DTU Chemical Engineering
Department of Chemical and Biochemical Engineering

Annual Report 2024

At Pilot Plant they use math to make the bioreactor run more smoothly.
Jørgen True

Contents

Annual Report 2024

Every six years, DTU's departments undergo a research evaluation by an external panel. It serves two main purposes; to assess the department's current quality of research and PhD education compared to international standards and to provide recommendations for the future. This year, it was DTU Chemical Engineering's turn.

I was incredibly proud to witness our dedicated and competent employees working tirelessly to prepare for the best possible evaluation. The evaluation adds to our motivation to continue improving the department, and it pays off. In 2024, once again, we ranked no. 1 in Chemical Engineering by EngiRank, while DTU secured the top spot in EngiRank's European ranking and placed third in Engineering and Technology in Research.com's global ranking.

In this Annual Report, we highlight several research projects that have positioned the department at the forefront of chemical and biochemical engineering. You can read about our efforts to demonstrate carbon capture and utilization technologies across Europe, transform the future of soft wearables and how we are using microbes to facilitate the green transition. Additionally, we show how our digitalization strategy has led to several research initiatives across our centres, where researchers employ modelling in the digitalization of chemical and biochemical unit operations and biomanufacturing. Finally, we are making significant progress in developing bio-based solutions for anticorrosive coatings.

Well-trained engineers and PhD graduates are KT's most significant contributions to society, making teaching quality a top

priority for us. Two notable achievements in this ongoing effort include Ulrich Krühne being awarded the DTU Teaching Award for 2024 and PhD student Randi Neerup receiving the DTU Young Researcher Award for her thesis titled "Large CO_2 Pilot: Energy Consumption, Emission, and Corrosion."

External grants have helped the department grow. Our researchers attracted substantial funding this year, such as a €10 million (out of which €2,6 million is to DTU Chemical Engineering) EU Horizon grant awarded to Associate Professor Seyed Mansouri for the SEAFAIRER project. Additionally, Associate Professor Xiaodong Liang received a prestigious ERC Consolidator Grant for REMOTE. The SEAFAIRER project aims to showcase advanced biofuel technology to decarbonize the maritime sector and REMOTE seeks to establish the foundation for a paradigm shift in molecular thermodynamics.

To maintain our commitment to excellence in education and research, we must attract and retain the next generation of faculty. This year, we welcomed two new members; Assistant Professors Magdalena Skowyra and Narayanan Rajagopalan. Both will make valuable contributions to our teaching and scientific research. Looking ahead, in 2025, we will also appoint new professors to further enhance our department.

Our future goals include expanding our research collaborations with industry and international partners, increasing our focus on sustainable and green technologies, and enhancing our PhD programs to attract top-tier talent from around the world.

DTU Chemical Engineering is prepared for the future and committed to maintaining and improving our research excellence to the benefit of society.

Kim Dam-Johansen
Professor, Head of Department

Kim Dam-Johansen
Professor,
Head of Department

Christian O. Carlsson

EDUCATION

347
STUDENTS*

26
COMPLETED BSC PROJECTS

37
COMPLETED BENG PROJECTS

112
COMPLETED MSC PROJECTS

RESEARCH

198
SCIENTIFIC ARTICLES IN WOS-INDEXED JOURNALS

29
PHD DEFENCES

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

INNOVATION

5

NOTIFICATIONS OF INVENTION

ORGANIZATION

295

EMPLOYEES IN TOTAL

58

TECHNICAL /ADMINISTRATIVE EMPLOYEES

84

RESEARCHERS / SENIOR RESEARCHERS

33

FACULTY MEMBERS

120

PhD STUDENTS (INCLUDING 10 INDUSTRIAL PHD'S)

Fully digitalized State of the Art bioprocessing equipment at the Pilot Plant 📷 Jørgen True/ Studie-E

With math, the bioreactor runs more smoothly

At the DTU Chemical Engineering Pilot Plant, researchers are using mathematical modelling to predict and actively act on cellular behaviour and product formation in bioreactors.

Microorganisms can be used to produce pharmaceuticals, food additives, carbon-neutral fuels and biodegradable plastics using renewable resources, different waste streams or even CO_2. Towards a more sustainable and circular economy, biochemical engineers aim to turn these exciting microbial abilities into products and processes.

