DTU

DTU Chemical Engineering
Department of Chemical and Biochemical Engineering

Annual Report 2022

CO2 capture facility at Aalborg Portland A/S. The plant will be at Alborg Portland until the autumn autumn 2023 and will then be installed at the Skærbæk biomass plant for testing during 2024.

Philip Loldrup Fosbøl

Contents

Collaboration is key in our pursuit of solutions to global issues

A part of the vision of the Department of Chemical Engineering is to be an attractive partner for research-based industry as well as support development of sustainable solutions in the fields of chemistry, biotechnology, food, pharma and energy through research and research-based consultancy. This permeates everything we do.

Our pursuit of solutions beneficial to society requires solid collaborations with industry. From the consortium model which is an industry-academia collaboration where members receive networking opportunities and state-of-the-art methods and tools for chemical and biochemical engineering to multi-partnerships where several partners from both academia and industry join forces on large projects. We also give industrial partners access to our equipment for the benefit of both partners and the department researchers.

A range of collaborations are reflected in this year's annual report. You can read about how DTU Chemical Engineering, SaltPower and Danfoss have joined forces to take a new green energy source to the next level and how our collaboration with 21st.BIO opens new frontiers in automated fermentation. Members of the KT Consortium explain why thermodynamic modeling is essential in developing renewable energy and sustainable use of resources and in an eleven partner EU Horizon project we aim at solving the question about the transportation of captured CO_2, by pipeline or ship?

In 2022 we welcomed a new advisory board consisting of leading members of the research-based industry covering the matrix that encapsulates the department's research areas, namely product and process design as well as production across chemistry, food, pharma, and energy. They represent vital expertise in bringing our department forward at a time of many challenges within climate, sustainability, lack of energy resources and global health.

Global health is at the center of Professor Anne Skov Ladegaard's research in artificial muscles and controlled medicine release. She received two prestigious prizes for her work this year, the Elite Research Award, and the Grundfos Prize. Anne Ladegaard Skov is a splendid example of how an education and career at DTU Chemical Engineering can bring you to the forefront of innovation and research that potentially can end up having a significant impact on people's lives.

After a quiet 2021 due to the Covid-19 pandemic, life returned to the department in 2022. Besides all our students, over 40 guest researchers from all over the world visited the Department and 82 American college students took part in our Summer University.

This year we once again broke our high set goals for attracting grants. This is apparent evidence of the department's prominent level of research and bodes well for 2023 as we continue to solve societal challenges and contribute to pushing the boundaries for sustainable solutions in close collaboration with the research-based industry.

Kim Dam-Johansen
Professor, Head of Department

Kim Dam-Johansen
Professor,
Head of Department

Christian O. Carlsson

EDUCATION

352
STUDENTS*

13
SINO-DANISH STUDENTS*

24
COMPLETED
BSC PROJECTS

32
COMPLETED
BENG PROJECTS

83
COMPLETED
MSC PROJECTS

RESEARCH

219
SCIENTIFIC ARTICLES IN
WOS-INDEXED JOURNALS

14
CONTRIBUTIONS TO BOOKS
AND REPORTS

25
PHD DEFENCES

* Based on STÅ. One STÅ is the equivalent of one student studying full time in a year.

INNOVATION

10

NOTIFICATIONS OF INVENTION

ORGANIZATION

277

EMPLOYEES IN TOTAL

58

TECHNICAL /ADMINISTRATIVE EMPLOYEES

79

RESEARCHERS / SENIOR RESEARCHERS

41

VISITING GUESTS RESEARCHERS

33

FACULTY MEMBERS

107

PHD STUDENTS (INCLUDING 6 INDUSTRIAL PHD'S)

Thermodynamics as a framework for technological transition

Industry members of the KT-Consortium: Thermodynamic modeling needs to have a stronger position when it comes to renewable energy and sustainable use of resources.

Thermodynamics is the science of the interactions between energy and matter. While many of the pioneering works of thermodynamic modeling were done with a view to either upstream or downstream hydrocarbon applications, the field is equally relevant in many of the transitional technologies which currently sweep across society.

This is the main point of an opinion paper where Professor Georgios Kontogeorgis, leading the KT-Consortium, participates. The paper is an example of the KT-Consortium being a vehicle for industry-academia collaboration.

One consortium member company is Neste corporation headquartered in Finland. Coming from a history of crude oil refining, Neste has expanded its range of starting materials to include renewable feedstocks.

"Crude oil refining is tricky in many respects. Still, introducing renewable feedstocks does add a new level of complexity. This highlights the importance of the thermodynamic models as well as their further development. If the quality of your model is poor, the results are not to be trusted, the business case is not met, and ultimately the risk of both safety hazards and environmental damage will increase," says Dr. Susanna Kuitunen, physical properties, and thermodynamics expert in the process modeling team of Neste. She represents Neste in the KT-Consortium, and she is a co-author of the opinion paper.

The goal is predictive tools

The opinion paper is entitled "A view on the Future of Applied Thermodynamics "(published in Industrial & Engineering Chemistry Research). It builds on two surveys carried out in 2010 and 2020, both by the Working Party on Thermodynamics and Transport Properties of the European Federation of Chemical Engineering (EFCE).

"As thermodynamics specialists we do possess an expertise which is key to practically all the current trends be it transition to renewable energy, electrification, manufacturing through fermentation etc. Thermodynamics is just a very good framework for addressing these issues," says Dr. Antoon ten Kate, Principal Scientist at Nouryon, and co-author of the paper.

"We must face the fact that many – even some of our engineering colleagues in other fields – find thermodynamics very difficult. Therefore, we cannot assume that they automatically aspire our views. We need to be ready to actively pursue involvement, acknowledging that we are in a unique position to make statements about which are the key issues to address," Antoon ten Kate continues.

Nouryon is a leading producer of essential chemistry in the manufacture of everyday products such as paper, agrochemicals, building materials, and personal care items. Products are mainly sold business-to-business. The company is a long-standing member of the KT-Consortium, and Dr. Ten Kate has attended several Annual Meetings of the consortium, representing industry in its Advisory Board.

"Personally, I have always found collaboration between industry and academia important. Our role as industry will be to name the issues that are important, allowing researchers to work on solutions relevant to practice. We will also do our own research, obviously, building further on these developments."

"Further, I would say that in this context we need to maintain the triple collaboration with software providers being the third corner of the triangle besides academia and industry. Typically, the software providers make the methods available to industry that were originally developed at the university."

Dr. Antoon ten Kate, Principal Scientist, Nouryon
Christian O. Carlsson

As for the commercial software products and the software developed in KT-Consortium, Antoon ten Kate is happy about the level of activity but still sees plenty of scope for further development:

"E.g., what we would really love in industry is predictive tools. In other words, that we can envision for instance a manufacturing process and simulate reliably what will happen even before we engage in experiments. Some progress has been made in that direction, but we are not there yet."

Dr. Jean-Charles de Hemptinne of IFP Energies Nouvelles (IFPEN) Christian O. Carlsson

A learning process going both ways

Another opinion paper co-author is Dr. Jean-Charles de Hemptinne of IFP Energies Nouvelles (IFPEN), France:

"We see a trend in society towards renewable energy forms, recycling of materials etc. As chemical engineers we have a lot to offer, since thermodynamics is an essential element in the development of all these fields. Coming originally from oil and gas exploration and use, we are broadening our scope to encompass for example new energy sources (bioresources, wind or geothermal energy), carbon capture and storage technologies, energy storage technologies (hydrogen economy, gas storage in salt caverns or batteries) and increasingly the circular economy (recycling of polymers or metals). These applications require processes in sometimes extreme conditions, and therefore an advanced understanding of thermodynamic modeling tools."

"It is exciting to see how we as chemical engineers are able to contribute to energy transition and ecological transition," Jean-Charles de Hemptinne continues, mentioning geochemistry as an example:

"Traditionally, equations of state are not much applied to geochemistry, but to a chemical engineer it seems obvious that they should be. On the other hand, geochemists have a large body of data on equilibrium reactions with minerals, which lie beyond our expertise but are essential. So, this is a learning process which goes both ways."

Increasing responsibility for academia

Ioannis Economou is Professor of Chemical Engineering at Texas A&M University, USA, at Qatar. He too co-authored the opinion paper:

"To my mind, the most important thing is that we as thermodynamics researchers continue to work closely with industry. Recent years have seen a trend where the industry thermodynamics groups are shrinking. For instance, several of the large international energy corporations have reduced the sizes of their groups. Instead, companies are relying more on university collaborations. This is a nice thing for us on the academic side. You might even say that this is a natural division of work. But it also increases our responsibility when it comes to assuring that our projects are relevant to the industrial practice."

Assuring industrial relevance is not always straightforward, Professor Economou continues:

"In general industry tends to focus on achieving results within a short time horizon. This demand is not easy for us to meet. Research takes time and especially when it is done with students who also have other responsibilities with courses. Thus, we constantly need to balance considerations over academic versus industrial relevance."

Ioannis Economou has been associated with the thermodynamics group at DTU Chemical Engineering for more than two decades:

"Since Denmark is a small country, its implementation of new sustainable energy

Ioannis Economou is Professor of Chemical Engineering at Texas A&M University, USA, at Qatar
Christian O. Carlsson

systems and industrial processes may not in itself have that much impact on a global scale. Still, by setting an example in these areas I believe the impact is actually very significant worldwide."

Keen on electrolyte systems modeling

To Dr. Susanna Kuitunen of Neste, the work in KT-Consortium on new software for property assessment and thermodynamics modeling is especially interesting.

"Neste was founded in 1948, so before the emergence of computers. Thus, I cannot say that the company has always applied thermodynamic modeling, at least not with the help of software tools. I had a colleague, now retired, who remembers that distillation columns were sized with manual calculations before computers became available. However, those calculations were also based on the thermodynamic principles. But soon after relevant software was introduced, and developed in-house, Neste came onboard and ever since thermodynamic modeling has played a strong role," says Susanna Kuitunen.

She further notes the current research in KT-Consortium on software for thermodynamic modeling of electrolyte systems.

This research is anchored in the project "New Paradigm in Electrolyte Thermodynamics," funded by the European Research Council (ERC) and headed by Professor Georgios Kontogeorgis, DTU Chemical Engineering.

"At this point the research is focusing on fundamentals and I do appreciate how much the involved scientists commit to sharing their results," Susanna Kuitunen comments.

"Qualitative understanding might help us immediately, for example, in the planning of experiments or interpretation of the observations from the laboratory and full-scale setups. But for the actual technology development and process design, we use simulators. Thus, I hope that among the developed or tested models the best ones are implemented into the commercial simulators or made available as plug-in solutions together with parameter databanks or parameterization guidelines."

Dr. Susanna Kuitunen, Neste Christian O. Carlsson

Interviews for the article were made during the KT-Consortium Annual Meeting 2022 held June 6-10 at the Comwell Borupgaard conference center in Snekkersten, Denmark.

Danish industry opinion on green transition

Headquartered in Copenhagen, Calsep provides consulting services, PVT (Pressure, Volume, Temperature) and flow assurance software to the energy sector. With offices in Houston, Dubai, and Kuala Lumpur the company is active across four continents.

"It is positive that the modeling framework from the oil and gas exploration and production can be used in the green transition, for instance to simulate transport and injection of CO_2. Later, the requirements to accuracy may increase, but what we have now seems to be good enough to get started," says Henrik Sørensen, R&D Manager & Senior Principal Consultant at Calsep.

Calsep was founded in 1982 with oil and gas applications as the main the focus. However, new assignments have appeared, says Henrik Sørensen:
"One aspect is to get rid of CO_2, another is to find alternative fuels. H_2 may be next in line, and it appears that the modeling framework from the oil and gas exploration and production can be used as it can for CO_2. It is good if the industry does not have to invent or adapt a new modeling framework as it could reduce the pace and incentive in pursuing the green transition."

The company name is derived from CALculation of SEParation processes. With a background in physical chemistry and liquid physics, founder Karen Schou Pedersen aimed to expand the use of compositional simulation techniques for reservoir fluids in the energy industry. The fact that Aage Fredenslund and Peter Rasmussen, both Professors at DTU Chemical and Biochemical Engineering, were co-founders, underlines the importance the thermodynamic expertise at DTU had on the company.

Collaboration opens new frontiers in automated fermentation

Recent biotech developments enable production of protein through fermentation. Danish-American company 21st.BIO and DTU join forces to achieve economies of scale.

