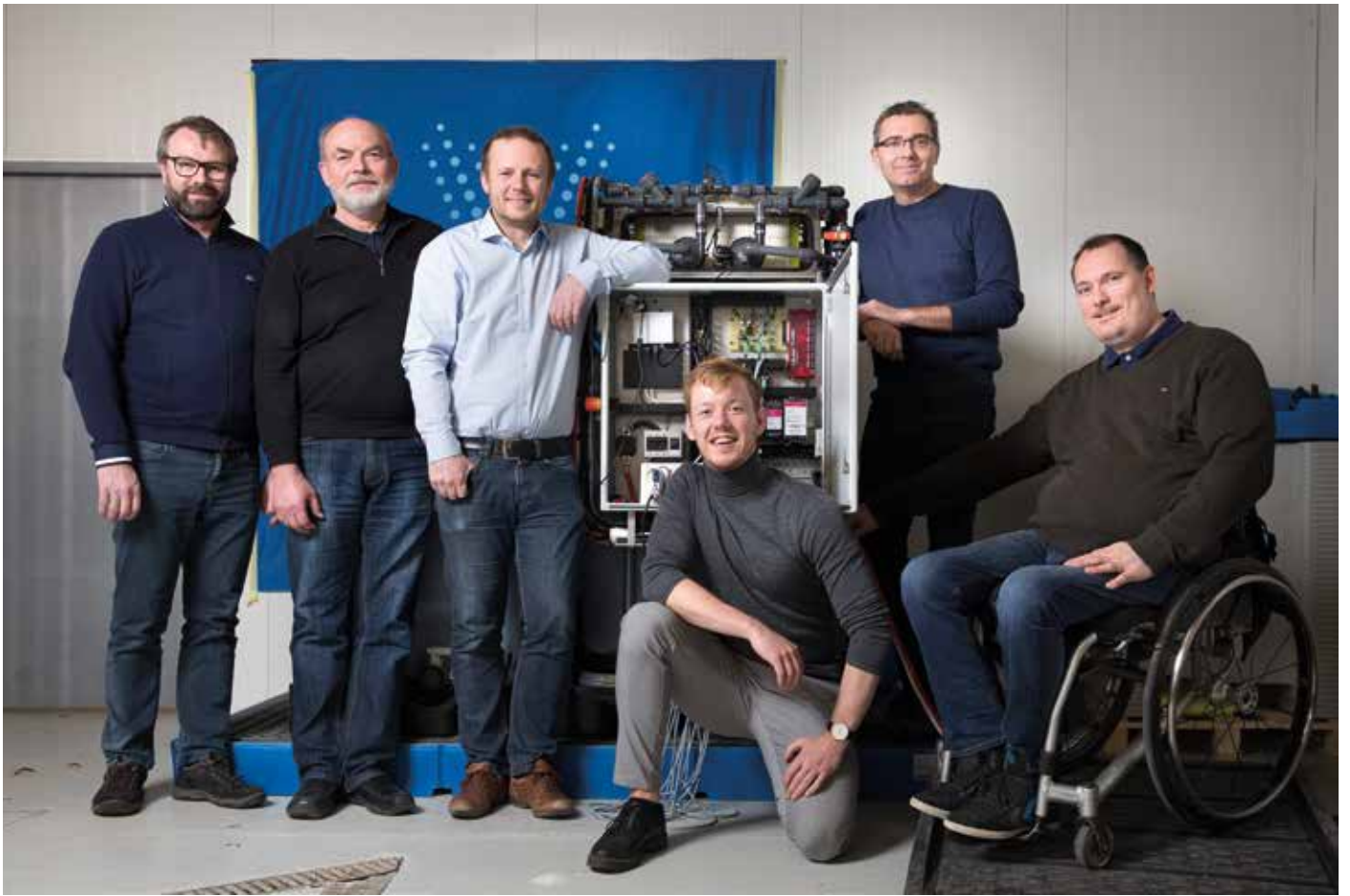




*How can we allocate the cost of future energy systems in the most efficient way? That is exactly what PhD Student Bo Tranberg is working at.*

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bo@eng.au.dk



*What started out as basic research in a chemistry laboratory has today become a business with a promising global market potential. Visblue has its head office in Denmark and a branch in Portugal, and it has five full-time employees. The first production of flow batteries for the Danish market is in full swing.*



*University know-how still plays a crucial role in commercialisation of next-generation batteries for solar-energy storage. The researchers are working on developing new chemical technologies that can keep prices low and optimise power.*

# Danish invention makes solar cells good business

It all started a few years ago with a dream of developing a battery to store electricity. Today, the research has become a business, and production of the first batches of flow batteries is in full swing in a small Danish company with a very promising global market potential.

Enabling residential properties and companies to store energy from the sun in our homes cheaply and safely could be nothing less than a game-changer in our energy system. In both the US and China, private individuals are beginning to erect entire parks of flow batteries, and the first batteries for storing solar energy have now also been put into production in Denmark.

According to the researchers behind the battery, even under Scandinavian weather conditions, costs will be recouped in the course of just ten years.

"We've matured the technology very quickly, and we're now preparing the first large Danish installations for sale. Development work is still a core activity in the company, and our clear expectation is that we can improve the technology so that the return on investment for the consumer is even better in the future," says Associate Professor Anders Bentien, one of the driving forces behind the development of the flow battery and co-owner of the Visblue company.

## New collaboration with Harvard University

Basically, the battery is based on vanadium technology, which gives a very long service life and makes it possible to scale power and energy capacity independently of each other. This makes the battery cheap in the long run and at the same time very flexible for the individual customer to use.

In 2018, the researchers and the Visblue spin-out company started a new project in collaboration with, among others, Danish wind turbine producer Vestas and Harvard University. The aim is to develop an improved generation of batteries based

on new fluid compositions with organic electrolytes. This will make it environmentally friendly and at the same time reduce the cost per kilowatt hour.

## One of the cornerstones of the future energy mix

Initially, the company is primarily producing batteries for the Danish market. This is being done while they are upgrading production facilities for the growing global demand for new technologies that can store green energy.

"If we're to have a 100 per cent green energy supply, one of the most important issues is storage. What are we to do with solar and wind production that fluctuates from day to day and from season to season? How do we secure stable supplies without backup from power stations? Flow batteries could play a crucial role here," says Associate Professor Bentien.

According to the associate professor, batteries for storing energy could also turn our distribution system on its head.

"Who says that, in future, it'll be a good idea to transport electricity between countries. In principle it's unnecessary, as individual householders can store their own electricity for their own needs," he continues.

In many cases, private storage of surplus energy from solar cells is already much more profitable than selling electricity back to the grid.

## Important relief for the supply grid

The new flow battery solves another important problem in the way the modern world has organised its energy systems. In many countries, underground cables are getting old and they come from a

time when no account was taken of the amounts of electricity from solar energy we transport today.

"This is most evident in Danish residential areas from the 60s. They're connected to a substation through a supply grid that has difficulties coping with the solar energy from the large number of solar cells on house roofs. In the middle of the day, when production is typically greater than consumption, large amounts of electricity flow in the opposite direction, and the system isn't dimensioned to deal with this," says Associate Professor Bentien.

Over the coming year, the researchers want to test the possibilities of using the battery technology to relieve the supply grid in full scale in a Danish residential area.

## project facts

### TITLE

Organic Redox Flow Battery Systems (ORBATS)

### SCHEDULE

2017-2021

### FINANCIAL FRAMEWORK

EUR 2.5 million Innovation Fund Denmark

### PARTNERS

Technical University of Denmark, Harvard University, Vestas, Visblue, Li-Balance

### CONTACT

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# Climate change and the future European electricity supply

Temperatures are increasing, but it seems that our electrical power supply will be able to cope with the challenges posed by new weather phenomena for many years to come. Comprehensive forecasts have mapped the impact of climate change on European production and consumption of electricity up until 2100.

The climate is changing everywhere on Earth as a result of anthropogenic global warming. The weather is becoming more extreme, with more droughts, storms and rainfall.

Most scientists agree that this will have serious biological, geographical and social consequences in the near future. Therefore, it is obvious to assume that the extreme weather will also affect how we organise our future electricity system in Europe, which will predominantly be based on solar and wind power. However, this is not the case.

"We've examined how global warming will affect wind and solar energy in all European countries. What we see is a sustainable and robust power system for the future, which as a whole will only slightly be affected by climate change," says Smail Kozarcanin, a PhD student.

## A robust mix of energy sources

Researchers have completed the most comprehensive analysis of climate data so far, and with a high level of certainty, they can demonstrate that global warming will only have a very limited impact on Europe's future mix of energy sources for electricity supply.

"This is a good thing, because it means we can continue to use wind and solar energy in the hope of preventing climate change. And if climate change occurs anyway, we won't be facing any dire problems," says Associate Professor Gorm Bruun Andresen.

The researchers have used forecasts and projections of weather changes in Europe up to 2100 in their analyses.

The scientific results provide valuable knowledge for decision-makers at both government and intergovernmental levels when they have to prioritise investments in tomorrow's energy systems.

## A hot and cloudy future for Europe

Even though climate change will only have a marginal impact on the way we organise our electricity system in the future, according to the researchers, climate change will lead to significant changes in sun and wind conditions.

However, these changes will primarily be intermittent and local and they will not affect electricity supply and demand in Europe as a whole.

The researchers have also ascertained that increases in temperature will influence electricity consumption and solar-energy production to some extent. However, it is difficult here too to identify any major consequences for our electricity system. The warmer weather will simultaneously result in lower electricity consumption for heating and more cloud cover with a resultant reduction in solar radiation.

"We won't get more solar energy because temperatures rise. This is because warming will result in more cloudy weather and this will reduce the effectiveness of solar panels. On the other hand, a warmer climate will affect our electricity consumption, because we'll need more cooling. But this increase in demand will actually be neutralised by less need for heating in the European system as a whole," says Smail Kozarcanin.