Accurate process control

For a stable operation, all environmental factors and nutrient additions need to be kept at optimal levels. The living cells are very sensitive to changes and if changes happen, they often cannot be reversed. Therefore, proactive control strategies, such as model predictive control are necessary. And here comes the difficulty! How can we foresee cellular behavior, production rates as well as nutrient demand to proactively and optimally act on the process?

Assistant Professor Julian Kager tackles this challenge by mathematically describing the reactor system and especially the cells inside it. Thereafter these mathematical models can be used to predict events and to take proactive actions. "It is just like coupling the temperature control of a building with the weather forecast. So, you can start to preheat the building before the cold front hits. This avoids a sudden drop in room temperature," Julian explains: "In our bioreactors, we predict cell growth and product formation instead and can plan nutrient supply to avoid any future starvation or overfeeding".

From simulation to lab- and pilot-scale

The potential of these advanced and proactive control strategies has been shown in many simulation studies but their verification in lab- and especially pilot -scale is still lacking behind. "After the digitalization efforts in our Pilot Plant over the last years we are now ready to take this step," says Julian Kager and explains that they can now access the Pilot Plant's state-of-the-art equipment from anywhere and anytime and can run the same programming code (e.g. Phyton® scripts) on different scales and systems from different vendors.

Ongoing research projects

Two PhD projects are associated with the ongoing start grant in Bioprocess Control and Digitalization. One of the projects with the working title "Physiological Process Control" is looking into ways to shift the control focus away from the physical/chemical parameters of the bioreactor to more cell-specific parameters. The ultimate goal is to be able to directly regulate and stabilize production rates by influencing the cells' metabolism. The other thesis project is about automatic

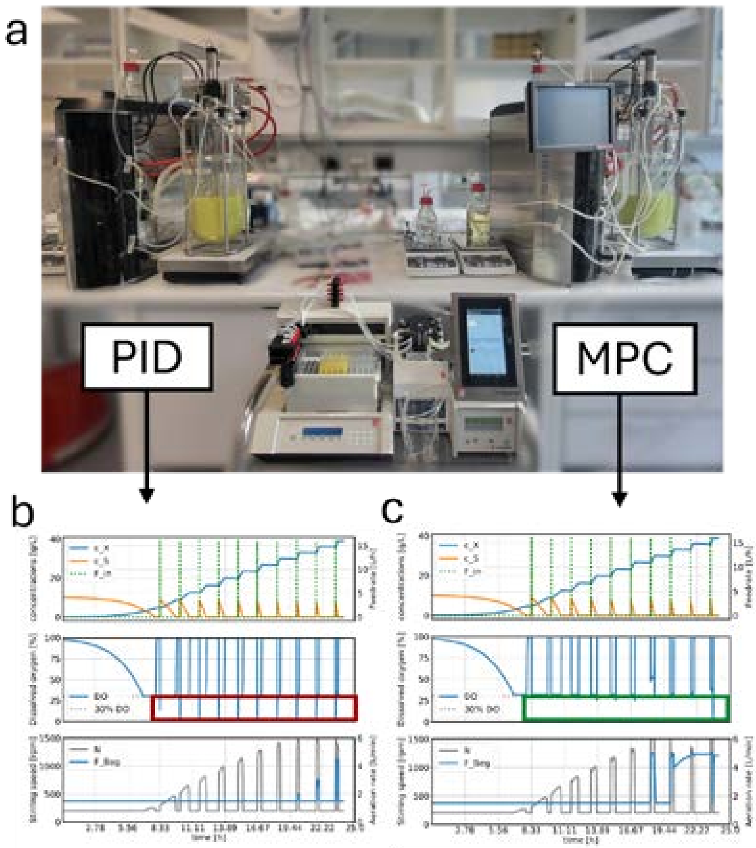


Figure 1 a) Lab -Reactor setup at DTU Chemical and Biochemical Engineering Pilot Plant for verification of advanced control algorithms. b) classical PID control of dissolved oxygen with oxygen limitation periods after feed addition (red rectangle) c) Model-Predictive Control (MPC), which can avoid any oxygen limitation with his predictive behavior (green rectangle). Result presented at the 8th BioProScale Symposium and awarded with a poster prize.

Jørgen True

execution of experiments and self-learning algorithms to plan and execute new "best experiments", which is also referred to as model-based re-design of experiments.