Biotech company 21st.BIO is on a mission to enable protein production in a more efficient and sustainable manner. The company works with fermentation-based methods to replace the traditional animal-based food proteins and materials currently made from fossil fuels. As of late 2022, the Danish-American startup began testing at the Pilot Plant facilities of DTU Chemical and Biochemical Engineering.

"Protein production in farm animals has been optimized through thousands of years, and it will just not be possible to optimize much further to feed the growing population in this way without dramatic consequences for the climate. In my mind, there is only one solution: recent biotech developments enable us to produce any given protein through fermentation at reasonably competitive cost," says Per Falholt, Chief Scientific Officer of 21st.BIO.

The company name refers to one of the main challenges of the 21st century: how to feed the growing global population in a sustainable manner. Also, the name carries a nerdier implied message: much like astronomers used to debate whether Pluto should count as a planet or not, there is an ongoing argument in the biotech community on the possible classification of selenocysteine as the 21st proteinogenic amino acid.

Proteins produced in large quantity

With active R&D groups and labs in Copenhagen and USA, 21st.BIO works with clients on establishing fermentation-based manufacturing of various proteins for consumption and materials. While the details cannot be disclosed at this point due to client confidentiality, Per Falholt can give a broad outline:

"We are talking about proteins which are currently produced in farm animal systems at huge bulk quantities. On the one hand side, this equals a large market opportunity for our products, but on the other hand it is obvious that we need to be extremely focused on cost minimization, since these markets are very sensitive to even minor fluctuations in price."

"Directly and indirectly, conventional farming is massively subsidized. Farming is currently not charged for the negative impacts on climate and environment, such as massive emissions of greenhouse gasses, water consumption and land use. Currently, by fermentation we can produce milk proteins with about 20% of the carbon input, and an equivalent reduction in CO_2 emission. To compete with the subsidized traditional farming, we need to optimize our methods of production even further. The collaboration with the KT Pilot Plant is one of the routes to achieve that."

Digital twins and online sensors

The collaboration has a dual scope, explains Associate Professor Ioannis Skiadas, DTU Chemical and Biochemical Engineering:

21st.BIO supported PhD student Vroni Czotscher planning new experiments with supervisors Ioannis V. Skiadas and Seyed Soheil Mansouri both associate professors at DTU Chemical Engineering.
Christian O. Carlsson

"Firstly, the company will use our facilities for their own purposes, meaning actual production of certain proteins. This will be according to terms negotiated with the DTU administration and subject to strict regulation on IPR (intellectual property rights, ed.). Secondly, we will have a range of research and development collaborative projects. This is obviously our main interest as scientists."

The DTU researchers will recruit PhD students and supply co-supervision for projects of interest to 21st.BIO. The PhD students will be able to publish their results in the open scientific literature.

For example, the research and development collaboration will involve digital twins for fermentation processes, and development of new equipment for online monitoring.

"Current methods typically rely on analyzing samples at the end of a fermentation process. We want to be able to sample during the processes, analyze, and adjust the process accordingly without having to stop the experiment. Also, we want to develop new online sensors as an addition to sampling," says Ioannis Skiadas.

"We are confident that the methods and technologies developed in these projects will go beyond the setup of 21st.BIO and be of interest to other companies in the Danish biotech sector and beyond. Thereby, the work will benefit Danish industry in a broader sense and ultimately the Danish society."

Automation will be key to survival

To 21st.BIO, the importance of developing new technologies for monitoring fermentation processes can hardly be overestimated, says CSO Per Falholt:

"Automation will be the key to our survival as a company. While we do have ample opportunities for optimizing our current setups, this will not bring about the revolution we need to be truly competitive against conventionally produced food proteins, and materials based on fossil fuels. Instead, we must improve the manufacturing of fermented products to a new level through new equipment with a high degree of automation and digitization. Notably, these should be integrated allowing for automated collection of production data, analysis, and adjustments. In this manner, we will be able to save months relative to current production and R&D cycles."

"Fortunately, the timing is perfect as the various technologies we need have reached a high degree of maturity. By implementing them we will be able to learn much faster, and ultimately be able to reduce the price of our end products to competitive levels," Per Falholt concludes while noting that much more than the survival of the young company is at stake:

"Ultimately more efficient and affordable fermentation processes will be the answer to the challenge of feeding the growing global population."

Ioannis Skiadis, Assistant Professor
Seyed Soheil Mansouri, Assistant Professor

An initial duration of three years

Dictated by the duration of PhD projects, the collaboration between 21st.BIO and the Pilot Plant facilities of DTU Chemical and Biochemical Engineering is set to run for three years. "But surely we hope this to be just the beginning of a longer collaboration," says Associate Professor Ioannis Skiadas of Pilot Plant. He coordinates the Pilot Plant participation jointly with Associate Professor Seyed Soheil Mansouri who coordinates the participation from PROSYS center at DTU Chemical and Biochemical Engineering.

Anchoring innovative bio solutions

The collaboration between 21st.BIO and DTU Chemical and Biochemical Engineering is one of many partnerships under the umbrella of the Biosolutions Zealand initiative. Funded by the Danish Board of Business Development and the EU, the initiative has a budget of 60.4 million DKK for the advancement of green growth projects on Zealand and the Danish islands. Biosolutions Zealand is anchored at DTU Chemical and Biochemical Engineering. Associate Professor Seyed Soheil Mansouri, PROSYS, coordinates in collaboration with Associate Professor Ioannis Skiadas, Pilot Plant.

"DTU Chemical Engineering and 21st.BIO are part of a larger mission in establishing a fermentation-based scale-up infrastructure in Kalundborg. This mission is supplemented by 2 PhD projects co-funded by Biosolutions Zealand project as well as establishing a new MSc education in Kalundborg in close collaboration with industry to develop the industry in the area," says Christian Beenfeldt, Project Director at Knowledge Hub Zealand, Biotech City.

The full-scale measurements behind green transition

Replacing fossil fuels with biomass and waste in industrial processes is highly desirable but often challenging from a chemical engineering point of view.

“We have had active collaborations with many companies over the years, and the demand continues to grow. This is to a large part due to the new challenges faced by industry as it seeks a transition to more sustainable energy sources,” says Peter Arendt Jensen, Senior Researcher in the CHEC research center.

A major focus area in CHEC is chemical engineering principles applied in combustion, emission control, gasification, and catalysis.

“Our activities include lab scale and pilot scale experiments, advanced modeling, and computer simulations, for instance by using Computational Fluid Dynamics including chemical kinetics – to simulate full scale multi-phase reactors. However, some problems are best investigated by combining the simulations with full-scale measurements carried out under everyday operation,” explains Peter Arendt Jensen.

He coordinates many of the collaborative projects, which involve full-scale measurements on-site.

“That doesn’t mean I will always be active in the measurements. We are some ten employees – engineers, PhD students and technicians – who divide our time between the various projects.”

An engineering project in its own right

Often the solution will involve the construction of a probe – a device with instruments – to be inserted into the actual industrial process, for instance in a furnace or an industrial reactor. The probes are typically water cooled to withstand the harsh environment.

In the hall of building 228 at DTU, Peter Arendt Jensen demonstrates a probe. The core of the probe is a long steel tube. The roughened surface bears witness of hours of exposure to high temperatures under real-life industry conditions. The probe system is used for measuring of ash deposit formation in boilers.

“Development of the probe will most often be an engineering project in its own right,” the senior researcher notes.

The probe was recently deployed at a waste to energy plant in collaboration with Babcock & Wilcox Renewable. At the plant a novel method to reduce corrosion is investigated. The distinguishing feature of the new technology is recirculation of captured sulfur. This will favor formation of alkaline sulfates over alkaline chlorides in the boiler, which in turn will lower the risk of corrosion.

“The downside, however, may be the formation of a harder type of ash deposits on the

Senior Researchers Sønnik Clausen and Peter Arendt Jensen with the probe used in the ProBu project for laser measuring of gas velocities in the Rockwool melting cyclone. The measurement takes place approx. 5 cm in front of the tip. The probe is water-cooled to protect the optics and fibre optics since the temperature in the cyclone is 1,600-2,000 °C. Christian O. Carlsson

boiler walls. This is unwanted, and we hope to be able to assist the company in finding the optimal conditions, thereby minimizing the problem," says Peter Arendt Jensen.

"Many clients want to use biomass or waste derived fuel instead of fossil fuel. The companies have come a long way in this direction, but it is still needed to research for further improvements," he says.

Biomass as fuel for cement production

Similar challenges face the cement industry. Producing cement without high carbon dioxide emissions is presently not possible without carbon sequestration. However, the industry does have possibilities for substituting the traditional fossil energy sources with biomass and waste and thereby obtain some significant reduction.

Through a collaboration with the cement technology equipment manufacturer FLSchmidt, the CHEC researchers did full-scale measurements at a cement plant in Ireland operated by Mannok.

"The collaboration with FLSmidth and Mannok addresses a range of topics related to use of waste derived fuel for cement production. We are looking at how to obtain a full incineration of the fuel, how to keep the formation of ash deposits at an acceptable level, how to avoid migration of unwanted substances from the waste into the cement, etc. Further, controlling formation of nitrogen oxides is an area of focus", Peter Arendt Jensen comments.

Tracing particles inside a boiler

In another project with Babcock & Wilcox Renewable, the CHEC researchers develop advanced measuring technology able to visualize the various flows occurring in the boiler.

"Technology able to measure key properties in the boiler do exist, but typically they are limited to single-point measurements. So, when you want to have a more comprehensive flow overview, you need to move your point of focus to several different locations, and measurements soon become difficult to manage. We have developed a visualizing technique which avoids this laborious exercise."

In the novel technique, a light plane is established inside the boiler whereafter a cloud of particles is injected into the boiler. The movement of the particles within the light plane is then traced – and the results obtained used to improve the plant operation.

Not an off-the-shelf service

This example is another illustration of the fact that full-scale measurements is rarely an off-the-shelf service.

"As a university, we can only accept projects which involve research. We do have projects which are classified as acquired research, meaning the company gets exclusive rights to data and pay accordingly. But for most projects – like the collaborations with FLSmidth and Babcock & Wilcox Renewable – we do keep the rights for the research data, and we are able to openly publish scientific articles based on these data," says Peter Arendt Jensen, noting that the mentioned projects have been co-funded by public agencies, namely Innovation Fund Denmark and the EUPD. The latter program is operated by the Danish Energy Agency.

"This type of research is costly and public co-funding is imperative and, notably, justified in view of the large societal interest in greening industrial processes," says Peter Arendt Jensen.

Peter Arendt Jensen, Senior Researcher
Sønnik Clausen, Senior Researcher

Measurements under extreme conditions

State-of-the-art cyclone melting technology take the temperature during production of rock wool to very high temperatures above 2,200°C. Through a collaboration with ROCKWOOL International the researchers at DTU Chemical and Biochemical Engineering have set an unofficial world record by studying the processes in full-scale.

"We and others have previously studied the output gas and products at the furnace outlet, but to the best of our knowledge we are the first to be able to follow the events inside the melting cyclone in full scale as they happen," says Senior Researcher Sønnik Clausen from the CHEC research center. The measurements have included imaging of the internal processes as well as laser-based velocity measurements, gas composition and spectroscopic temperature measurements.

Next level testing of anti-corrosive coatings

Not many academic research groups are able to say that their work has led to radical changes in the procedures of a well-established ISO standard. A collaboration between scientists at the CoaST center, DTU Chemical and Biochemical Engineering, and the Technological Centre (CTC), Spain was initiated in 2018 to achieve just that. Notably, the standard which has been challenged is widely used in industrial and academic research and development.

"The coatings society needs faster and non-destructive test methods," says Technical Manager, PhD Claus Erik Weinell, CoaST. With more than 16 years' experience from the coatings industry he knows how time and resource demanding it is to develop new coating systems based on the current pre-qualification test protocols. ISO 12944 describes how a manufacturer of anti-corrosive coatings should verify the properties of the coating for limiting so-called rust creep. In other words, how well the coating performs in inhibiting the progress of corrosion from a damaged area.

"The current procedure laid out in ISO 12944 has several drawbacks which can be avoided through modern technical solutions. We have demonstrated a way to get results faster, thereby saving valuable research and development time in both academia and industry. This may lead both to large economic savings in testing, and ultimately to coatings of a higher quality," says Assistant Professor Huichao Bi from CoaST.