He stresses that the forecasts, in principle, could have shown a completely dif-

ferent future in which, to safeguard our energy system, we would need to pay much more attention to extreme weather events such as repeated heatwaves or long-term storms.

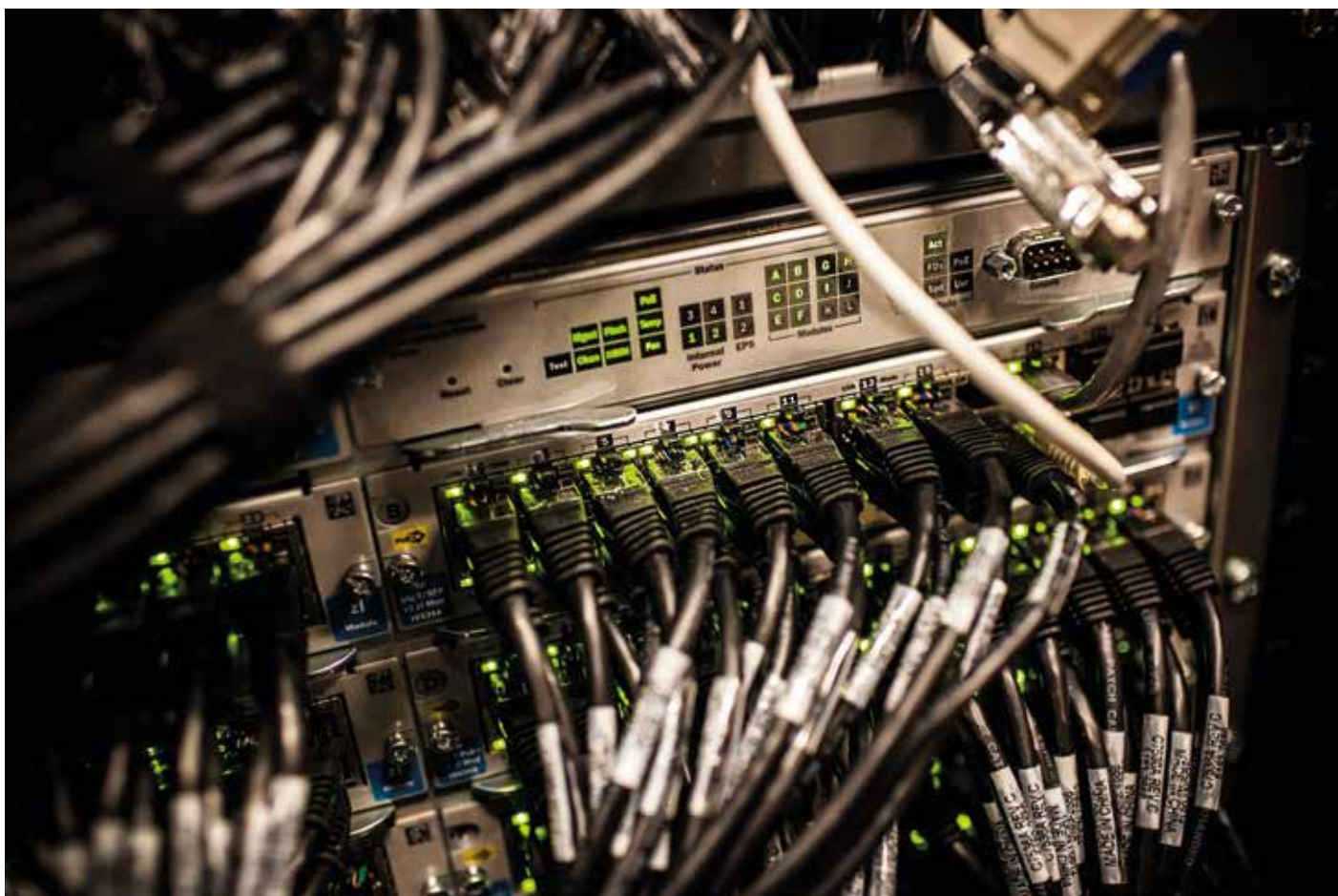
## Mathematical model predicts supply and demand across countries

The researchers base their analyses on three different scenarios for the future climate behaviour of the European population. Each scenario takes into account one specific political regulation of emissions of greenhouse gases.

These scenarios are coupled to weather data in a mathematical model that simulates the European electricity grid. All countries are connected in the transmission grid, and each country is assigned a time series for wind and solar production as well as electricity consumption. This makes it possible to study trends in electricity supply and demand at intervals of only three hours.

"We're operating with huge volumes of data and some extremely advanced mathematical calculations that, in principle, allow us to predict developments in European electricity consumption. This is crucial in planning a future sustainable energy supply for Europe," says Smail Kozarcanin.

In the years to come, researchers will expand their modelling of the European energy system to include heating, cooling, industry and transport.



It is no easy task for researchers to predict the European energy situation up to 2100. They have to feed enormous amounts of climate and consumption data into the computer. Two huge servers have to crunch through no less than 60,000,000 megabytes each time a simulation is run.



How will climate change affect our electricity supply? What mix of solar and wind power is best suited for future conditions? And does it matter how much CO<sub>2</sub> we emit today and in years to come? The picture shows Gorm Bruun Andresen and Smail Kozarcenin.

## project facts

### TITLE

Climate change impacts on large-scale electricity system design decisions for the 21st Century

### FINANCIAL FRAMEWORK

AUFF Aarhus University Research Foundation

### SCHEDULE

2017-2019

### PARTNERS

DMI The Danish Meteorological Institute, SMHI (The Swedish Meteorological and Hydrological Institute, KNMI (The Royal Netherlands Meteorological Institute), DKRZ (German Climate Computing Center)

**CONTACT**

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## Computer models to make wind turbines and wind farms far more efficient

Wind turbines have now reached the pinnacle of how much energy they can pull out of the air. But an enormous amount of energy still lies hidden in wind farms, as they don't yet work optimally due to extremely turbulent and complex wind conditions.

In March 2012, an energy agreement was adopted in Denmark with historically broad political backing. The framework for the development of renewable energy had been set, and the target for wind energy was that one-half of Danish electricity consumption is to be covered exclusively by wind turbines in 2020.

The same tendency can be seen in many countries around the globe. There will be increasing focus on the climate and sustainability, and this requires efficient energy solutions. The technology behind wind energy and wind turbines dates back more than two thousand years. A wind turbine was used to generate electrical energy for the first time in 1887. Modern wind turbines are close to exhausting the possibilities for further development with-

in the three-winged offshore and onshore turbines as we know them.

Therefore, researchers like Assistant Professor Mahdi Abkar are working hard to improve the output of wind turbines in other ways. Instead of looking at the output of the individual wind turbine, they are taking a broader perspective and looking at entire wind farms.

### Maximizing the output

"The increasing focus on renewable energy and sustainability will spawn a need for more and ever larger wind turbines and wind farms. The problem is that just having larger wind turbines and wind farms is not enough - they also need to be more efficient and reliable than they are today," he says and continues:

"We're therefore working to develop models that can describe how wind farms can be designed so that they get the best output with the least loads on the individual turbines. It's not about maximizing the output from the individual turbine; it's about getting the most out of the whole farm - and that's not the same thing," he stresses.

Even though the wind turbine technology is proven, the physics behind wind energy is much more complex and unpredictable. Assistant Professor Abkar is working to develop numerical and analytical models that can predict the complex interaction that takes place between the wind farm and the atmospheric boundary layer; i.e. the layer of air immediately above the Earth's surface.



Photo: Lars Kruse

*Assistant Professor Abkar in front of modern three-bladed windmills. That turbine technology is fully mature, and changes yield only very limited effect in relation to energy production. Yet there are still huge benefits to be gained, if we can design a wind farm that can take account of variables on a larger scale.*

In contrast to the upper layers of the atmosphere, the airflow in the atmospheric boundary layer is highly turbulent. The wind is constantly changing direction and speed and is made turbulent by the landscape and surface topography, for example. The sun also plays a major role for the characteristics of the wind, which is why we talk about particular cycles for day and night.

“There’s also a loss of wind energy in the wind farm itself due to the so-called wake effect,” explains Mahdi Abkar and he stresses that this effect is also affected by the cycles of day and night.

#### **Huge benefits in new design**

Wake effect occurs in wind farms when the wind hits a turbine’s blades. Ener-

gy from the wind is absorbed, but at the same time, the flow and speed of the wind are disturbed in the wake of the turbine. Depending on a large number of factors, this effect can have minor or major significance for the total output of the wind farm, but Mahdi Abkar explains that the effect can result in up to 40 per cent less energy output from the turbines in the wake.

The computer models will take into account these factors and others, so that, firstly, we can build and design an optimal wind farm array with different types of wind turbines, and secondly, so that we can develop a system that can automatically control the turbines individually to minimise the wake effect.

“The well-known three-bladed turbine technology is now fully mature, and the changes we’re still making in blade design, for example, are very small with only very limited effect in relation to energy production. What we lack are improved applied techniques to optimally control the individual wind turbines in wind farms in order to maximize the power output. We need a very accurate model that contains all the physical parameters at stake. There are huge benefits to be gained here, if we can design a wind farm that can take account of all these variables,” says Assistant Professor Abkar.

# Renewable energy from floating flywheel

Better magnets will help to store fluctuating energy from solar cells and wind turbines in flywheels. The process may help to remove one of the major barriers to further increasing the deployment of renewable energy.

Energy storage is one of the 21st century's biggest challenges, and it is a precondition for being able to exploit the full potential of renewable energy in the energy supply system. One solution could be to store energy from sources such as wind turbines and solar cells as kinetic energy in flywheels. This will mean that electricity is available when the sun is not shining and there is no wind.