"Currently we are experimenting with model predictive control algorithms and model-based design of experiment approaches in our labs. As soon as we have them successfully tested, we aim for their validation in pilot scale, which will generate a huge interest in the biotech industry and the research community," concludes Julian Kager.

Assistant Professor Julian Kager

Novo Nordisk Foundation Start Grant in Bioprocess Control and Digitalization
Time frame: 2023-2026
Total budget: 2,5 m DKK

PILOT

The DTU Chemical Engineering Pilot Plant offers and further develops our unique equipment infrastructure and our strong theoretical and practical unit operation competences within existing and state of the art technologies and processes of the chemical, pharma, biotech, food and energy industries.

Our aim is to provide world-class education for the students, and to be the most attractive research partner for our employees and for industry, educational institutions and society. The recent major expansion of the Department's pilot halls, laboratories and process and analytical equipment will ensure that our educational and research facilities and its activities will be even more attractive, modern and efficient.

With four new large pilot halls in addition to the existing five halls, and a huge investment in new process and analytical equipment, we are able to operate, simulate, and develop many types of unit operations and process lines in pilot scale, representing the life science industry as well as traditional chemical, biochemical and food industries.

A major investment in the digitalization of a significant part of our pilot units has been implemented during 2022-23. The project includes implementation of a Siemens Scada system for educational and research data collection and manipulation, and a virtual reality environment for e-learning to facilitate the remote study of some of the most used unit operations.

A new pilot scale fermentation-based manufacturing line for pharmaceuticals, food and biochemicals, including fermenters from lab scale to 250 litres, and a broad selection of relevant downstream separation and purification equipment, has been approved for handling of Genetically Modified Organisms class 1 in large scale. Furthermore, we have the amplest lab facilities also approved for GMO projects.

We are focusing on attracting new external collaborators to increase our research and innovation activities based on processes, technologies and equipment. This will continue to enhance a dynamic interface and activity between our capabilities and our existing and new external collaborators.

Carbon Capture and Storage in Denmark: The ConcenCus Project

The ConsenCUS project is a European carbon capture and storage (CCS) collaboration with 18 different partners from nine countries. Its main goal is to demonstrate carbon capture and utilization technologies. The new technologies being developed are all based on Power-to-X (PtX), and three demonstration campaigns are a key aspect of the project.

Carbon Capture and Storage (CCS) has emerged as a pivotal topic in both research and political arenas. Denmark has positioned itself as a frontrunner in CCS, driven by the ambition to meet the Danish government's climate targets by reducing CO_2 emissions. Achieving these goals necessitates the development of innovative technologies, and DTU Chemical Engineering is at the forefront of this effort, continuously advancing CCS technologies. The ConsenCUS project, initiated in 2021, is now producing results.

PtX Carbon Capture

At the heart of the ConsenCUS project lies the PtX carbon capture technology. This solvent-based capture method utilizes electricity to regenerate the solvent and extract CO_2. The process involves capturing CO_2 with a high-pH solvent and subsequently lowering the pH within an electrochemical cell. By splitting water, a local decrease in pH occurs at the anode, while the pH at the cathode increases. Water splitting is energy-intensive, so the project has developed advanced membranes and innovative process configurations to reduce energy consumption.

CO_2: Resource or waste product?

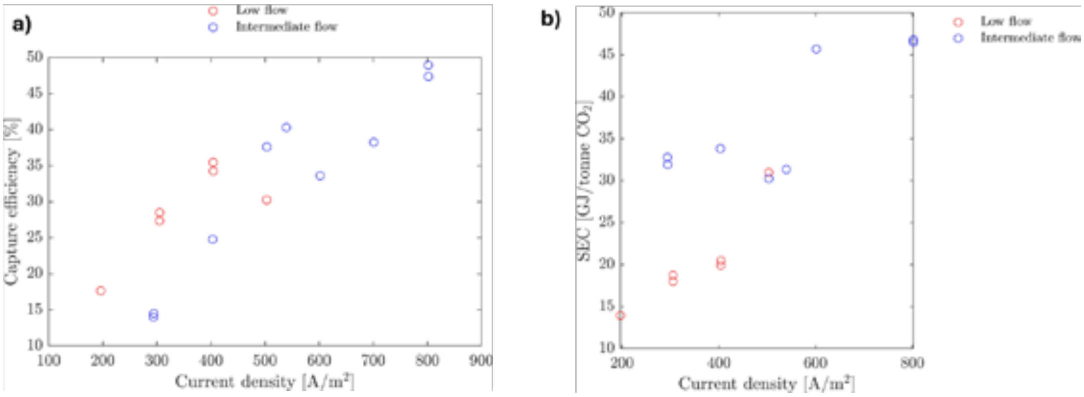
"Typically, CCS projects focus on the long-term storage of CO_2. However, there is a growing interest in utilizing CO_2 as a building block for chemicals and fuels. Converting CO_2 is energy-intensive, and its commercial viability depends on energy prices. With fluctuating energy prices, temporary CO_2 storage could enhance the business case for CO_2 conversion plants," explains Associate Professor Philip Loldrup Fosbøl. The project explores whether temporary CO_2 storage can facilitate the renewable energy transition, considering the potential of European energy and industry clusters.