According to the World Corrosion Organization, the annual global cost of corrosion amounts to 2.5 trillion USD. Equivalent to 3-4 % of global GDP, the figure highlights the importance of having reliable anti-corrosive coating systems.

For CoaST, the marine industry is a main area of focus. Not only hauls of vessels, but also ballast tanks and several other types of onboard installations are at risk of corrosion. The same goes for related industries such as offshore wind turbines, offshore hydrocarbon production platforms etc.

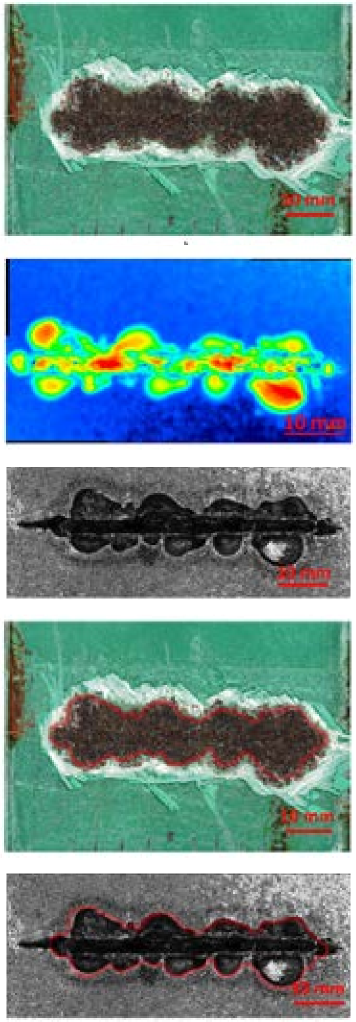
"The coating industry faces demands to develop more sustainable products. A lot of progress is made in this direction. However, it is imperative that the improved sustainability does not come at the cost of poorer anti-corrosive properties. Therefore, the demands for effective, reliable, and fast testing of the new innovations are high," explains Huichao Bi.

In theory, the best way to test new coatings would be to expose relevant materials with coated surfaces to real-life conditions for the expected life span of the coatings. However, coating developers obviously do not have the luxury of waiting that long. Modern anti-corrosive coating systems will if they remain intact during the service life maintain a high performance for 10-15 years, and sometimes even 25 years.

Instead, samples are subject to accelerated testing. They are exposed to even more corrosive conditions than in normal use, and defects are deliberately induced to stress the coatings. These trials results in scores for the new coating candidates.

According to ISO 12944, rust creep is assessed by measuring the progress of rust from a scribe line after removal of the degraded coating around the scribe. After 25 weeks, the progression – the creep – of the corrosion is measured in nine points across the sample. These nine measurements are averaged to give a resulting figure for rust creep.

In contrast, tests are now done using a combination of scanning acoustic microscopy (SAM) and 3D profilometry. In these trials, no coating is removed from the sample. Rather than measuring in nine positions, the researchers can do as many measurements as they desire, and they can do so throughout the entire dura-



a)
b)
c)
d)
e)

Figure Demonstration and a comparison of rust creep assessment by a destructive method according to ISO 12944 and two non-destructive methods (3D Profilometry and SAM) – an example, rust creep assessment of a coated sample after exposure testing: a) Optical image, according to ISO 12944-9 after coating removal around the artificial scribe; b) 3D Profilometry topography without coating removal; c) SAM image without coating removal; d) & e) Overlapped images of the line map of b) with a) and c), respectively. ** Figure adapted from Fig. 3 in [*]
[*] Huichao Bi, Claus Erik Weinell, Raquel Agudo de Pablo, Benjamín Santos Varela, Sergio González Carro, Álvaro Rodríguez Ruiz, Kim Dam-Johansen, Rust creep assessment - A comparison between a destructive method according to ISO12944 and selected non-destructive methods, Progress in Organic Coatings, 157 (2021) 106293.

tion of the trial period rather than at the end.

"The main drawback of the current test regime for rust creep is the destruction of the sample. Once the coating is removed you cannot make any modifications. In other words, each prepared sample will only yield one set of results. In contrast, the methodology which we advocate is non-destructive. Thereby, you can acquire as many data sets from each sample as you desire," the Assistant Professor notes.

"And further, as coating is not removed from the sample, we have the opportunity of following the development regarding loss of adhesion through the trial period. This is obviously not possible when the coating has been removed."

Another advantage is the time horizon

"Often you may see after a short period that some problem exists. If you see early degradation, there is no reason to wait 25 weeks before adjusting. Also, the current demand for presenting results as an averaged value of nine measurement points is not ideal from a research point of view. An average may conceal individual problematic measurements. In our methodology, the individual measurements are included in the presentation. Moreover, you can have a much higher number of measurements than the currently required nine," argues Huichao Bi.

"So, to summarize, we have shown a way to cut measurement time drastically without compromising accuracy. To the contrary, our methodology provides more reliable results, and allow new possibilities for coating researchers and developers."

"Now, ISO standards are not changed overnight, but as we disseminate our results through scientific papers and conference presentations, still more in the community realize the advantages of our approach. At the very least it is fair to say that we are challenging the current practice."

The collaboration on corrosion testing

This project on non-destructive methodology for rust creep assessment was developed in a collaboration between CoaST (The Hempel Foundation Coatings Science and Technology Centre) at DTU Chemical and Biochemical Engineering and the Technological Centre (CTC), Spain. CTC is a private not-for-profit foundation, recognized as a Technological Centre by the Ministry for Economy and Competitiveness.

Teresa Bi, Assistant Professor
Claus Weinell, Technical Manager

Christian O. Carlsson

Strengthening soft robotics

Tailor-made polymers connected to a power supply can replicate the labor carried out by human muscles. The challenge is to increase the power to levels that may, for instance, improve the everyday life of people recovering from illness or accidents.

Imagine a person with reduced muscle strength putting on a shirt with built-in artificial muscles. This may become reality a few years from now, according to Professor Anne Ladegaard Skov, DTU Chemical and Biochemical Engineering.

"In our labs we have developed artificial muscles strong enough to lift a strawberry, or even a small apple. But to become commercially interesting they need to perform somewhat better. If, for instance, a person barely able to lift his or her own arms can suddenly lift two bags filled with groceries just think how much this would improve quality of life."

How is the magic done? Anne Ladegaard Skov shows a di-electric silicone elastomer sample in size and shape much like the tiniest weight stick you might find in your fitness center. The polymer sample bends or stretches easily, and it feels very much like a relaxed human muscle. Due to the di-electric properties, the sample will bend or extend when voltage is applied. The amount of movement can be controlled through the voltage level and is fully reversible. This is much like the way electric signals from the brain triggers movement in our muscles.

Next generation pacemakers

Notably, the strength of the artificial muscles can be varied for a person under rehabilitation.

"Possibly you would not want the devices to do all the work for you. You might want your own muscles to take part for training purposes. And gradually you can change the ratio, so your own muscles lift more as they become stronger," says Anne Ladegaard Skov, continuing:

"This is not just relevant for patients under rehabilitation. We all become weaker as we get old and will at some point be inclined to want a bit of help. Also, a market is likely to emerge for people who have normal muscle strength but may still want some relief for instance because they have a physically demanding job."

On top of this comes entirely different applications:

"Take pacemakers as an example. These devices have become very advanced, when it comes to the main challenge of controlling the heart rhythm of the patient. However, many patients also have a secondary problem, which is lack of sheer muscle power of the heart. Imagine a dual function pacemaker that could both keep the right pace and deliver additional power through an artificial muscle."

High safety requirements

What does Anne Ladegaard Skov see as critical for achieving the desired increase in strength of the artificial muscles?

"Well, since we are looking at devices that are in close contact with the body, or even implants, the safety requirements are obviously high. On the one hand, the materials need to be soft and biocompatible. On the other hand, we need materials, which are very stable, so they do not break due to the repeated contractions. Stability is also key to avoid short-circuits. I can say from personal experience that the typical voltage level we currently operate at, about two kilovolts, while not dangerous may still give you a very unpleasant experience."

Therefore, the critical task ahead is to develop materials, which meet both the stability and biocompatibility requirements.

"This will take a highly cross-disciplinary research effort over the coming years."

The research is anchored at the Danish Polymer Center (DPC) that is led by Anne Ladegaard Skov but will include groups outside the center and even outside DTU Chemical and Biochemical Engineering, not to mention industry partners.

"As a chemical engineer I find it very natural to engage in such broad collaborations. The polymer research is the core but many other disciplines such as electronics, physics, and mechanics are essential to get the necessary results," says Anne Ladegaard Skov, adding that this is not just about development:

"We still have a range of basic research issues to tackle."

Early approach from venture companies

As an example, Anne Ladegaard Skov mentions a polymer material developed in another project. The polymer in question performed well in the lab and seemed to have all the right properties but failed once being worn for several months by subjects during a real-life trial.

"This goes to show that many issues remain to be understood even for someone like me who has worked in the field for more than 20 years. Of course, experience will help you. Sometimes you just know that a given solution will work, but you cannot explain why. As a scientist, you want to be able to understand the mechanism behind your innovation. Not only because this is fulfilling but also because this is often the foundation for further breakthroughs."

Given the huge market possibilities, no wonder the research of the professor and her colleagues receives wide attention. Both the Independent Research Council and the Novo Nordisk Foundation (NNF) have provided generous funding, allowing the work to continue for at least the next four years. In addition, no less than three venture companies have shown their interest.

"This was a bit surprising since the research is still basic. Normally you must come close to commercialization and put in a lot of effort in attracting venture capital. Here, we were approached before we even had a prototype ready," Anne Ladegaard Skov notes, smilingly.

Model of commercialization remains to be found

Besides the obvious market potential in the soft robotics field, the personal track record of Anne Ladegaard Skov in entrepreneurship may have played a part in the interest of venture companies. She has been involved in three startup companies during her career. Will she have a fourth go to commercialize artificial muscles?

"That may well be, but it is too early to say. We still have four years left on the research project funded by NNF, and things can evolve in different directions. My feeling is that the potential is large, but whether commercialization should happen through collaborations with existing industry or through startups is not clear at this point."

Anne Ladegaard Skov, Professor

Soft robotics

Unlike classic robots, soft robotics are made from soft and compliant materials, and thus has a smoother interaction with humans or can be used for implantable devices due to their compatibility with soft tissue. Soft robotics often rely on very thin materials, e.g., elastomers in thickness of less than 0.1 mm, and upscaling is not simple but sometimes requires independent innovations. The soft robotics era thus requires scientists involved in materials science, chemical engineering, production technologies, and other disciplines involved throughout the maturation from lab curiosity to commodity product.

Targeting the full value chain of carbon capture

All aspects - capture, utilization, storage, and not least transportation – are important to protect the climate through carbon capture.

Through several decades and regardless of fluctuations in the political interest in the field, the researchers in AT CERE (Applied Thermodynamics, Center for Energy Resources Engineering), DTU Chemical and Biochemical Engineering, have been active in carbon capture. Today, as many nations, including Denmark, see carbon capture as an important element in climate change mitigation, AT CERE is active in all the subdisciplines of the field.

For many years, the abbreviation was CCS – for Carbon Capture and Storage. In recent years, CCUS has come to dominate, with the added U for Utilization. Still, yet another letter – T for Transportation – should be added to give the full picture. This is according to Professor Nicolas von Solms:

"Since we are looking to lower carbon emissions quite soon, it is not realistic to imagine that the captured carbon can be utilized as raw material in large scale. Thus, storage is necessary. Further, it is well established that the economy in carbon capture is much better when you target high-emission sources such as power plants and large industrial facilities. These installations are rarely located near feasible geological sites for storage. So, how to best transport the CO_2 to the storage sites has become a crucial issue for the overall feasibility of carbon capture."

CO_2 transportation: pipeline or ship?

Due to their long-standing involvement and expertise, Nicolas von Solms and Associate Professor Philip L. Fosbøl were invited to participate in an ambitious European project. Eleven academic and industrial partners from six European countries are building a world-leading plant for capture of CO_2 at the Arcelor-Mittal steel factory in Dunkirk, France. The project is called "DMX Demonstration in Dunkirk" (or "3D" for short). DMX is a carbon capture technology patented by IFP Energies Nouvelles, overall coordinator of the 3D project.

The total budget of the 3D project is 19.3 million euro, of which the European Union's research and innovation program Horizon 2020 has supplied 14.8 million euro.

"While most of the budget is dedicated to the development of the capture plant itself, a part of the financing will be for development of transportation solutions. This is our main scientific interest," explains Nicolas von Solms.