Aarhus University researchers and a number of private companies have now joined forces to optimise and further develop the technology.

"The project works using the principle behind a flywheel, whereby we keep a heavy cylinder floating in a vacuum-filled container by means of a magnetic field. Electrical energy from a wind turbine, for example, can be used to set the flywheel in motion. As long as the flywheel is rotating, it will store the energy that initially started it," says Associate Professor Søren Peder Madsen.

The kinetic energy can later be converted into electrical energy when it is needed, and the flywheel can function as a storage facility for the fluctuating solar and wind energy.

The company WattsUp Power has designed the flywheels, so that they hover on magnetic bearings with no air resistance. This reduces the energy loss in the storage technology to an absolute minimum.

## Compact and environmentally friendly

Research circles call the flywheel technology Flywheel Energy Storage (FES), and it has been well known for many years. In fact, it is already being used at some locations in the US: among other things to even out fluctuations in the power supply in New York.

The advantage of the technology is that the flywheels can "charge up" very quickly and then release large quantities of energy very rapidly. The researchers expect that, in the future, they'll be able to get the flywheels to last for far longer than the batteries available today.

Furthermore, the materials in the flywheel have less impact on the environment and, in principle, they can be recycled infinitely. They don't take up a great deal of space: a 30 kWh installation, corresponding to the consumption of a detached house with solar cells on the roof, is approximately the size of a small refrigerator.

However, Søren Peder Madsen stresses that there is still one significant obstacle to overcome before the technology can make a significant contribution to meeting our storage needs.

"At the moment the flywheels lose energy too quickly to be useful storage. They self-discharge far too much, but we're working on the problem, and we're aiming at making them a real alternative to modern batteries."

## Small magnets with a difficult job

Researchers in the project want to improve the technology by holding the flywheel's floating cylinder in the air with new nanomagnets, all the dimensions of which, from atomic structure level up to millimetre scale, have to be controlled with great precision. Researchers expect that this will enable them to generate storage potential for up to two days.

"We hope that we can crack the code to cheap and efficient energy storage. This is absolutely crucial if, in the long term, we're to become independent of fossil fuels such as coal, oil and gas," says Søren Peder Madsen.

He is in charge of the development of numerical methods to calculate the composition of the new materials to improve the properties of the magnets.

"We need to develop algorithms that can calculate the best material combinations in the magnets and in the flywheel. The aim is to make sure they can keep the floating cylinder in the air and, at the same time, tolerate rotating at up to 100,000 rpm. The quicker we can get the wheel to rotate inside the airtight box, the more energy we can store," he says.

Researchers from Aarhus University are working with the companies Haldor Topsøe and Sintex on developing the small magnets.

## project facts

### TITLE

Novel Magnets for Flywheel Energy Storage MAGFLY

### SCHEDULE

2017-2021

### FINANCIAL FRAMEWORK

DKK 17 million Innovations Fund Denmark

### PARTNERS

Haldor Topsoe, Sintex, Grundfos, WattsUp Power, Technological Institute Denmark

### CONTACT

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Same procedure for  $\mathcal{I}_2$  and  $\mathcal{I}_3$

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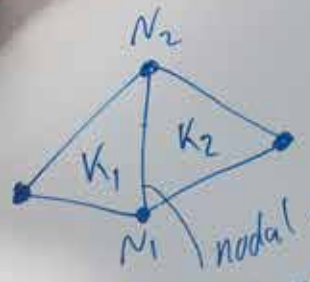
$$A \begin{bmatrix} c_0^{(2)} \\ c_1^{(2)} \\ c_2^{(2)} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$V = \alpha_1(1-x_1-x_2) + \alpha_2$$

Space of continuous functions on a  $\mathcal{K} = \{K_i\}$ ,  $V_h$ :

$$V_h = \{v \mid v \in C^0(\Omega), v|_{K_i} \in \mathcal{P}_1\}$$

Example:



nodal basis  $\{1-x_1-x_2, x_1, x_2\}$

nodal  $N_1$  or  $N_2$  complete linear basis

$$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

Advanced and efficient algorithms are needed to calculate the optimal composition of materials for the magnets that keep the flywheels rotating. And making an optimal and durable design requires highly specialised insight into fracture mechanics. The picture shows Søren Peder Madsen.





# HEALTH



# New research can put an end to allergic reactions

Researchers have found a new mechanism in which an antibody can prevent allergic reactions in a broad range of patients. It is a scientific breakthrough, which could pave the way for a far more effective allergy medicine.

There was great excitement in the laboratory when researchers from Aarhus University recently discovered the unique mechanisms of an antibody that blocks the immune effect behind allergic reactions.

The team of researchers has now described the molecular structure and mechanisms of action of the antibody, and the results are surprising.

They were hoping to find new methods to improve existing treatment, but instead they identified how a specific antibody is apparently able to completely inactivate the allergic processes.

The antibody interacts in a complex biochemical process in the human body by which it prevents the human allergy antibody (IgE) from attaching to cells, thus keeping all allergic symptoms from occurring.



## When we can remove the trigger, the allergic reaction and symptoms will not occur

Associate Professor Edzard Spillner

“We can now describe the interaction of this antibody with its target and the conformational changes very accurately. This allows us to understand how it interferes with the IgE and its specific receptors on the immune cells of the body, which are responsible for releasing histamine in an allergic reaction,” says Associate Professor Edzard Spillner.

## project facts

### TITLE

Structural, functional and clinical characterisation of anaphylactic IgE antibodies to the alpha-Gal epitope

### SCHEDULE

2015-2018

### FINANCIAL FRAMEWORK

DKK 2.5 million Independent Research Fund Denmark

### PARTNERS

University Giessen

### CONTACT

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The research results have been published in the scientific journal Nature Communications.

### Allergic effects of birch pollen and insect venom eliminated

Generally, an allergic person produces high levels of IgE molecules against external allergens when exposed to them. These molecules circulate in the blood and are loaded onto the effector cells of the immune system, which triggers the production of histamine and thereby an immediate allergic reaction in the body.

The function of the antibody is that it interferes with the binding of IgE to the two specific effectors (CD23 and FcεRI) on the immune cells, thereby making it impossible for the allergy molecule to bind.

Furthermore, the researchers have observed that the antibody also removes the IgE molecules even after binding to its receptors.



Photo: Lars Kruse

Researchers have discovered a new approach for antibody-based treatment of allergy and asthma. It is a breakthrough that could have a major impact on development of new medicine in years to come. The photo shows Edzard Spillner and his research group.

“Once the IgE on immune cells can be eliminated, it doesn’t matter that the body produces millions of allergen-specific IgE molecules. When we can remove the trigger, the allergic reaction and symptoms will not occur,” says Edzard Spillner.

In the laboratory, it took only 15 minutes to disrupt the interaction between the allergy molecules and the immune cells.

The researchers have conducted *ex vivo* experiments with blood cells from patients allergic to birch pollen and insect venom. However, the method can be transferred to virtually all other allergies and asthma.

#### Hope for better medicine

Today, one in three Europeans suffers from allergic diseases, and the prevalence is steadily increasing. The treatment options are limited, but the researchers now expect that their scientific results will pave

the way to developing completely new types of allergy medicine.

“We can now precisely map how the antibody prevents binding of IgE to its receptors. This allows us to envision completely new strategies for engineering medicine of the future,” says Assistant Professor Nick Laursen (the Department of Molecular Biology and Genetics, Aarhus University).

The antibody is particularly interesting because it is effective, and at the same time, considerably smaller than therapeutic antibodies currently used to produce allergy medicine.

“It is a so-called single domain antibody which is easily produced in processes using only microorganisms. It is also extremely stable, and this provides new opportunities for how the antibody can be administered to patients,” says Edzard Spillner.

Unlike most therapeutic antibodies already available on the market, the new antibody does not necessarily have to be injected into the body. Because of its chemical structure, it might be inhaled or swallowed, and these new consumption methods will make it easy, cheap and much more comfortable for the patients to handle.

However, before new allergy medicine can be produced, the researchers will have to conduct a wide range of clinical trials to document the effect and safety of the antibody.

## New connective tissue for the pelvic floor

Researchers at Aarhus University have got stem cells to form new connective tissue by giving them scaffolding materials to work on. There are great perspectives for treating tissue injuries such as prolapse of the reproductive organs in women.

The scaffold is thin and soft and readily breaks down in the body. This sounds like a case for the health and safety authorities, but so far the scaffold has proved to be safe and effective.

“However, we’ll have to complete many more trials before the scaffold can be used in human beings. We’re still in the process of testing it on mice and rats,” says Assistant Professor Menglin Chen.

She is in the research group, which has recently published news of an important breakthrough in stem cells to form new connective tissue by means of scaffolds built of nanofibres.

### **Connective tissue does not readily heal**

In principle, stem cells can develop into any type of cells in the body. The problem is to get them to do so on command: to

get them to create new and healthy versions of specific cells that, due to injury, illness, age or pregnancy, no longer function as they should.

“Many women injure the connective tissue in the pelvic region when they give birth. And that’s not good because the cells, which make up the main component of the connective tissue, are not good at repairing themselves when they’ve been damaged,” says Menglin Chen.

Furthermore, connective tissue weakens with age, and there are fewer and fewer of them.

Almost 20 per cent of all women – and up to 50 per cent of all women over the age of 50 – in the industrialised world suffer prolapse of the reproductive organs, because the connective tissue in their pelvic

floor is weakened.