"Since many nations share the same challenge of capture, transport, and storage of CO_2, it will not be rational for each project or capture facility to develop their individual logistics solution. This would be a waste of taxpayers' money."

Still, there may be more than one solution to the challenge, he notes:

"In the 3D project, we are considering three alternative sites for storage in The Netherlands, UK, and Norway respectively. Since the Dutch location is not that far from Dunkirk, it could be feasible to establish a pipeline for the CO_2 transportation. But if Norway is chosen as the storage site, building a pipeline would be way too expensive. In this case, it would be necessary to liquify the CO_2 and establish transportation by ship."

The pressure of a reservoir changes over time

Currently, various ideas for both pipelines and seaborne CO_2 transportation are in play.

Transporting CO_2 through a pipeline will require a very large compressor to provide the necessary pressure, but this is possible. However, in the case of CO_2 storage one faces an additional challenge. Initially, the pressure inside the targeted geological formation – for instance a depleted oil field or a saline aquifer offshore – will be significantly lower than the pressure of the transport stream.

"We are maybe talking about transportation at 120 bars and an internal pressure in the geological structure of 50 bars. These are good conditions for pumping the CO_2 into the underground. But gradually the pressure of the reservoir will rise as CO_2 is injected, and it will become more costly to create the pressure difference needed to inject more CO_2. For how long will it be feasible to continue? We will need to look very carefully at the economy here," explains Nicolas von Solms.

Similar issues are addressed for the transportation of liquified CO_2 by ship:

"Currently the standard recommendation for this type of transport is to keep your CO_2 under a pressure of 15 bars. However, the quantities which are transported today are much lower than in a future carbon capture scenario, and the issue has not been addressed from a large-scale optimization perspective. If we can lower the pressure to 7 bars, large amounts of steel for tanks and pipes can be saved and the overall feasibility will be significantly improved."

Christian O. Carlsson

On top of these issues comes other technical considerations:

"Captured CO_2 will not be pure. Thus, you will need some level of "polishing" as it is called in the technical terminology before you either send your CO_2 through a pipeline or prepare it for liquification. Also, it is desirable to avoid having more than one phase in your stream. These specifications need to be worked out carefully. And again, with huge amounts of CO_2 in the future system, small optimizations can be crucial to the overall feasibility."

From bachelor projects to extensive involvement

How did the involvement of AT CERE in carbon capture begin more than 20 years ago?

"It started a bit by chance," Nicolas von Solms recalls.

"At that time carbon capture didn't have much political attention, but we had an idea for a simple absorption column. We found a cheap way to get it tested through a couple of bachelor projects. Using the state-of-the-art amine MEA (mono-ethanolamine, ed.) for capture of CO_2 from artificial flue gas, we could demonstrate that we had an ideal set-up for testing the performance of solvents. These results were noted internationally, and we were invited to take part in an EU program called Interact."

The European funding allowed for a new so-called wetted wall column to be developed and constructed in the lab in addition to the first column in the main hall of building 228 at DTU. The equipment allowed the DTU researchers to test many new techniques. For example, the performance of the enzyme carbonic anhydrase in carbon capture.

"We were able to show that a combination of small amounts of carbonic anhydrase and the amine solvent MDEA (methyl diethanolamine, ed.) were performing as well as the baseline MEA. This was very encouraging and surprising since use of MEA had been optimized over many years."

This and other scientific results allowed AT CERE to continue participation in all European programs which came after Interact, even though Denmark did not devote much funding to carbon capture research for several years.

"Norway, USA, UK, China, and other nations became the leaders in carbon capture. I think it is fair to say that Denmark arrived a bit late to the party, but in recent years this has all changed," says Nicolas von Solms.

Contributing to full-scale implementation

Coordinated by Philip L. Fosbøl, AT CERE researchers are today active in a range of Danish carbon capture projects. These include mobile demonstration units at the Amager Resource Center (ARC) and at biogas plant Hashøj with several others planned. Further, a large project under the national research and development program Innomission has just kicked off.

In the European perspective, a project demonstrating a new electricity-based carbon capture technology in Denmark, Greece, and Romania has recently been initiated. Philip L. Fosbøl coordinates the AT CERE participation. Also, he and Nicolas von Solms continue their involvement in the 3D project in Dunkirk.

Together, all these activities contribute to the coming full-scale implementation of carbon capture both in Denmark and in a wider European context, Nicolas von Solms summarizes:

"Being chemical engineers, we are not strangers to having medium or even full-scale implementation in mind. But since we are university researchers, we also insist that we should be concerned with the basics. Demonstrating a technique is fine, but we also want to understand what goes on. Which fundamental parameters are involved, and how are the kinetics performing? Knowing the answers to these questions is not just an academic exercise. This will be crucial for later upscaling of the processes, which is very relevant in the case of carbon capture."

Nicolas von Solms, Professor

Strong bio-chemical invention goes pilot scale

Patented by DTU, the first biogas upgrading technology that binds CO_2 into a valuable biochemical has been scaled up and will be ready from 2023.

Industry with sugars in their by-product streams can expect to be approached by partners in a European collaboration with participation from DTU Chemical and Biochemical Engineering.

"Since we have developed a technology which produces both biomethane and succinic acid, the business case for companies with sugary by-product streams is promising. An additional advantage is capture of CO_2," says Professor Irini Angelidaki, head of the Bioconversions group (or BioCon for short) at DTU Chemical and Biochemical Engineering.

Succinic acid is an important industrial platform chemical with applications in a wide variety of polymers. The feedstock for production of succinic acid has traditionally been crude oil.

"It is not new, that succinic acid can be produced from renewable feedstock through fermentation of sugars and CO_2. However, previous attempts to commercialize this have failed possibly because the raw materials, typically glucose and addition of CO_2 source, were too costly. The innovation patented by DTU utilizes sugar from industrial by-product streams and integrates CO_2 capture from biogas, resulting in biomethane production, thereby adding value, and reducing the cost of raw materials," explains Irini Angelidaki.

A flexible microorganism

In Denmark and many other countries, production of biogas from agricultural waste streams, household waste etc. is well established. The value of the gas can be significantly improved by removing its content

Pilot installations for the biosuccinic acid production from sugar containing side streams J. Enrique López de los Mozos

of CO_2 which will result in (bio-)methane. The upgrading will add to costs, but this is balanced in the patented process since the captured CO_2 is used as a raw material in the production of succinic acid. The succinic acid is produced through fermentation with *Actinobacillus succinogenes* as the active microorganism.

In collaboration with Aristotle University in Greece, and a range of industrial partners, BioCon has taken the invention to pilot scale.

In the ongoing trials, the partners are utilizing a by-product stream from a candy producing company.

"The microorganism has been adapted to the industrial by-product stream, and to tolerate high sugar content, in collaboration with DTU Biosustain. A high concentration of carbohydrates is advantageous, since we then get a high concentration of succinic acid in the fermentation broth which makes the downstream purification of the final product more efficient," says Irini Angelidaki, while noting that the technology is not limited to using by-product stream with very high content of sugars:

"Utilization of by-product streams with lower concentrations of carbohydrates is possible but will require some removal of water in the downstream purification of the product."

Further, *Actinobacillus succinogenes* is very flexible when it comes to the type of carbohydrates:

"We don't need to feed the microorganism glucose, it could be any type of carbohydrates, including for instance starch. Many industries have relevant by-product streams, and in Ireland trials using seaweed are ongoing."

Plug-and-play installation

In Spain, containers are ready with the necessary equipment. The standard-size containers will allow for plug-and-play installation.

"What we need to do now is to operate the equipment, thereby obtaining enough data to present the technology to the relevant industries," says Irini Angelidaki.

Optimizations are still underway, but the cost of the succinic acid produced with the innovative technology will end up being a bit higher compared to having fossil feedstock, she predicts:

"Although the pilot tests are still ongoing and the business cases are not fully made, the economic feasibility has good prospects. Market investigations by the industry partners in our project indicate that several companies are prepared to pay even a little more for their succinic acid when it is produced in a sustainable manner. Also, the capture of CO_2 is a strong argument."

Summing up, Irini Angelidaki expects to see the first full-scale implementations of the technology in 2023.

Irini Angelidaki, Professor

The NEOSUCCESS project

Funded by the EU, the NEOSUCCESS project aims to build the first plug-and-play industrial solution integrating biogas upgrading into biomethane and fermentation-based bio-succinic acid production. The name NEOSUCCESS is a reference to production of succinic acid.

The basis of the project is a technology patented by DTU using a bacterial strain able to fix the CO_2 contained in the biogas. Thereby the biogas is upgraded to biomethane. Simultaneously, the sugars present in industrial by-product streams are metabolized to produce second-generation succinic acid.

Partners in the project are the Bioconversions group at DTU Chemical and Biochemical Engineering, the Aristotle University (Greece), and industrial companies BIOTECHPRO (Denmark), IVEM (Spain), Norvento Enerxia (Spain), and technological center AINIA (Spain).

In Spain, the project partners are building container-size versions of the NEOSUCCESS technology able to produce from 10,000 to 100,000 Nm^3/year of biomethane and 35 to 350 t/year of bio-succinic acid.

The project was initiated in 2019 and is planned to terminate in 2023 and deliver a ready to commercialization technology.

Besides Irini Angelidaki, several researchers, and students from DTU Chemical & Biochemical Engineering have been involved in the project. Dr. Merlin Alvarado-Morales has been in the Neosuccess project up till recently, while currently Dr. Antonio Grimalt Alemany continues the investigations in optimizing the process.

The power of osmosis

Electricity produced by exploiting the difference in potential between saline and non-saline water is becoming a commercially viable green energy source. Danish start-up company SaltPower, Danfoss, and DTU Chemical and Biochemical Engineering have teamed up to take the promising technology to the next level.

"This is a highly ambitious project. The technological improvements which we hope to achieve in the collaboration can become a game changer, opening new markets," says SaltPower CEO Lars Storm Pedersen.

When two bodies of water with different salinities are separated by a selectively permeable membrane, a process of water diffusion will begin. This is osmosis. The process is constantly occurring in all living cells. In recent years it has transpired that osmosis can be utilized for energy production.

In a world that craves renewable and non-carbon-emitting energy, the market for osmotic power production – or "salt power" if you will – is large.

Salt producers are the first customers

SaltPower already has several commercial projects in the making or under discussion. The first plant will be operational in March 2023 at the Nouryon salt producing plant in Mariager, Denmark.

"Salt producing plants are obvious candidates to become our clients, since they have high salinity water readily available. Further, we don't need to produce electricity for the grid, since production of salt, like so many industrial processes, require energy consumption," Lars Storm Pedersen explains.

Since 300 million tons of salt are produced worldwide annually, this market holds plenty of opportunities for growth for SaltPower.

"Salt production mainly in USA and Europe will be our initial market. But not so far further down the line will be hydrogen storage. These storages can be built in underground salt structures, and they also require large amounts of power to be built, and thereby could benefit directly from establishing osmotic power facilities," the CEO comments, noting that in this context the young company will depend on market developments:

"Several nations have announced or are considering programs which will make hydrogen a significant part of their energy supplies. Therefore, we expect many new hydrogen storages to be built in the coming years."

Differentiating over a set of equations

The main role for DTU Chemical and Biochemical Engineering is development of an improved membrane able to sustain high pressure.

The solutions currently marketed by SaltPower operate at a pressure of 70 bars. While this is a high pressure it is still quite a lot lower than the optimal for the purpose, notes Lars Storm Pedersen:

"The higher the pressure, the more power can be produced per cubic meter of water through osmosis. However, you do reach a point where a further increment in pressure would be unfeasible since the additional costs begin to outweigh the extra power production. This is a classic engineering problem. When you compose your set of equations and differentiate, you end up with 200 bars as the optimal pressure," Lars Storm Pedersen explains.

So, why does the current solutions operate at 70 bars? This is because the underlying technology was originally developed for de-salination. In collaboration with DTU Chemical and Biochemical Engineering and Danfoss, SaltPower strives to develop the first generation of technology specifically with osmotic power production as its purpose.

While the DTU researchers cooperate with SaltPower on membranes able to tolerate 200 bars, Danfoss is developing pumps able to supply this level of pressure under the challenging conditions encountered in the relevant industries. Also, Danfoss is engaged in development of novel energy recovery devices for osmotic systems.

Disruptive improvements ahead

A further role for the DTU researchers is contributing to simulations across the osmotic system.