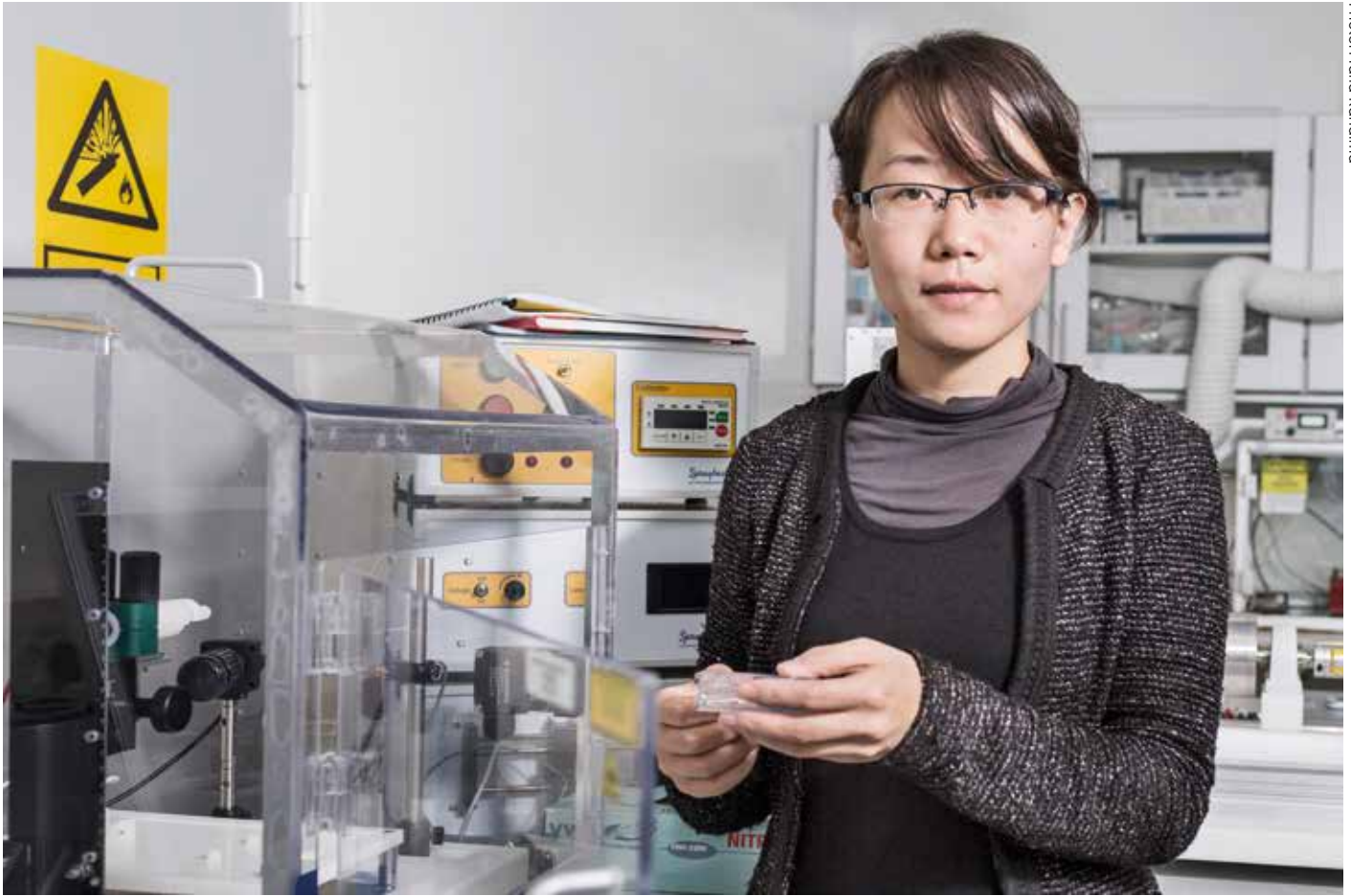
### **Fibres replace bad implants**

In addition to the general discomfort, prolapse of the reproductive organs can also lead to incontinence. Many women have an operation, but the existing options are not particularly reliable. Stitches in the weak connective tissue are not very strong, so the risk of relapse is up to 30 per cent.

Furthermore, the implants of synthetic meshes used today have in many cases proven to do more harm than good because they can easily perforate the healthy tissue. In the US, use of these meshes has resulted in tens of thousands of actions for damages.

“So it’s crucial that we find an alternative that does not damage the tissue and has





Menglin Chen is the principal architect behind the new nanofibres that can be used as scaffold for stem cells in the body.

no complications: preferably something that supports the patient's own tissue. It'd be brilliant if we could get the patient's own connective tissue cells to grow," explains Susanne Maigaard Axelsen, a consultant physician taking part in the development work at the Department of Clinical Medicine, Department of Gynecology and Obstetrics at Aarhus University Hospital.

#### **Electrospinning with great health potential**

The researchers have used electrospinning to create a scaffolding of biodegradable nanofibres that mimics the extracellular matrix – i.e. the structure that holds the cells together and supports the tissue.

The fibres have been provided with hydrogel and growth factors, which are signal molecules that initiate the processes

that cause the stem cells to develop in the direction desired.

The whole thing is as thin and flexible as silk paper (actually it looks a lot like paper) but strong enough to be sewn onto the living tissue.

"We've got the stem cells to attach themselves to the scaffold and start forming new fibroblastic connective tissue. So far, we've got it to work with human stem cells in mice and rats, but the test animals are very small and walk on four legs, so they can't be used as models for how it would work in humans. We'd like to test it on larger animals such as pigs and sheep," says Menglin Chen.

In the current case, the researchers have used normal skin cells, which, by means of genetic engineering, have been

'back-programmed' to behave like stem cells - so-called induced pluripotent stem cells (iPSC), which can be influenced to become virtually any type of cell in the human organism.

The researchers have been working closely with Coloplast on the new pelvic-floor implants. Coloplast already has sharp focus on the treatment of incontinence. The Danish Council for Strategic Research has invested DKK 10 million in the project, which has now achieved promising results.

## project facts

### TITLE:

3D Nano-biointerfaces Capture Circulating Tumour Cells for Metastasis Prognosis and Modelling

### SCHEDULE

2017-2019

### FINANCIAL FRAMEWORK

DKK 2.6 million (Danish Council for Independent Research)

### PARTNERS

Aarhus University Hospital

### CONTACT

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# Nanofiltre to remove cancer cells from blood

A filter based on a fine mesh of nanofibres might be able to remove cancer cells circulating in blood (circulating tumor cells) through simple dialysis treatment. It's a crazy idea, but if the researchers succeed, it will be a game changer in modern treatment.

When, more than ten years ago, Menglin Chen started her work on electrospinning nanofibres, not many people could see the potential in the technology. Since then, she has built up impressive knowledge in the area. In publication after publication she has documented how she can control production of the nanostructures so that they can function as scaffolds for stem cells and thus become new tissue, bones, cartilage or organs.

"In principle we can build scaffold of nanofibres for stem cells which can grow and rebuild degenerated tissue. By controlling the electrospinning process, we can design a scaffolding structure with specific mechanical and biochemical properties that make stem cells become the desired body tissue," says Assistant Professor Menglin Chen.

### Intelligent medication in a thin mesh

Menglin Chen achieved her latest scientific breakthrough when she succeeded in loading nanofibres with drugs and different types of growth factors that could then release under external stimuli.

"Active delivery makes the technology interesting in a wide variety of biomedical contexts. We work with light- and heat-responsive molecules and this means we can control the release of drugs through illumination and by adjusting the temperature," says Menglin Chen.

In experiments on pigs, researchers can cure a slipped disc by inserting a small plug of nanofibres into the spinal column. A precise dosage of growth factor in the area makes it grow, so that it gradually lifts away the tissue pinching the nerve roots.

Assistant Professor Chen is also investigating the possibilities of using the same technology for patients with constriction of the arteries, to maintain an optimal flow of blood and minimise the risk of blood clots.

The nanofibre scaffold with drugs looks like thin pieces of mesh. The material is biodegradable and dissolves in the body as the new tissue is formed.

### New approach to cancer treatment

The next major scientific venture with electrospinning is for cancer treatment. Menglin Chen has received a new grant of several million DKK from the Danish Council for Independent Research to design a nanofiltre with antibodies on the surface that can capture circulating tumour cells in the blood.