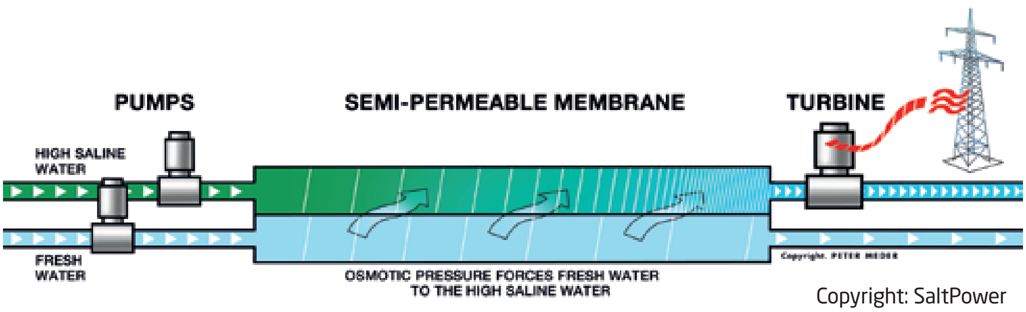
"This is not just about developing the individual technologies – pumps, membranes etc. You need to be careful with the details, and especially assure that you are not wasting energy across the system," Lars Storm Pedersen notes.

"Only if we manage to get this right, will we be able to harvest the benefits from operating the system at the optimal 200 bars. We estimate that the current power production per cubic meter of water can be increased by somewhere between 50 and 300 per cent. This will reduce the cost of produced power significantly, representing a disruptive improvement."

"Notably, we are not only concerned with the technological development. As a commercial company, we are always looking at costs. Since we are talking about a technology with a very wide market potential, it will be crucial for us to be able to offer the solutions at competitive prices."

The "Hi-PreM" project (High Pressure Membranes) project is supported by Innovation Fund Denmark under its Grand Solutions investment program. Participants are Danfoss, DTU Chemical and Biochemical Engineering, and SaltPower. The project will run until 2024.

Manuel Pinelo, Professor
Ulrich Krühne, Associate Professor



Copyright: SaltPower

SaltPower is based on the technology of Pressure Retarded Osmosis (PRO). Two water sources with different salinity are mixed via a membrane to produce electricity. Water flows across the membrane and builds up pressure, and by passing the pressurized water through a turbine electricity is generated.

Osmosis could become the next wind power adventure

Probably best known as former Chairman of the Danfoss Corporation, Jørgen Mads Clausen is also engaged in a range of entrepreneurship activities. One of them is SaltPower which he not only owns but also founded.

"I was inspired by trials in Norway. Their idea was to exploit the difference in salinity between sea water and the freshwater of their rivers. The experiments were successful from a technical perspective, but the economic feasibility was not satisfactory. Later I visited the geo-thermic facility in Sønderborg. Since their water has a salt concentration of 16 % - much higher than the 3.5 % of sea water – I wondered whether it might be possible to achieve a higher energy production and thereby improve the business case for osmotic power production," Jørgen Mads Clausen recalls.

"To my surprise it seemed that no one else had thought along those lines."

When trying to generate interest around osmotic energy production, the entrepreneur often meets skepticism:
"Many do find it hard to believe that you can produce energy from salt. Think about it this way: we all know that it is possible to desalinate sea water through reverse osmosis, and that the drawback of this technology is a high energy consumption. Since reverse osmosis requires energy, it shouldn't surprise us that osmosis generates energy."

Exemplary collaboration on research

Some may think that the technology will be limited by the fact that water with high salinity is required:

"The world is not short of high salinity water. After all, only iron is extracted in larger quantity than salt."

After six years, SaltPower is ready to launch its first commercial facility with a production of 100 kW.

"This may appear a modest number, but just think about how the wind power adventure began. The production from the first mills was far from impressive. Now wind power is a huge industry. The same may well happen to osmotic energy production," Jørgen Mads Clausen continues.

"Notably, we do not have to wait for development of much bigger installations like the development in wind power. If you want to increase your osmotic energy production, you just increase the number of units."

While the installations do not need to get bigger, it remains desirable to increase the energy production from each unit.

"This is where the collaboration with DTU Chemical and Biochemical Engineering is relevant. If the researchers succeed in developing membranes which can tolerate a higher pressure, we can produce much more energy from the same amount of water. This will be very significant," says Jørgen Mads Clausen while describing the collaboration as "absolutely exemplary".

A clean and climate friendly technology

The third party in the collaboration is Danfoss.

"Osmotic energy production will involve utilization of several devices which are already produced by Danfoss. So, this is a very exciting development for Danfoss too," notes Jørgen Mads Clausen.

As for further developments, the entrepreneur sees plenty:

"As an example, we are currently using freshwater since thereby we get the maximum gap in salinity between the two bodies of water. However, it might be possible to use sea water instead. This will increase the relevance of the technology in locations where freshwater is a scarce resource."

Summing up, Jørgen Mads Clausen sees a bright future for osmotic energy production:

"Clients can expect to get power 24-7, and this without any CO_2 emission. Further, the only biproduct from the facility will be water with a slightly elevated concentration of salt."

Osmosis research at DTU

The main role for the researchers at DTU Chemical and Biochemical Engineering in the collaboration with SaltPower and Danfoss is development of an improved membrane.

"Osmosis, which is a spontaneous phenomenon in nature, can be used to produce green, sustainable energy. Membranes are central in this process, and therefore membrane technology plays a crucial role in the successful development of a system like this," says Professor Manuel Pinelo from the Process and Systems Engineering Center (PROSYS), noting that the membranes need to fulfill a set of criteria.

"First and foremost, the membrane must be able to withstand pressures higher than current commercial membranes are able to. To achieve that, membranes can be coated with materials, which ensure a higher resistance. New generation materials and deposition technologies, which ensure higher resistance but do not compromise the membrane performance are being investigated for that purpose right now," Manuel Pinelo explains.

Secondly, the membrane must have a high permeability for water.

"When coated, membranes may lose or have their mass transfer abilities reduced. Therefore, the materials used for coating must have special hydrophilic properties and need to be disposed in a very strategic fashion."

Thirdly, the membrane must hinder the transfer of salt, so the difference in osmotic pressure is maintained. Physical-chemical interactions between salt and membrane material needs to be studied in detail.

"To achieve these objectives, membrane technology, materials science, mechanical engineering, and robust analytical characterization techniques and being synergistically used to achieve our final goal in this project: to obtain one of the greenest and sustainable forms of energy," says Manuel Pinelo.

Deep investigation of membrane properties

Among the used methods is Computational Fluid Dynamic (CFD).

"CFD models are vastly used for the simulation of thermo-fluid phenomena in different engineering applications such as chemical, mechanical, environmental and energy systems. CFD models can be considered as efficient tools for the design, optimization, and parametric study purposes from the system-level performance analysis to the micro-scale detailed modeling," explains Associate Professor Ulrich Krühne from PROSYS.

Moreover, such models can be coupled to other solvers like Finite Element Models (FEM) to capture more complex and realistic behavior of engineering systems, e.g., Fluid-Structure Interactions (FSI).

"In reversed osmosis systems, where we have a thin membrane undergoing high pressure loadings and multi-specie masse transfer, CFD models are used firstly to investigate the fluid flow and the coupled transport of salt due to concentration gradients. The modeling of the membrane yields knowledge about key process parameters like fluid flow fields, pressure drops, local flowrates and salt concentration gradients, shear stress and mechanical forces balances on membrane surfaces," says Ulrich Krühne.

Subsequently, the fluid dynamic models will be coupled with mechanical and structural models, such as FEM, to account for the effect of high pressure on the membrane.

"This can for example be the bending of the membrane considering the fluid forces and the structural mechanical conditions in the membrane. In this way, it will be possible to improve and optimize geometric designs of e.g., membrane support material or flow modules. Finally, microscopic geometric sketches of the membrane pore system and detailed modeling of the flow regime inside these will be made. Here, the detailed interaction between flow, geometry, surface treatment, and the salt concentration can be investigated," Ulrich Krühne ends.

Life returned to KT in 2022

Covid-19 caused two quiet years at DTU Chemical Engineering. In 2022 life finally returned.

Amongst the visitors that we were happy to welcome back were the foreign students attending DTU Chemical Engineering's Summer University. The course in unit operations ran from 4-28 July and 82 American college students took part.

The international students attend Summer University for many reasons.

"The pilot plant is one of the reasons I have come to DTU. We have a similar plant at home, but only on a much smaller scale. It is nice to see that you want to invest money in it here," says Maddy Long who studies chemical engineering at Clemson University.

Her study partner, Zachary Schauer agrees:

"We have three options at Clemson and here there are over twenty processes to try. It is much better to work with a process and see it happen rather than reading about it in a textbook. It is a huge positive of coming here."

Grant Van Horn studies Chemical Engineering at Virginia Tech and is a huge fan of LEGO, so coming to Denmark was an easy choice.

"Your facilities are unparalleled and world class in scale and variety. Also, at Virginia Tech our facilities are not centered around pharma and food, and I am interested in both," he explains.

Professors and graders accompany the students. Heath Turner is head of the department of Chemical Engineering at University of Alabama. He always makes time for the KT Summer University:

"DTU Chemical and Biochemical Engineering has the best facilities in the world. I have been to China, around Europe and to top universities in the US and none of them have facilities as impressive. It is well equipped and well-staffed, which is a huge benefit to our students and their future careers."

He continues:
"DTU has plugged into the trend to keep large scale equipment. Other universities have not. We must fight to keep the equipment we have. DTU has made the right decision to keep and expand its large-scale equipment."

The students are certain the stay in Denmark will help their later careers.

"This course will help my career. I love working with different minds of people and people from diverse cultures. With this course I show that I can go to another country and work with other nationalities, and this will be a talking point at a future job interview," says Grant Van Horn before heading to yet another experiment at the Pilot plant.

Christian O. Carlsson

Highlights **2022**

13 JANUARY
NEW EUDP GRANT TO PHILIP FOSBØL
AT CERE at the Department of Chemical Engineering received EUDP funding for the project Green Carbon Capture and Hydrogen production (CCCH2). The project will develop a new carbon capture technology based on electrochemical regeneration of the solvent combined with hydrogen production. AT CERE is partner in the project with Assoc. Prof. Philip Fosbøl and Senior Project Manager Sebastian Villadsen.

23 FEBRUARY
ELITEFORSK AWARD TO ANNE LADEGAARD SKOV
Professor Anne Ladegaard Skov received the EliteForsk Award, which is one of the most prestigious research prizes in Denmark. She received the award for her research in artificial muscles that mimic the way our muscles work. These rubbery materials move if they are exposed to an electrical voltage.

8 MARCH
NACAT KICK-OFF MEETING
Senior Researcher Xavier Flores-Alsina, Postdoc Helen Liu and Professor Krist V. Gernaey participated in the kick-off meeting of the NACAT project, a EUDP project in collaboration with Haldor Topsøe, Vandcenter Syd, Hillerød Forsyning and Tårnby Forsyning, aiming at catalytic removal of the greenhouse gas N_2O from wastewater systems.

25 MARCH
VISIT FROM THE HEMPEL-DTU AWARD WINNERS 2021
DTU Chemical Engineering welcomed one of the two winners of the Hempel-DTU award 2021, Roskilde Gymnasium. After an introduction to DTU, Department of Chemical Engineering and the CoaST center, the students were shown the large-scale experimental facilities at our Pilot Plant and in the CoaST Labs.


Christian O. Carlsson

28 MARCH
HEMPEL'S TALENT PROGRAM VISIT
The CoaST center hosted a visit of 22 talents from the Hempel Talent Program, talents recruited widely within Hempel A/S. The visit included introductory lectures on coatings, a tour of the CoaST laboratories and finally a poster session where the visiting talents had the opportunity to interact with CoaST students.

1-3 APRIL
QUANTUM COMPUTING WORKSHOP
Some of the World's leading experts on quantum computing gathered in Copenhagen for the workshop, Quantum Computing Applications in Chemical and Biochemical Engineering. DTU Chemical Engineering, American Institute of Chemical Engineers (AIChE) and Knowledge Hub Zealand hosted the workshop. Quantum computing technology is gaining a lot of interest as an impactful problem-solving tool that can be used in fields such as biotechnology and sustainability to accelerate the process of developing novel technologies. The event was organized by Assoc. Professors Seyed Mansouri from PROSYS and Martin Andersson from CHEC and supported by The Novo Nordisk Foundation.