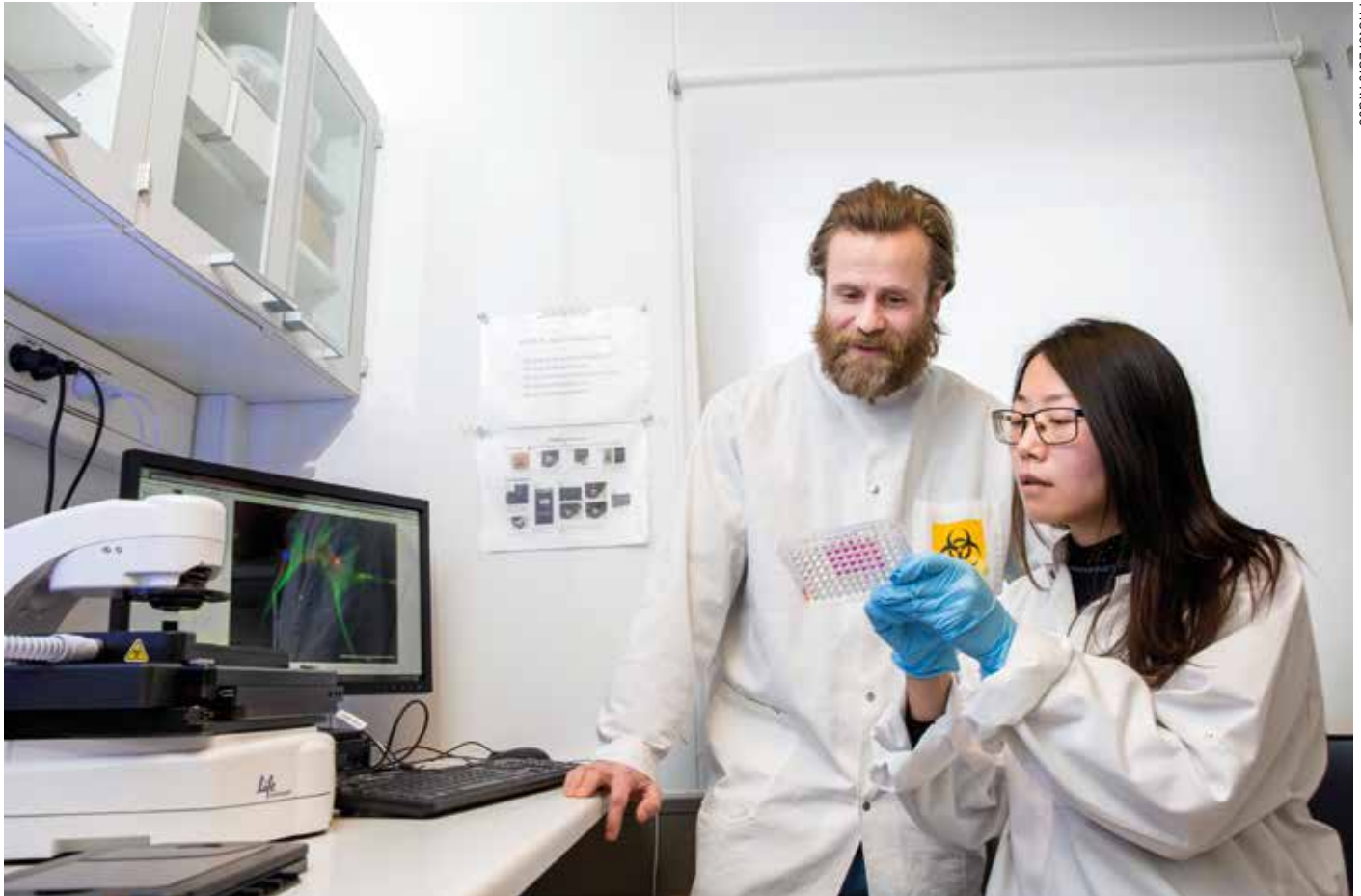


Photo: Lars Kruse

Perhaps it doesn't look much like high technology. But it is. Researchers use electrospinning to design nano fibres. Now they want to develop a mesh that can filter out tumour cells circulating in the blood. The photo shows Menglin Chen and Mathias Lindh Jørgensen.

Some may think it's a crazy idea. However, she has brought together a team of the world's leading oncologists and researchers from the best laboratories, and they have great expectations for the technology.

"The quest for the dangerous tumour cells in the blood stream has so far been like looking for a needle in a haystack because they circulate between millions of blood cells. Now, we are modifying the surface of our nanofibres with antibodies that recognise cancer-specific changes in cells' surface structure," says Menglin Chen.

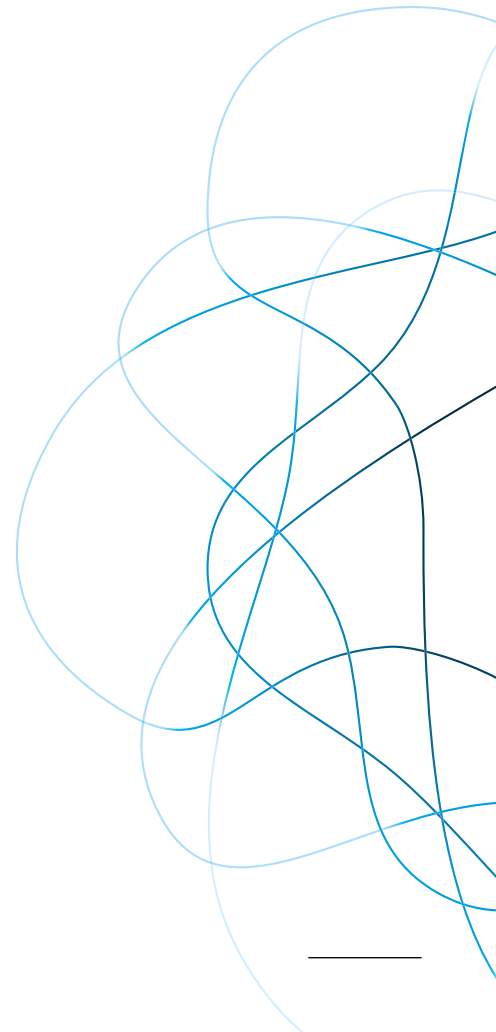
The plan is to do a sort of dialysis in which all the blood from a cancer patient is led through the electrospun nanofilters, which work by catching the cancerous cells and

letting the healthy cells pass through.

The researchers are still very uncertain about the extent to which it is possible to clean the blood, but at all events, there is great scientific value in being able to study closely in the laboratory the development of the circulating cancer cells.

"If we can catch the dangerous cells, we can cultivate them in the laboratory and obtain new knowledge about how they grow and develop new tumours (metastasis). This could provide new opportunities to differentiate patient treatment," says Menglin Chen.

She is conducting her research in close collaboration with Aarhus University Hospital.





## LED brain implants to fight Parkinson's disease

Aarhus University researchers have launched a multi-million euro project that aims to use wireless micro-scale implants inside the living brain to cure movement disorders using LED light.

.....

With a European Union (EU) grant of more than DKK 28 million, researchers aim to enter the living brain with micro-robotics in a treatment that could have a monumental effect on curing movement disorders like Parkinson's disease in the future.

The project is called STARDUST, and it uses wirelessly controlled microscopic implants that illuminate selected brain neurons with LED light and even carry an internal drug delivery system. This is something that has never been done before.

"Until now, electrical stimulation in the brain has affected all neurons in the targeted area. With this project, we can target individual neurons using optogenetics with a completely wireless micro-scale device," says Associate Professor Farshad Moradi.

## project facts

### TITLE

STARDUST

### PARTNERS

Humboldt University of Berlin (Germany), University College Cork (Ireland), National Centre for Scientific Research – CNRS (France), Vlaams Institute for Biotechnology – VIB (Belgium), Biomedics ApS (Denmark), Spinverse Innovation Management OY (Finland), Federal University of Pará (Brazil), Fraunhofer Society for the Promotion of Applied Research (Germany).

### BUDGET

EUR 3.8 million from H2020 – FET Open

### CONTACT

Associate Professor Farshad Moradi;  
moradi@eng.au.dk



Lighting up neurons with tiny LEDs, Associate Professor Farshad Moradi hopes to modulate brain circuit in order to cure a wide range of diseases.

### Massive impact

The tiny device is just 200 cubic micrometres in size. If successful, it will be very versatile, since it will be able to modulate brain circuit activity with artificial light, deliver drugs and record signals from the target brain cells. Power supply comes from harvesting energy from ultrasonic waves using a piezoelectric device.

“The main challenge is to provide the tiny device with sufficient energy using ultrasonic waves. That is why we have to use very, very low-power electronic chips and very efficient materials,” Associate Professor Moradi says.

**We can target individual neurons using optogenetics with a completely wireless micro-scale device**

Associate Professor Farshad Moradi

The project was launched on 1 October 2017 and will run for four years. STARDUST is funded by the prestigious Future and Emerging Technologies (FET) actions, under Horizon 2020 – the EU Framework Programme for Research and Innovation.

“This project, if it proves successful, could have a massive impact on the future clinical treatment of a wide variety of disorders – not just movement disorders, but also diseases like brain cancer,” says Farshad Moradi.

# New earplug will tell us more about sleep disorders

By inserting a small computer in the ear, researchers can wirelessly monitor brain activity while we are asleep. They are now conducting a comprehensive clinical study to find new answers to how doctors can optimise treatment of sleep disorders.

Sleep disorders are far more widespread than most people think. It is reckoned that at least 40 per cent of Danes suffer from a sleep disorder to such an extent that it affects their health and quality of life. Sleep disorders cost society billions, but we know very little about why the problems arise and how we can treat them.

For many years, doctors at Danish sleep clinics have been using so-called polysomnography measurements to diagnose the most seriously affected patients. This takes place using EEG equipment which, via electrodes stuck to the patient's head and face, measures voltage fluctuations in the cerebral cortex for a defined time period corresponding to one night.

The method is accurate, but it has the major disadvantage that it must be carried out at a hospital. A successful night monitoring requires at least eight electrodes on the patient's head and four on the face, which is wrapped in gauze to secure the equipment and the wires. This is both an intrusive and expensive method of diagnosis, as Professor (Docent) of Engineering Preben Kidmose explains:

"It goes without saying that the equipment disturbs the patient's sleep and measurements may therefore differ significantly from the patient's average sleep patterns. Our ear computer can measure with the same accuracy, but it doesn't disturb sleep, and it offers completely new opportunities to improve the qual-

ity of intervention studies. At the same time, it goes without saying that you can save time that currently goes to fitting the equipment on patients and then manually reviewing the results."

Professor (Docent) Kidmose has spent a large part of his research career on developing the technology, which now makes it possible to detect and decode the signals from the brain through the ear.

## First long-term studies of sleep

The earplug used by the researchers in the clinical trials contains miniature electrodes to measure and collect signals from the brain. It is powered by an external magnetic field and therefore has very low electricity consumption. Therefore, the device works without a battery, which means it can operate for a long time. In principle, researchers can therefore carry out continuous monitoring of human brain activity for weeks and perhaps even months.

"Long-term monitoring enables doctors to obtain a detailed insight into the nature of sleep disorders and thereby a better basis for recommending relevant treatment with behavioural therapy or drugs. We can see how phases of sleep take over from each other, and we can map out where the system is muddled," says Professor (Docent) Kidmose.

Another research benefit from replacing the conventional EEG systems with dis-

crete, comfortable and wireless technology is that measurements can be taken outside the clinic in patients' everyday surroundings.

Over time, sleep disorders break down our cognitive functions, and the researchers hope that the technology will be a tool for doctors to conduct more accurate diagnoses and treatment.

## Mental disorders can perhaps be treated better

The new method for long-term sleep monitoring could also pave the way for new knowledge about psychiatric diseases where patients often have severe sleep complications. Today, we assume that poor sleep patterns are induced by the diseases, but we don't know for sure. The causality has never been reported in the literature.

"This opens up for a fascinating research field. We can now study relationships between mental disorders and sleep patterns, and we can investigate whether specific types of sleep disorders are linked to specific diseases. At the same time, we have an objective way to measure the effect of a given treatment," says Professor (Docent) Kidmose.

Concurrently with the clinical trials, researchers will try to develop a number of algorithms capable of translating the signals from the brain to valuable informa-



Monitoring brain activity through the ear can give doctors completely new insight into the phenomenon of sleep. Professor (Docent) Kidmose is behind technology that in years to come will have a major impact on diagnosis and treatment of patients suffering from sleep disorders, and the consequences of these.

tion about sleep in its various phases. This will make it possible for a computer to automatically score the individual patient's sleep and efficiently present long-term measurements for doctors.

"Every phase of sleep is characterised by some specific patterns in the electrical signals that the tiny electrodes in the ear pick up and identify. This enables us to say something about what the individual patient's sleep cycle looks like and how the patient moves through the sleep phases down into deep sleep," says Professor (Docent) Kidmose.

Deep sleep, where electrical activity in the brain is characterised by very slow oscillations, is particularly important for

well-being. In the long term, the researchers hope that doctors will be able to use ear measurements to treat mentally ill patients, because they will have better opportunities to plan relevant sleep interventions for the individual patient.

## project facts

### TITLE

Ear-EEG Sleep Monitor (EESM)

### SCHEDULE

2017-2021

### FINANCIAL FRAMEWORK

DKR 26 million

### PARTNERS

Widex A/S, UNEEG medical, T&W Engineering, Aarhus University Hospital, Zealand University Hospital

### CONTACT

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## Gel technology to minimise the risk of premature birth

Premature birth is the most common cause of death among infants worldwide. Danish researchers are therefore working on a very special project that will make it possible to identify women at risk long before their child is born.

Approx. 60,000 babies come into the world every year in Denmark. Around 4,000 of them are born prematurely, i.e. before the 37th week of pregnancy. Even though this has no impact on the vast majority of these preterm newborns, the risk of complications is greater if the birth is extremely early.

About 200 babies are born extremely early in Denmark every year. And these extremely premature infants, who come into the world more than 12 weeks before the expected birth date, usually weigh less than 1,000 grams. This means there is a significant risk of complications, brain damage or even death. In fact, premature birth is the leading cause of death for children under the age of five worldwide.

A significant reason why some women give birth prematurely is to be found in the biomechanical properties of the cervix. Researchers are therefore working on a project in collaboration with Aarhus University Hospital, Randers Regional Hospital, and others to quantify these properties and thus predict women at risk of preterm delivery.

### Soft as velvet

"Back in the 1980s, it was discovered that the hardness of the cervix is proportional to the risk of giving birth prematurely. And actually there is a great difference in this hardness from person to person - one cervix can be soft as velvet, while another may be hard as granite. The softer cervix is correlated with increasing risk of giving

birth prematurely. Conversely, a very hard cervix can make it difficult to give birth naturally at all. We're trying to quantify the hardness of the cervix with a special gel we've developed, because it's actually very difficult to measure," says Associate Professor Mogens Hinge.

The gel is used in combination with elastography, a special medical ultrasound technique that assesses the rigidity and the elasticity of human tissue. For instance, elastography is used to diagnose cancer, as a cancerous tumour is often harder than the surrounding tissue.

"If you suspect a tumour in the breast, for example, you can use elastography to measure the hardness of the tumour. You compare the hardness of the tumour with the surrounding adipose tissue, which you already know the elasticity and hardness of. But there isn't any adipose tissue in the anatomical region surrounding the cervix, and therefore there isn't any reference material to scan," explains Christine Rohr Thomsen, a PhD student and doctor from the Department of Obstetrics and Gynaecology at Randers Regional Hospital.

The project therefore involves using the gel as the missing reference material by applying it as a cover on the ultrasound scanner before measuring the stiffness of the cervix.

### Very promising technique

"Today, the hardness of the cervix is meas-

ured using the fingers of doctors and midwives. This doesn't give a particularly precise picture of the hardness, and it is a very difficult technique to use before pregnancy as a screening method for risk of premature birth. Therefore, we can't really find out about the risk of giving birth prematurely in advance, when we would otherwise be able to take action with preventive measures," says Christine Rohr Thomsen.

Although the project has not yet been tested on humans, the results, so far, look very promising, says Mogens Hinge.

"We hope that, using this technique, we'll be able to predict problems caused by a very soft or hard cervix long before the child is even conceived."

If they succeed, the opportunities to plan pregnancy and thereby avoid preterm births due to reduced biomechanical strengths of the cervix will be much improved, adds Christine Rohr Thomsen:

"Premature birth is the most common cause of mortality among children around the world, and it's also responsible for some extremely expensive admissions and results in huge socio-economic costs. Many of these children lie in intensive care for a long time, and a nurse is assigned to each child. It's also a very tough start for the new parents and not least for the baby, so there's a lot to gain by knowing the risk in advance and being able to take early preventive measures," she says.





## project facts

### TITLE

Gel for ultrasound imaging

### PARTNERS

Aarhus University Hospital  
Randers Regional Hospital  
Massachusetts Institute of Technology

### CONTACT

Associate Professor Mogens Hinge;  
hinge@eng.au.dk

Associate Professor Mogens Hinge from the Department of Engineering at Aarhus University and PhD Student and doctor Christine Rohr Thomsen (left) from the Department of Obstetrics and Gynaecology at Randers Regional Hospital are developing a special screening technique, that can identify women at risk of premature birth problems long before the child is even conceived.

# PRECISION AGRICULTURE



## Laundry washing air: new technology to significantly limit emissions from animal housing

Researchers are close to a copper-based solution to significantly limit sulphur emissions and odours from animal housing. The new technology could have a major impact on the environmental challenges facing the farming industry.

It's hard to avoid unpleasant smells when you move around in the countryside, so it's not surprising that obnoxious odours from emissions of ammonia and hydrogen sulphide are one of agriculture's most pressing environmental challenges.

In fact, livestock production is currently responsible for a great deal of the air pollution in Denmark and therefore, since 2017, a team has been working on the Ecometa project, the purpose of which is to measure and limit emissions from modern pig and cattle housing units.

The team has just reached a golden milestone in their endeavours to limit emissions. They've managed to develop a new and improved technology to clean the air, and they've come up with an air scrubber that uses copper ions to remove foul-smelling hydrogen sulfide from the air.

"In our quest for an efficient air-cleaning process, we've discovered that copper ions dissolved in aqueous solution react surprisingly efficiently with volatile sulphur compounds. Contrary to our initial expectations, the copper used in the process doesn't precipitate, but can be regenerated and reused to serve as a catalytic reagent," says Postdoc Pernille Kasper.

### Can also remove odours

In existing air-cleaning systems based on microbial oxidation in a water phase or in a biofilm surface, for example, the poor water solubility of hydrogen sulphide and organic sulphur compounds inhibits a

high removal efficiency. However, copper ions react so fast that the reaction overcomes this limitation.

"A further advantage of the process is that, in addition to hydrogen sulphide, it removes certain smelly organic sulphur compounds called thiols, which are challenging for both biological processes and existing chemical scrubber processes. The new process can be built into a so-called air scrubber, which typically consists of a support material onto which the reactive solution is sprinkled. The solution is exposed to the polluted air as it trickles through the support material, and due to the fast reaction, the gaseous sulphur compounds are transferred to the solution and degraded," says Associate Professor Anders Feilberg, who is heading the project.

Current research activities aim at achieving a better understanding of the reaction mechanisms and product formation, and this will enable optimisation of the process and its application in full scale.

### Far cheaper than previous tech

The process will also be applicable for reducing sulphurous odorants emitted from biogas plants, wastewater treatment plants and sewer systems. As a part of the Ecometa project, the air-cleaning process will be tested in full scale at a commercial pig farm in collaboration with the Danish company, Agrifarm.

In addition to developing a prototype purification plant, the team is also working on

monitoring ammonia vapours and odours.

"We're developing some new measuring methods to control the technology and reduce ammonia emissions. We're currently working on three different sensors that can all measure ammonia emissions from livestock housing far more cheaply than previously," Associate Professor Feilberg says.

### Streamlining operations

Today, Danish livestock housing is granted environmental approval to produce a certain number of animals depending on the production area of the housing. Approval does not take into account the actual emissions.

The purpose of the project is to provide farmers with an opportunity to monitor emissions continuously, and thereby produce a time-resolved image of the pollution situation. The project will also open up for the possibility to regulate farms based on actual emissions.

"If farmers are able to carry out accurate monitoring of ammonia and sulphur emissions from animal housing, they'll be able to streamline their operations. Moreover, if they can clear the air of ammonia at the same time, and even collect it for fertilising purposes, they'll also be able to significantly reduce their environmental impact. That's the scenario we hope to achieve in this project," says Anders Feilberg.

## ***project facts***

### **TITLE**

ECOMETA (Emission Control: Methods and Technologies for Agriculture)

### **FINANCIAL FRAMEWORK**

DKK 17.4 million  
Innovation Fund Denmark,  
Grand solutions

### **SCHEDULE**

2017-2020

### **PROJECT PARTNERS**

SEGES  
Agrifarm Innovation Aps  
Infuser Aps  
Wagening Livestock Research

### **CONTACT:**

Associate Professor Anders Feilberg;  
af@eng.au.dk



Associate Professor Anders Feilberg (left), Erling Friis Pedersen, CTO at Agrifarm, and Postdoc Pernille Lund Kasper (right) standing in front of the towering air scrubber at a farm north of the city of Aarhus, Denmark.