Highlights **2022**

4 APRIL
VIP VISITS TO OUR PILOT PLANT
Frederik, Crown Prince of Denmark, and Dan Jørgensen, Minister for Climate, Energy and Utilities visited DTU to learn about future energy solutions. AT DTU Chemical Engineering, Assoc. Prof. Philip Fosbøl presented a model of his CO_2 capture plant. Throughout 2022 we had several other VIP visits to our Pilot Plant, Ministry of Higher Education and Science, the Confederation of Danish Industry and TotalEnergies' management, hosted by Professor Anker Degn Jensen.

Mikal Schlosser

6 APRIL
CONSENCUS GENERAL ASSEMBLY
The Horizon 2020 funded project CO_2 Capture and Utilisation Nomads held their general assembly. The project, led by Assoc. Prof. Philip Fosbøl, wants to demonstrate electrochemical CO_2 capture at three industrial sites: Aalborg Portland Cement factory, Denmark, OMV PETROM refinery, Romania, and Grecian Magnesite mine in Greece. The first demonstration facility was successfully established at Aalborg Portland in October.

26 APRIL
THE HEMPEL-DTU AWARD 2022
This year, Thisted Gymnasium STX and HF won the Hempel-DTU Award for the second time. The high school received DKK 100,000 for its work with promoting natural sciences amongst high school students. The prize supports High Schools that will make a special effort to strengthen teaching in Science, Technology, Engineering and Mathematics, also called STEM subjects.

5 MAY
HYPROFUEL KICK-OFF MEETING
Kick-off in the Innovation Fund Denmark project 'HyProFuel - Hydroprocessing Sustainable Fuels for Aviation and Heavy Transport.' The project aims at developing a process to convert tar-like pyrolysis oil to useable jet fuel. The pyrolysis oil is made from organic residual products from farming and forestry. The process can be integrated with existing oil refineries enabling them to convert their production to become more sustainable. CHEC is partner in the project with Professor Anker Degn Jensen.

6 MAY
COAST ADVISORY BOARD MEETING 2022
The CoaST Advisory Board evaluated the performance of CoaST based on several KPI's and subsequently issued its recommendation to the Hempel Foundation regarding a continuation of the grant to CoaST.

10 MAY
POSTER WIN AT FBC24 CONFERENCE
Emil Lidman Olsson from CHEC won the poster competition at the 24th International Conference on Fluidized Bed Conversion (FBC24) in Gothenburg. He won the award for the poster 'Thermal conversion of sodium phytate using the oxygen carrier ilmenite, interaction with Na-phosphate and its effect on reactivity.'

20 MAY
KT POSTER COMPETITION
Three PhD students from AT-CERE arranged the KT poster competition as an opportunity for the whole Department of Chemical Engineering to come together and socialize with colleagues from other research centers. Prizes were awarded to the jury's top three best posters and the most popular with the popular vote. Lucas Correa from AT-CERE won the jury's first prize.

MAY

IRINI ANGELIDAKI RECEIVED TWO HORIZON EUROPE GRANTS

Professor Irini Angelidaki received two Horizon Europe grants in the same week. One for the project SEMPRE-Bio (SEcuring doMestic PRoduction of cost-Effective BIOmethane) which has the objective to secure domestic production of cost-effective biomethane. The second project 'Capture and reuse of biogenic gases for negative-emission - sustainable biofuels' focuses on using pyrolysis gas and convert it to biomethane.

30 MAY - 3 JUNE

COURSE ON ARTIFICIAL INTELLIGENCE

Otto Mønsted visiting professor Venkat Venkatasubramanian from Columbia University, USA held a mini course on Artificial Intelligence in Bio/Chemical Engineering. Professor Venkatasubramanian has been at the frontier of AI-based research in Chemical Engineering for decades. The course explored the 35+ year-long history of AI in chemical engineering and how AI based modeling can be incorporated into first principles-based modeling arsenal of chemical engineering.

Christian O. Carlsson

6- 8 JUNE

PUTTING PAT INTO USE: A COURSE IN FUTURE QC TECHNOLOGIES

The course in future QC technologies, targeting industry people, was organized for the first time at DTU. Researchers Carina L. Gargalo, Pedram Ramin and Assoc. Prof. Ulrich Krühne and Professor Krist V. Gernaey introduced course participants to a range of topics that are relevant in view of future development towards increased digitalization.

7- 9 JUNE

CERE DISCUSSION MEETING

After two years of pandemic, 55 members of the CERE industry consortium were happy to meet each other again in person to discuss the wave of transition in the energy resources sector with focus on thermodynamics and CO_2 capture.

8-10 JUNE

KT CONSORTIUM ANNUAL MEETING

This year's KT Consortium Annual Meeting 2022 included 22 industrial participants from as many companies to discuss process and bioprocess systems engineering with 33 faculty and researchers from DTU Chemical Engineering. Among the highlights were industrial talks on Alfa Laval's road towards a carbon neutral 2030 and the impact of downstream modeling in the biopharmaceutical industry at Novo Nordisk.

Christian O. Carlsson

Highlights **2022**

16 JUNE

FIRST FBM SYMPOSIUM

350 participants, including 180 online, joined the first symposium of the FBM-Initiative 'Innovation for Biomanufacturing - Next Generation Cell-Factories and Process Development' at DTU. The programme consisted of talks from academia and industry as well as poster pitches and presentations from PhD students and early career scientists.

21 JUNE

ANNE LADEGAARD SKOV RECEIVED NOVO NORDISK FOUNDATION GRANT

Professor Anne Ladegaard Skov received a grant from The Novo Nordisk Foundation Challenge Programme for the project 'Soft wearables with high energy density: merging chemical biology and silicone chemistry with compliant active devices (WeArAble).' The vision of the WeArAble project is to build the scientific foundation for future development of soft wearables that are mechanically transparent in the sense that the wearables are worn without the wearer noticing them.

27 – 30 JUNE

HANDS-ON WASTE VALORIZATION SCIENCE

The annual WasteEng (Engineering for Waste and Biomass Valorization) conference has evolved into the world's leading academic forum for practical circular economy solutions. Based on 435 submitted abstracts, some 350 oral and poster presentations were provided during the WasteEng22 conference, showing the richness of this ever-growing field. Assoc. Prof. Hariklia N. Gavala from AT CERE co-chaired the conference.

27 – 30 JUNE

17^{TH} COATINGS SCIENCE INTERNATIONAL CONFERENCE

With seven out of 29 oral presentations, CoaST were the institution with most presentations at the 17th Coatings Science International Conference, which took place in Noordwijk, The Netherlands from the 27 to 30 June.

28 JUNE

EUDP GRANT TO THE SKYCLEAN SCALE-UP PROJECT

Senior Researcher Ulrik Birk Henriksen from CHEC received a EUDP grant for the SkyClean Scale-Up project. The goal is to build the first 20 MW SkyClean pyrolysis plant while in parallel initiating the relevant changes necessary to make pyrolysis-based carbon sequestration an efficient and essential climate technology for Danish agriculture.

1 AUGUST

KICK-OFF INNOMISSION 2

Kick-off in the Innomission 2 Green fuels for transport and industry partnership funded by Innovation fund Denmark. CHEC, via Professor Anker Degn Jensen and Assoc. Prof. Martin Høj, participate with the sub-project Methanol-to-jet fuel process. The aim is to make jet fuel from methanol along with partners Ørsted, Topsoe, SkyNRG, Neste, Aalborg University, Copenhagen Airport, NISA, SAS, and Aarhus University.

8 SEPTEMBER

PROFESSOR GEORGIOS M. KONTOGEORGIS RECEIVED VILLUM EXPERIMENT GRANT

Professor Georgios M. Kontogeorgis received a Villum Experiment grant for the project 'Is Water a Two-State liquid?' The goal of this project is to investigate whether the combination of the two-state concept and the advanced thermodynamic models based on the SAFT framework can describe the anomalous properties of water. Another Villum Experiment recipient, Postdoc Tian Wang, from DTU Offshore, will from 2023 join DTU Chemical Engineering to work on her project, 'Soil remediation by salinity waves', in collaboration with Assoc. Prof. Alexander Shapiro.

8 SEPTEMBER

HORIZON EUROPE GRANT TO THE CO_2 VALORIZE CONSORTIUM

CHEC is partner in the CO_2Valorize consortium funded by the European Commission working to further eliminate CO_2 emissions from the production of cement. Senior Researcher Peter Arendt Jensen will in collaboration with FLSmidth develop a high temperature carbonation technology, that can utilize some of the heat streams on a cement plant to assist the carbonation process.

BIOPRO WORLD TALENT CAMPUS

The 9th edition of BIOPRO World Talent Campus was organized for 25 international PhD students, in collaboration with the companies Chr. Hansen, CP Kelco, Novo Nordisk, Novozymes and Xellia Pharmaceuticals. The final event at Herlev Bryghus was attended by 80 guests.

29 SEPTEMBER

CHEC ANNUAL DAY

The CHEC Annual Day was held as a hybrid event with about 90 participants of which 30 were external. The event included several talks from industrial collaborators, among others Jacob Hjerrild Zeuthen (Mærsk), Jan Kamyno Rasmussen (Sempercycle) and Claus Thulstrup (AquaGreen).

30 SEPTEMBER

DPC ANNUAL POLYMER DAY

101 participants, hereof 37 online, attended the DPC Annual Polymer Day, 33 were external partners. Professor Herbert Shea from EPFL gave this year's international research presentation on the topic of flexible polymer-based actuators. Other presentations were given by a range of researchers from DPC, CoaST and PROSYS.

14 OCTOBER

PROSYS ANNUAL RESEARCH SEMINAR

The PROSYS Annual Research Seminar was held as a hybrid event for 160 participants including 100 participants from our external partners, representing 32 different organizations. Per Falholt (21st.Bio), Lars Storm Pedersen (SaltPower) and Alexandra Russo (Imperial College, London) attended as external speakers.

10 NOVEMBER

PROFESSOR ANNE LADEGAARD SKOV RECEIVED THE GRUNDFOS PRIZE

The Grundfos Prize was awarded to Anne Ladegaard Skov in recognition of her research in silicone-based elastomers, which, among other things, is used for artificial muscles and controlled drug release from patches. Established by the Grundfos Foundation in 2001, the prize has since 2018 targeted young researchers through the theme "The Stars of Tomorrow".

Grundfos Fonden/Lars Holm

2 DECEMBER

ENGINEERING FOR SUSTAINABLE TRANSITION

Professor Michael Zwicky Hauschild from Centre for Absolute Sustainability at DTU gave a presentation on engineering for sustainable transition at the KT Christmas Seminar. After two years of online Christmas Seminars everyone enjoyed being able to gather again across centres and celebrate the end of a successful year at DTU Chemical and Biochemical Engineering.

Cooperating companies

2

21st.Bio

3

3V TECH EQUIPMENT & PROCESS SYSTEMS

A

Alfa Laval
AquaGreen
Aquaporin
ARC
ARKEMA FRANCE
Arla Foods
AVEVA Software
AWAPATENT
Axens

B

Babcock & Wilcox Renewable
BASF
Bayer
Biomar
Biopro
Bioscavenge
Biosyntia
Blue Chemney
BP
BTG Bioliquids
Burkert

C

Calsep
Carbfix
Carlsberg Research Laboratory
Centro Tecnológico Componentes
Chevron
Chr. Hansen
Chreto
Ckj Steel
C-LEcta
Coloplast
Copenhagen Atomics
Covestro
CP Kelco

D

Dall Energi
Dalum
Dampskibsselskabet Norden
Dansk Gasteknisk Center
Dan-Unity
DHI
DSM
DTI

E

Electrochaea.dk
EnCoat
EnviDan
Equinor
ESSO

F

Ferrosan Medical
Finnesementti
Firmenich
FlowLoop
FLSmidth
Fluor Corporation
Foodture
Freesense
Fujifilm Diosynth Biotechnologies

G

GEA Process engineering
Geminor
GLYCOM Denmark
GR3N SAGL
Greenlab Skive
Grundfos

H

H. Lundbeck A/S
Hafnium Labs
Harriot Wiat
Hashøj
HCS
Hempel
Henkel
(H&M) HENNES & MAURITZ
Holm Christensen Biosystemer
Hundested Havn

I

IFP Energies nouvelles
Innosyn
Insatech

J

Janssen
Jiangsu Industrial Technology Research Institute

K

Kalundborg forsyning
Karup Kartoffelmelsfabrik
KBC
KMT Cables

L

Landbrug & Fødevarer
LEGO
Lemvig Biogas
Leo Pharma
Linde
LiqTech International
Lundsby Biogas

M

Madsen Bioenergi
MAN Energy Solutions
Mash Energy
Metricorr
Microsoft
Mitsubishi Chemical Corporation

N

NEO GROUP
Neste Corporation
New Energy Coalition
Nordic Sugar
Nouryon Specialty Chemicals
Nova Pangeae
Novartis
Novo Nordisk
Novozymes

O

OMV Petrom

P

ParticleTech
Pharmacosmos
Polyloop
Pond
Process-design
PROCESSI INNOVATIVI
Processium

Q

Q-Interline

R

Rambøl
Resino
Rockwool

S

Saltkraft
Schlumberger
Scienciox
Shell
Sinopec
Stiesdal Fuel Technologies
SYNESIS
Syngenta

T

Teknologisk Institut
Topsoe
TotalEnergies

U

Ucomposites
Umicore Denmark
Unibio Group
Unilever
Union Engineering
US Navy

V

Valmet

W

Waste Plastic upcycling
Wetsus
Wintershall
WPU

X

Xellia Pharmaceuticals

Ø

Ørsted

Aa

Aalborg Portland

A new KTStudents

The student organization at DTU Chemical Engineering, KTStudents works to improve the study environment for students through social and professional activities. Coming back from the challenging times of lockdown, KTStudents this year has been focused on encouraging social interactions between students at the department.

The year 2022 has been an active year for KTStudents with both activities and development of the organization.

"At the start of 2022 the term 'lockdown' was becoming something from the past and students were eager to socialize and find new friends. This led to the KTStudents taking action and arranging events that contributed to networking and friendship." says Brynjolf Ernstsson, Chairman of KT Students.

After the summer break of 2022 the organization shifted focus from social to professional events. With a strong portfolio of company presentations and visits, KTStudents managed to host Novo Nordisk, Rockwool, Novozymes, Topsoe and visited the R&D facilities at Hempel. These events combined contributed to more than 400 participating students, which is the largest influence the organization has ever had.

"The year of 2023 will be packed with ambitions and development. KTStudents has shifted from an (only) board organization to a board along with active members. In 2022 we were 8 students and now we are 23 active students in total! With more hands we set the bar high with ambitions of increasing our contribution of academic content as well as social events for students at KT," Brynjolf concludes.

Brynjolf Ernstsson, Chairman of KTStudents

KTStudents Board. From left to right: Yashomangalam Bhutada, Guilherme Frizado, Sanskar Vaishnav, Brynjolf Ernstsson, Ümit Bozyilan, Gauri Undegaonkar, Simon Knudsen, Cristina Hotea, (missing Melissa Jensen)
Christian O. Carlsson

Organization

LEADER GROUP
- Head of Centres
- Head of Secretariat
- Head of Study Committee

HEAD OF DEPARTMENT
- Kim Dam-Johansen

ADVISORY BOARD
- Lars Bang
- Hanne Everland
- Per Falholt
- Susanne Grøn
- Katarina Lindstrøm
- Carsten Riisberg Lund
- Michael Hallgreen

COMMITTEES / BOARDS
- Study board (elected/appointed)
- Research & Innovation (appointed)
- Cooperation (elected)
- Work environment (elected)

STUDY COMMITTEE
- Anker D. Jensen

SECRETARIAT & BUILDINGS
- Mette Bjørnlund

WORKSHOP
- Søren V. Madsen

BEeng Chem & Bio Eng

BEeng Chem & Int.Bus

MSc Petroleum Engineering

MSc Chemical & Biochemical Engineering

MSc Chemical & Biochemical Engineering (SDC)

FACULTY

AT CERE	PROSYS	CHEC	CoaST	DPC	BioCon
Georgios Kontogeorgis	Krist V. Gernaey	Kim Dam-Johansen	Kim Dam-Johansen	Anne Ladegaard Skov	Irini Angelidaki

PILOT Steen Larsen

KT CONSORTIUM Georgios Kontogeorgis

The Faculty **2022**

SCIENTIFIC


Alexander Shapiro
Associate Professor


Anders E. Daugaard
Associate Professor


Anne Ladegaard Skov
Professor


Anker D. Jensen
Professor


Georgios Kontogeorgis
Professor


Gürkan Sin
Professor


Hao Wu
Associate Professor


Hariklia N. Gavala
Associate Professor


Helena Junicke
Associate Professor


Huichao (Teresa) Bi
Assistant Professor


Ioannis V. Skiadas
Associate Professor


Irini Angelidaki
Professor


Jakob K. Huusom
Associate Professor


Jakob M. Christensen
Associate Professor


Jens Abildskov
Associate Professor


Jochen Dreyer
Assistant Professor


John Woodley
Professor


Julian Kager
Assistant Professor


Kim Dam-Johansen
Professor,
Head of Department


Krist V. Gernaey
Professor


Manuel Pinelo
Professor


Martin Andersson
Associate Professor


Martin Høj
Associate Professor


Nicolas von Solms
Professor


Peter Szabo
Associate Professor


Peter Glarborg
Professor


Philip L. Fosbøl
Associate Professor


Seyed S. Mansouri
Associate Professor


Stig Wedel
Associate Professor


Søren Kiil
Professor


Ulrich Krühne
Associate Professor


Xiaodong Liang
Associate Professor

ADMINISTRATIVE


Mette Bjørnlund
Head of Secretariat


Steen Larsen
Head of PILOT PLANT

EMERITUS


Gunnar E. Jonsson
Associate Professor
Emeritus


Kaj Thomsen
Emeritus


Ole Hassager
Professor Emeritus


Sten B. Jørgensen
Professor Emeritus

Advisory Board

LARS BANG
EXECUTIVE VICE PRESIDENT
H. LUNDBECK A/S

"Every day serving more than 7m patients with brain diseases around the globe from European factories requires competitive technological solutions. Our partnership with DTU Chemical Engineering is a cornerstone in developing solutions that really make a difference and is attracting talented new employees."

HANNE EVERLAND
VICE PRESIDENT
EMENDO R&D APS

"As Senior consultant at Emendo Consulting Group, I service the Danish medical device industry broadly. Here I see how innovation is promoted by collaborations with DTU Chemical Engineering and I meet remarkably knowledgeable students and graduates from the department. Plastic are the main components of most medical devices and with the increased focus on the environment impact of plastic the Danish Polymer Center is an important partner for the industry in the development of new and more sustainable polymers."

PER FALHOLT
CHIEF SCIENTIFIC OFFICER
21ST.BIO

"I am a biotech entrepreneur with a long experience from launching industrial biotech products to many different industries, food, feed and technical. With my experience from Industry combined with my DTU insight from being Chairman of the board at DTU I can bring relevant societal needs and challenges into our research and education environment at Chemical Engineering and will use this to help educate the relevant candidates for the future."

SUSANNE GRØN
VICE PRESIDENT FOR R&D PROCESS
SCIENCE & DEVELOPMENT
CHR. HANSEN

"Climate change, food waste, global health and the overuse of antibiotics and pesticides are all pressing issues that society and industry need to address in the need to shape a more sustainable future. At Chr. Hansen, we are positioned to drive positive change and addressing these challenges through our sustainable microbial solutions. Department of Chemical and Biochemical Engineering is, as a close partner, uniquely situated to provide innovative solutions and strong engineering candidates contributing to this essential purpose."

KATARINA LINDSTRÖM
EXECUTIVE VICE PRESIDENT AND COO
HEMPEL A/S

"At Hempel, our purpose is to shape a brighter future with sustainable coating solutions. Across the globe, our paints and coatings protect and beautify buildings, ships, infrastructure, and other assets, lowering their impact on the environment and enhancing their performance. Our strategy to double in size by 2025 makes our commitment to sustainability even more important. We have set ambitious science-based targets to reduce 90% emissions from our own operations by 2026 and 50% from our value chain by 2030.
DTU Chemical Engineering is an invaluable partner for us to tap into the latest research, within the fields of formulations, processes, and sustainability. Cooperating with DTU Chemical Engineering also creates an excellent opportunity for attracting talent and developing future and existing Hempel employees."

CARSTEN RIISBERG LUND
BOARD MEMBER, FORMER GROUP
EXECUTIVE VICE PRESIDENT FLSMIDTH A/S

"The world must come together to solve the urgent challenges of global warming and scarcity of resources. Developing and commercializing practical technologies together is the hallmark of Danish industry and research institutions. DTU Chemical Engineering has for decades worked with Industrial partners to support and develop this hallmark on a local and global scale.
A unique technology position and strong engineering competences are the foundation for success for all process engineering companies that I am affiliated with. Through state-of-the-art education of international engineers, DTU Chemical Engineering shall continue to ensure the competence needed to maintain this foundation and together with industry we shall address the UN Sustainability Goals and develop practical and sustainable technologies applicable in the world at large."

MICHAEL HALLGREN
SENIOR VICE PRESIDENT
NOVO NORDISK A/S

"Kalundborg is the largest biomanufacturing hub in Scandinavia and an area in strong growth. From 2009 to 2019 it was Denmark's fastest growing municipality with an annual growth of 8.7% in GDP. Large investments have been attracted from both Danish and international companies. Since the turn of the millennium, Novo Nordisk has invested DKK 18 bn in the city – and recently we announced plans to invest DKK 18 bn. Establishing a world-class education and research environment targeted at the needs of the local industry will support continued growth in the region. Therefore, Novo Nordisk looks forward to collaborating with DTU Chemical Engineering on establishment of a MSc. in biomanufacturing in Kalundborg. With this initiative, DTU Chemical Engineering will contribute to further development in Kalundborg and in the region and support the future need for highly qualified labor."

Teaching

The Department participates in two 3½-year Bachelor of Engineering (BEng) programmes, one in Chemical and Biochemical Engineering, and one in Chemical Engineering & International Business, a three-year Bachelor of Science (BSc) programme in Chemistry and Technology, three two-year Master of Science (MSc) programmes in Applied Chemistry, Chemical and Biochemical Engineering, which includes an Honours programme, and Petroleum Engineering, and finally a Sino-Danish Master of Science programme in Chemical and Biochemical Engineering.

Our students work both theoretically and experimentally with the core disciplines in chemical engineering such as unit operations, transport phenomena, reaction engineering, mathematical modelling, and thermodynamics. They are taught by faculty specializing in these areas with applications in energy conversion, enzyme technology, and biotechnology, polymers, coating technology, catalysis, computer modeling, process and product design.

Courses

1 SEPTEMBER 2022-31 AUGUST 2023

PHD COURSES

28904	Polymer physics
28905	Advanced topics in process systems engineering
28908	Rheology of complex fluids (heavy)
28909	Thermodynamic models, fundamentals, and computational aspects
28917	Statistical thermodynamics for chemical engineering
28923	Uncertainty and sensitivity analysis of numerical models
28927	Advanced topics in process technology
28928	Electrolyte solution thermodynamics
28930	Advances in chemical and biochemical engineering
28932	Process engineering laboratory

SINO-DANISH CENTER (SDC) COURSES

88700	Industrial reaction engineering
88701	Transport processes
88703	Laboratory experiments
88704	Progress in research
88705	Process design—principles & methods
88706	Technology economic management and organization (TEMO)
88708	Green chemical engineering
88709	Fluidization and multiphase flow
88710	Combustion and high temperature processes
88711	Industrial bioreaction engineering
88713	Green Challenge
88715	Biorefinery
88716	Coating science and technology
88717	Research immersion

Courses

MSC, BSC, AND BENG COURSES

Below, course numbers and names are shown for 2021-2022, with the number of students attending shown in brackets. Bachelor of Engineering courses are marked with a **(B)**. The other courses are Bachelor of Science courses, Master of Science courses, or common courses.