# Agriculture contributes to the atmosphere's sulphur content

For the first time, researchers can determine the atmospheric content of sulphur caused by animal manure. A new study demonstrates that hydrogen sulphide from animal manure accounts for about one third of the total Danish sulphur emissions to the atmosphere.

Present emission inventories and climate models do not consider agricultural production as being a significant contributor of atmospheric sulphur. A recent study from Aarhus University proves that this assumption is wrong. Agricultural emissions of sulphur cannot be neglected and may be very important in areas with intensive livestock production.

The study was recently published in the scientific publication Nature Communications.

Livestock manure emits sulphur mainly in the form of hydrogen sulphide, which is quickly converted into sulphur dioxide in the atmosphere and thus has the same impact. The study further shows that in areas with a high livestock density, sulphur from animal manure accounts for about half of the known sulphur emissions (in the form of sulphur dioxide) to the atmosphere. This means that hydrogen sulphide from animal manure accounts for approximately one third of total Danish sulphur emissions to the atmosphere.

It may seem strange that the significant contribution of atmospheric sulphur from agriculture has been overlooked. Howev-

**The agricultural contribution has not been included in the climate models so far, and in the global perspective, this new knowledge will contribute to improving climate models**

Associate Professor Anders Feilberg

er, only few and very limited studies exist within this area, in Denmark as well as in other countries.

This is partly due to the difficulties of measuring sulphur emissions from livestock production, explains Associate Pro-

fessor Anders Feilberg. He is one of the researchers behind the study.

"The development of PTR-MS (proton-transfer-reaction mass spectrometry) allows us to monitor the emissions of sulphur compounds from livestock production very accurately and with a high time resolution, which provides extensive and very detailed data material," says Associate Professor Feilberg.

In principle, PTR-MS acts as an online molecular balance, measuring the weight and number of atmospheric molecules.

#### **New opportunities to limit emissions**

In the atmosphere sulphur and other substances form chemical compounds and produce harmful particles.

Based on this, recent years have witnessed significant efforts to reduce the atmospheric sulphur content. For obvious reasons, focus has been on well-known sulphur emission sources – primarily oil, coal and natural gases, which emit sulphur to the atmosphere via combustion engines, power stations, etc.

This study provides new opportunities to



Associate Professor Anders Feilberg climbing the towers of the air scrubber that uses copper ions to remove hydrogen sulfide from the air.

increase the focus on reducing sulphur emissions from livestock production.

The studies demonstrate that hydrogen sulphide emissions are caused mainly by slurry evaporation from pig and cattle houses. In addition, there is a minor loss in relation to storage and slurry distribution.

Aarhus University currently carries out research that is targeted towards the development of air purification technologies for animal housing, and technologies to reduce the evaporation from animal manure. These technologies will contribute to reducing sulphur emissions.

However, Anders Feilberg points out that emission of hydrogen sulphide from livestock production has a close relation to the emission of ammonia. Action plans for improved utilisation of nutrients in animal manure will therefore contribute to reducing emissions of hydrogen sulphide.

#### **Affecting climate models**

This new knowledge is important to the development of climate models. As mentioned previously, sulphur becomes part of chemical compounds and forms airborne particles. These particles reflect the rays of the sun, which in turn helps reduce global warming caused by climate gases. At the same time, the particles contribute to cloud formation, which increases reflection.

"The agricultural contribution has not been included in the climate models so far, and in the global perspective, this new knowledge will contribute to improving climate models," he says.

Yet, there is a need for more measurements in more countries before the significance in a global perspective can be clarified.

#### **CONTACT**

Associate Professor Anders Feilberg;  
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## A watchful eye on the self-driving tractor

Researchers have equipped a self-driving tractor with stereo vision and artificial intelligence, so it can very accurately identify foreign objects in the field and thereby significantly increase safety.

At Aarhus University, farming has for a number of years been a learning lab – an ‘experimentarium’ – for specific applications of artificial intelligence. Here the researchers feed supercomputers with data, and train them to recognise patterns so they achieve a power of analysis, interpretation and judgement that can exceed the human ability to solve advanced tasks.

It is concerned with a phenomenon known as the artificial neural network, where advanced algorithms get machines and robots to learn correlations and act autonomously. This is actually a

crucial step on the way to efficient farming with self-driving machines.

“Via deep convolutional neural networks, we teach the computer to analyse large amounts of visual information in the form of image data sets, so it eventually becomes capable of recognising visual characteristics such as a person, a house, a cat or a cow,” says PhD Student Peter Christiansen.

The technology has enormous potential, and the researchers can now demonstrate that the method could make driverless tractors safer than their human-controlled counterparts.

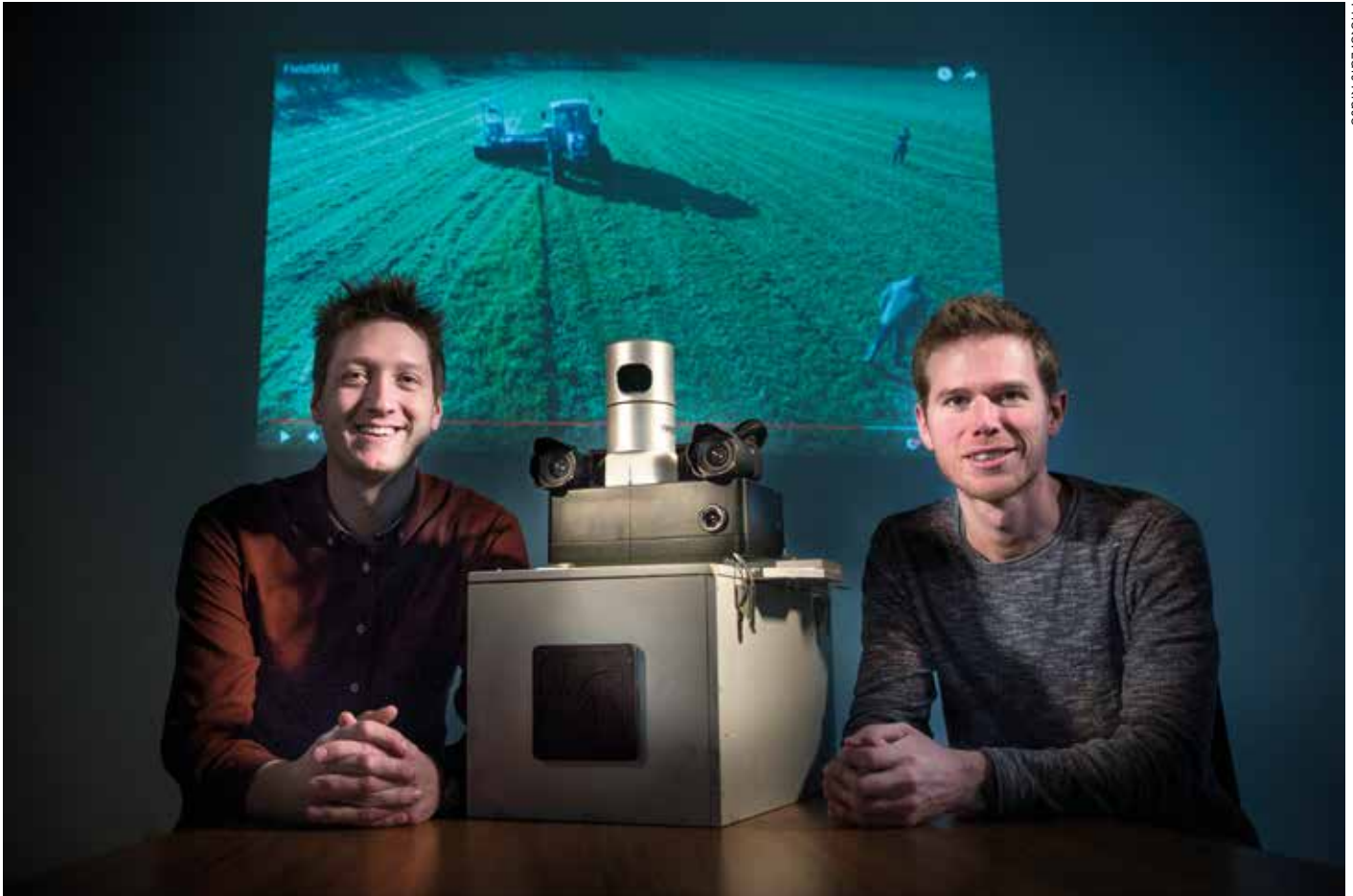
### **Sees 700,000 dots per second**

At the experimental stage, the researchers have equipped an ordinary tractor with a stereo camera, a thermal camera, a radar and a LiDAR, and these enable it to carry out 700,000 distance measurements per second and reproduce them in a 3D representation of the surroundings.

In this way, the tractor can identify obstacles in the field and spot specific objects without human intervention.

“The machine itself now interprets visual and geometrical information from the field at a level where even a very percep-





Peter Christiansen (left) and Mikkel Fly Kragh have trained a computer to register hazards on a field and then send a message to the tractor about the most appropriate speed and direction. In the long term, the same method could also make driverless cars safer.

tive farmer might give up," says PhD Student Mikkel Fly Kragh.

The researchers working on the project have built further on an existing neural network with an algorithm that can differentiate between 1,000 classes of objects. They have fine-tuned this so it can also identify unspecified objects that do not belong in a field.

"When the tractor drives across the field, it identifies different objects or elements in the image. This way, it registers the normal environment such as grass, trees, sky and bushes, and it activates the neurons in our network in a particular way. The computer recognises these usual neural activations and can therefore react if the activation deviates from the known pattern," says Peter Christiansen.