FALL SEMESTER

28001 Introduction to Chemistry and Chemical Engineering (66)
28012 Chemical and Biochemical Process Engineering (71) **(B)**
28016 Mathematical models for chemical and biochemical systems (57) **(B)**
28020 Introduction to Chemical and Biochemical Engineering (69)
28022 Unit Operations of Chemical Engineering and Biotechnology (59) **(B)**
28121 Chemical Unit Operations Laboratory (14)
28125 Chemical Unit Operations Laboratory (9)
28140 Introduction to Chemical Reaction Engineering (43)
28150 Introduction to Process Control (32)
28157 Process and Product Design (50) **(B)**
28213 Polymer Technology (33)
28233 Recovery and Purification of Biological Products (115)
28242 Chemical Kinetics and Catalysis (66)
28244 Combustion and High Temperature Process (32)
28310 Chemical and Biochemical Product Design (71)
28315 Colloid and Surface Chemistry (49)
28316 Laboratory Course in Colloid and Surface Chemistry (6)
28322 Chemical Engineering Thermodynamics (55) **(B)**
28342 Chemical Reaction Engineering (52) **(B)**
28344 Biotechnology and Process Design (23) **(B)**
28352 Chemical Process Control (57) **(B)**
28420 Separation Processes (66)
28455 Process adaptation in fermentation based biomanufacturing (64)
28480 Biobusiness and Process Innovation (154)
28515 Enhanced Oil Recovery (9)
28530 Transport Processes (84)
28831 Computational Fluid Dynamics in Chemical Engineering (20)
28845 Chemical Reaction Engineering Laboratory (16)
28852 Risk Assessment in Chemical Industry (43)
28864 Introduction to Matlab Programming (32)
28870 Energy and Sustainability (205)
28872 Biorefinery (40)

COURSES GIVEN IN CO-OPERATION WITH OTHER DEPARTMENTS:

23522 Rheology of Food and Biological Materials (12)
26010 Introductory Project in Chemistry (65)
41686 Materials Science (32) **(B)**

SPRING SEMESTER

28012 Chemical and Biochemical Process Engineering (45) **(B)**
28016 Mathematical Models for Chemical and Biochemical systems (36) **(B)**
28020 Introduction to Chemical and Biochemical Engineering (69)
28022 Unit Operations of Chemical Engineering and Biotechnology (45) **(B)**
28025 Bio Process Technology (30)
28121 Chemical Unit Operations Laboratory (14)
28157 Process Design (38) **(B)**
28160 Mathematical Models for Chemical Systems (41)
28212 Polymer Chemistry (32)
28214 Polymer Synthesis and Characterization (15)
28216 Organics Coatings Science and Technology (7)
28221 Chemical Engineering Thermodynamics (31)
28231 Laboratory in Chemical and Biochemical Engineering (16)
28271 Thermal gasification and sustainability (15)
28322 Chemical Engineering Thermodynamics (36) **(B)**
28342 Chemical Reaction Engineering (40) **(B)**
28344 Biotechnology and Process Design (23) **(B)**
28345 Industrial BioReaction Engineering (79)
28346 Advanced fermentation technology practicum (16)
28350 Process Design: Principles and Methods (72)
28352 Chemical Process Control (45) **(B)**
28361 Chemical Engineering Model Analysis (53)
28415 Oil and Gas Production (12)
28423 Phase Equilibria for Separation Processes (28)
28434 Membrane Technology (53)
28443 Industrial Reaction Engineering (43)
28451 Optimizing Plantwide Control (41)
28535 Rheology of Complex Fluids (light) (1)
28850 Quality by Design (QbD): Integration of Product and Process Development (97)
28855 Good Manufactoring Practice (100)
28864 Introduction to Matlab Programming (28)
28871 Production of Biofuels (27)
28885 Technology and Economy of Oil and Gas Production (13) **(B)**
28892 Research Immersion (1)

COURSE GIVEN IN CO-OPERATION WITH OTHER DEPARTMENTS:

12701 Introduction to Living Systems (60)
26317 Instrumental Chemical Analysis (34)
27455 Microbial adaptation to industrial processes (55)
41686 Materials Science (47) **(B)**
41687 Exercises in Materials Science (21)

BACHELOR OF ENGINEERING DEGREES

32 students finished their research programme for the BEng degree. The project titles are listed below:

Separation of enzyme products from culture broth using alternative filtration equipment
Deep-Learning modelling for nitrous oxide emission characterization
Biopolymer composites based on alginate and residuals from bio-based production
Cyclic high pressure and high temperature performance of epoxy novolac coatings
Dead-end/direct flow microfiltration of high-aggregate protein solution with (two) structurally different filters
Assessment of modular stirred tank reactor (MSTR) for bioprocess investigations
Filtration of mammalian fermentation broth
Micro-reactor for fragmentation of sugars
Hydrothermal treatment of plastic derived pyrolysis oil
Influence of draw solutes on the feed solute rejection in forward osmosis
Intumescent alkali silicate and geopolymer coatings against im-pinging flames (**2 students**)
Ion exchange of glucose
Development of modeling for primary packaging and drug product interaction (**2 students**)
Process optimization of industrial scale aluminium chlorohydrate production
Optimisation of ultrafiltratiion device for investigation of protein accumulation
Peptones as nutrients for cultivation of bifidobacteria
Process design of a geopolymer cement plant (**2 students**)
Screening of new catalysts for stabilization of pyrolysis oil (**2 students**)
Sulfation of KCl by sulfuric acid
Transparent antifouling coatings (**3 students**)
Development and testing of anticorrosive coatings using nanocellulose and lignin as fillers
Development of Hollow Fiber Forward Osmosis membranes for flavor and fragrance application
Investigation of density as a proxy for homogeneity in colloid mixture
Digitialisation as a value-adding asset: From conceptualisation to execution (**3 students**)

BACHELOR OF SCIENCE DEGREES

24 students finished their research programme for the BSc degree. The project titles are listed below:

Prediction of biomethane potential in biological wastes
P2X desulfurization of biogas: uses and behaviour of Redox potential **(2 students)**
Transparent antifouling coating
Dynamic modelling and simulation of the production of human growth hormone
Periodic Separation
Analysis of the adsorption rate on catalysts for ammonia synthesis
Image processing to determine topology of surfaces
Effect of pre-treatment on the support effect in catalytic methanol synthesis
Dosimetry by photometry in medical devices
Preparation of bio-based composites from animal glue
Catalytic hydropyrolysis of plastics (**2 students**)
Plasma catalytic conversion of CH_4 and CO_2 into value added chemicals
Lignin-based coatings at extreme conditions
Mechanical properties of intumescent coatings
Measurements of mass transfer and process economy for CO_2 capture in pilot scale
Measurement and modelling of innovative Power-to-X technology for carbon capture
Tuning the Hydrocarbon Distribution from CO_2 Hydrogenation over Combined High Temperature Methanol Synthesis and Zeolite Catalysts (**2 students**)
Surface functionalization of solids to improve the barrier properties of epoxy novolac coatings at high pressure and high temperature conditions
Developing a simulation platform for educational purposes with focus on chemical process dynamics and simple control strategies
Development of a plant-wide scheduling problem in bio-based production processes
Investigation of the curing and thermal stability of different condensation cured silicone systems

MASTER OF SCIENCE DEGREES

83 students finished their research projects for the MSc degree. The project titles are listed below:

Advanced model-based process understanding of industrial filtration unit
Analysis of pilot plant data from waste incineration CO_2 capture
Advanced Process Understanding of Industrial Fermentation via the study of Mass Transfer Gradients
Demonstration and optimization of methanol production from biomass pyrolysis
Design of alternative tobramycin purification process step involving resin and buffer screening
Dynamic simulation of green ammonia plant
The effect of mixing on enzyme stability
A data-driven, modelling and simulation approach for API capacity ramp-up
Enzyme immobilization by enzyme-polyelectrolyte conjugation on a membrane surface
Formulation of biochar briquettes for electrically heated cupola furnaces
Understanding and improving the fire protection of intumescent silicone coatings
Oligomerization of olefins for sustainable aviation fuel
Graph neural networks and uncertainty analysis for pure compound properties
Fundamentals of combining the transesterification and esterification reaction in enzymatic biodiesel production
Influence of system layout on phosphorous poisoning of Cu-SCR catalysts in close-coupled position
The influence of particle acoustic impedance on LEP coating durability
Influence of fermentation broth composition on life
Influence of type of particles on SNCR reaction
Characterization of an electrochemical biosensor for glucose monitoring in fermentation processes
Colloid Stability of Skincare product
Foundational and Platform Understanding of Continuous Chromatography
Mechanical properties of silicone coatings based on concatenated rings
Metabolic engineering to enhance serine production on glucose
Spin flash drier system modelling
Modelling and optimization of *Aspergillus niger* pilot fermentations (**2 students**)
Modifications of thin film composite membranes with enhanced antifouling properties and mechanical resistance for power generation from brackish water
Degradation analysis and recycling options for engineering thermoplastic composites
Degradation study of polyhydroxyalkanoates (PHA) for pharmaceutical device applications
Optimization of capacity and colour removal during chromatographic capture step of Vancomycin
Optimization of chromatographic polishing step of Vancomycin (**2 students**)
Optimizing seed tank duration by automated data analysis and temperature control
Surface modification of hollow fiber forward osmosis membrane for enhanced ammonium rejection
Pilot and simulation of P2X technology for biogas cleaning
Process models, simulations and optimizations on Human Milk Oligosaccharides (HMO) recovery
Screening and optimization of a novel technology for continuous microbial fermentation
A semiglobal model for ammonia/heptane ignition
Side-chain modification of a biopolymer via radical grafting
Simulation of insulin formulation processes with Computational Fluid Dynamics
Strain and process development for amino acid production through bio-catalysis
Fate of sulfur in melting cyclone-based stone wool production process
Synthesis, testing and recycling of systems for micellar catalysis
Elaboration and implementation of a Digital Twin/CAPS model for a more sustainable production
Exploring new enzymes, carriers and immobilization procedures for small batch enzymatic interesterification
Method for bench scale activity measurement of catalyzed hardware for eSMR
Investigation of the effect of CBD on skin properties
Investigation of methods for estimating interfacial tensions
Study of imbibition in carbonate rocks
Studies on continuous crystallization of APIs (**2 students**)
Composite inorganic intumescent coatings

Analysis of polymer sterilization methods
App development for simulation and optimization of a nanofiltration/diafiltration process
Formation of a biocatalytic membrane skin layer by enzyme-polyelectrolyte co-deposition and interfacial polymerization using enzymes as the aqueous mono
Prediction of pure compound thermodynamic properties
Characterization of DCF technology for microfiltration applications in enzyme recovery
LCA applied to processes for resource recovery of tannery effluents
Modeling of transdermal cannabinoid transport
Measurements of reaction kinetics and physical properties for innovative CO_2 capture solvent (**2 students**)
Periodic stripping - Digital Shadow
RPC Gel Regeneration
Scouting of environmentally friendly packaging for oral dosage forms
Thermodynamic and physical properties as basis for digitalization of glycol processes
Application of biochar for reduction of emissions from pig stables
Assessing the effect of dissolved gas concentrations on the physiology of *Yarrowia Lipolytica*
Functionality change by side-chain modification of a biopolymer
Experimental analysis of droplet behavior at the interface between gas diffusion layers and free flow in PEM fuel cells
Improving bioreactor scale-up through mixing characterization using an experimentally validates CFD model
Enhancing chain elongation of syngas fermentation products
Sensitivity analysis of sub-models for CFD simulation of cyclones
Commissioning and starting up of pilot scale fermentation equipment and processes
Modeling of high-efficiency separation columns with dividing walls
AI Assisted reverse engineering of molecules
Efficiency optimization in solvent recovery (**2 students**)
Oxidation of ammonia under Rockwool cyclone conditions (**2 students**)
Density functional theory calculations of N_2O decomposition in Fe containing zeolites
Development of process for loading of actives into cross linked emulsion
Development, cultivation and analysis of enriched microbial cultures for production of acetone or butanol
Carbon dioxide storage in the aquifer

SDC MASTER DEGREES

Ammonia synthesis at mild conditions over ruthenium nanoparticles supported on thinlayered MFI zeolites
Electro Synthesis of High Entropy Alloys
Preparation of ultrathin lithium metal anode by electrodeposition
One-pot integrated bioethanol production using biocompatible ionic liquids
Preparation of high-performance injectable hydrogels for biomedical applications
Electrocatalytic hydrogenation upgrading of model compounds of bio-oil.
Novel biochar supported perovskite-type catalyst in NH_3-SCR process
Mathematical modeling and CFD simulation of spiral wound pervaporation module for bioethanol separation
Electrocatalytic N_2 Reduction to Ammonia
Synthesis of 2D material-doped vanadium phosphorus oxide catalyst for n-butane selective oxidation
Green Catalytic Synthesis of Alicyclic Amine from Nitroaromatic
Simulation of 350tons MIP reactor with MPPIC method to investigate scale-up effect

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