#### Artificial brain finds danger in the field

The tractor can thus not only see that a person is approaching, but can also see whether an unknown object turns up. This

is a crucial step as regards making the technology safe," explains Peter Christiansen.

"What's special about our scientific work is the algorithm that can take unforeseen objects into account in the field. This could be a situation where a child playing in a snowsuit and balaclava is hidden by the crops, which would be difficult for the computer to recognise in the human category. In this case, the tractor with our system would have a chance to react to an unknown object and prevent running the child over," he says.

The mathematical work behind the algorithm is quite complicated, and it can get the tractor to spot objects such as people in the field at a greater distance than is possible with existing safety software for autonomous vehicles.

## project facts

#### TITLE

SAFE - Safer Autonomous Farming Equipment

#### SCHEDULE

2014-2018

#### FINANCIAL FRAMEWORK

29 million DKK, Innovation Foundation Denmark

#### PARTNERS

Kongskilde Industries A/S (project owner), Aarhus University, KeyResearch ApS, CLAAS Agrosystems, Conpleks Innovation ApS, University of Southern Denmark, Innovationsnetværket RoboCluster

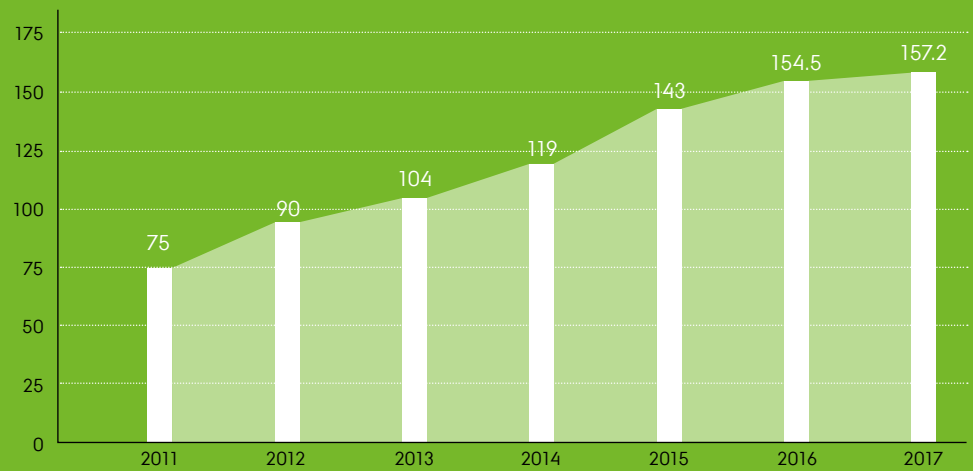
#### CONTACT

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# KEY FIGURES

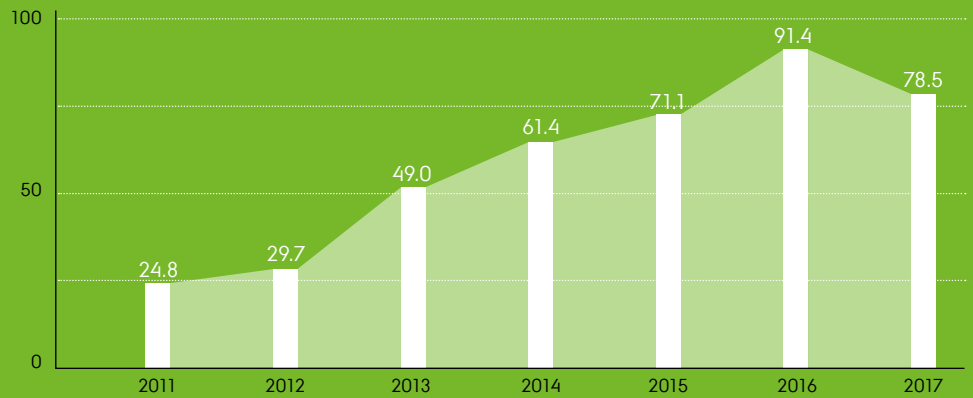
## TOTAL ENG TURNOVER (M DKK)

Based on annual FC3 budget

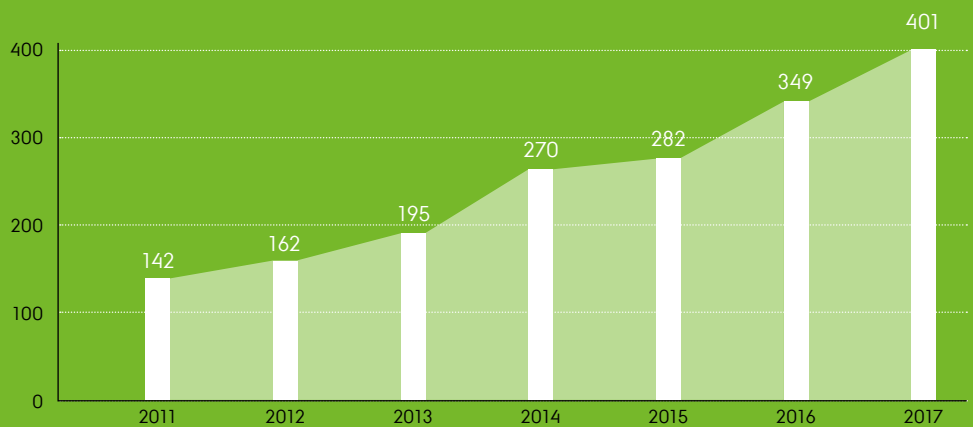


## EXTERNAL FUNDING TOTAL (M DKK)

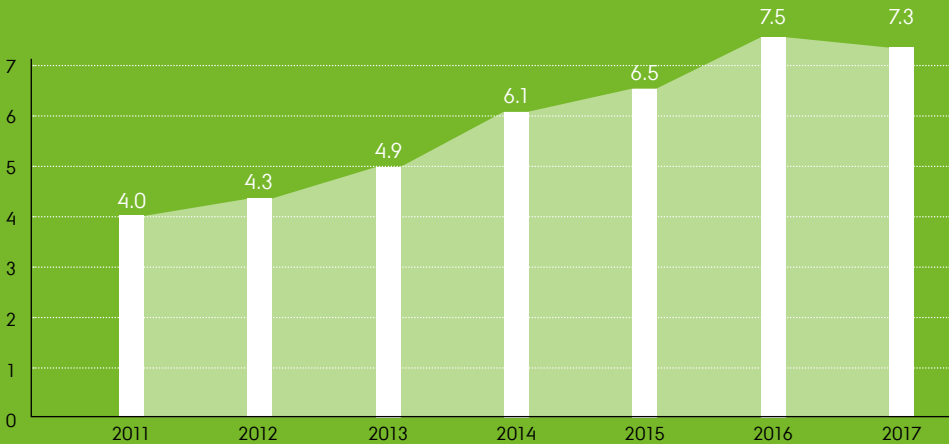
Based on annual FC3 budget



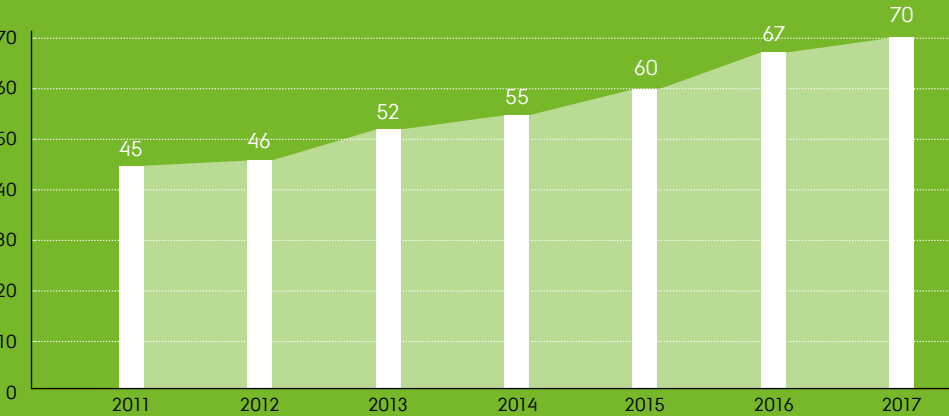
## PEER REVIEWED PUBLICATIONS



PEER REVIEWED PUBLICATIONS PER VIP

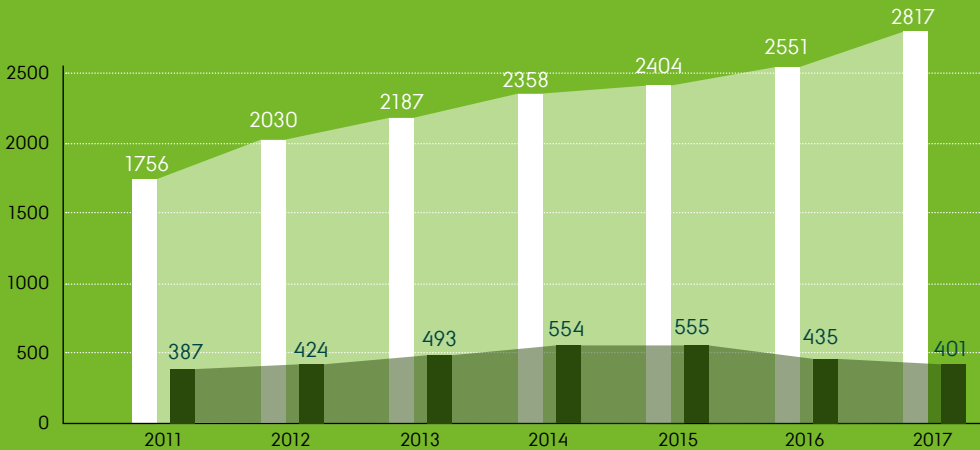


ENGINEERING PHD STUDENTS



ENROLLED ENGINEERING STUDENTS

■ BACHELOR  
■ MASTER





*Katrinebjerg Campus with the University Park and Navitas in the background.*





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