Initial findings

Initial findings emerged even before the demonstration plant's installation. A notable discrepancy exists between industry standards for clean gas and the requirements for carbon capture plants. Impurities such as NOx and SOx significantly impact the design and operation of carbon capture systems. In solvent-based technologies, NOx and SOx follow similar reaction paths as CO2, leading to the capture of these impurities alongside CO_2. Once inside the system, NO_2 and SO_2 tend to remain in the solvent, reducing its capacity to capture carbon over time and increasing energy consumption. Effective removal of NOx and SOx, without eliminating CO_2, is crucial for full-scale CCS plants.

Results from the first two demonstration campaigns

Two out of three demonstration campaigns have been performed. The data is currently



being analysed and prepared for publications. Early results have been included here and are presented in figure 1a) and 1b). In the first figure, 1a), the y-axis shows the capture efficiency of the CO_2 in the flue gas. A capture efficiency of 100% would mean that all the CO_2 is removed from the flue gas. For experimental purposes, capture efficiencies far from 0% and 100% are preferred, to avoid over- or undershooting. The x-axis shows the current density of the electrochemical stack. This is an important parameter for the operation of electrochemical cells. The red circles show results with a low flow rate of solvent through the system, while the blue circles show the results with an intermediate flow rate of the solvent. For both the red and the blue circles, it is observed that the capture efficiency increases as the current density increases, as a higher current density increases the solvent capacity to absorb more CO_2. In figure 1b), the x-axis is also current density, while the y-axis shows the specific energy consumption (SEC) in giga joule (GJ) per tonne of CO_2 captured. Similar to Figure 1.a, the red circles show results from a low flow rate of the solvent, while the blue circles show results from an intermediate flow rate of the solvent. In this graph, the trend is not as clear in graph 1a). However, a general tendency for the SEC is to increase with current density, albeit not in a linear fashion. The SEC for all experiments is high, much higher than that from comparable technologies such as amine CO_2 capture. The SEC is expected to be lowered when the system operates with all electrochemical stacks simultaneously.

"The ConsenCUS project represents a significant step forward in CCS technology, with promising initial results and ongoing research to address challenges and optimize processes. By leveraging renewable electricity and innovative technologies, the project aims to make CCS more efficient and economically viable, contributing to Denmark's and Europe's climate goals", Philip Loldrup Fosbøl explains.

Associate Professor Philip Loldrup Fosbøl and Senior Project Manager Sebastian Bay Villadsen

ConcenCus

The project is led by the University of Groningen in the Netherlands. It is developing new technologies and investigating potential carbon clusters in the EU. Associate Professor Philip Loldrup Fosbøl and Senior Project Manager Sebastian Nis Bay Villadsen, DTU Chemical Engineering lead the three demonstration campaigns in Denmark, Romania and Greece.

Timeframe: 2021-2025
Total budget: 104 M DKK
DTU budget: 34 M DKK
Main goal: Demonstrate carbon capture and utilization technologies
Target: 100 kg CO_2 per hour, 500 Nm^3 flue gas/hour

King Frederik X (Crown Prince at the time) opens the DTU CCUS plant for the first experimental campaign. Besides King Frederik X, the EU Commissioner for Energy, Cadri Simson (light brown jacket) and Danish minister for climate, Lars Aagard (m, dark suit behind the King) was also present. Next to the king is Philip Loldrup Fosbøl and Sebastian Nis Bay Villadsen, both in safety vests. Jesper Sand Damtoft

AT CERE - Applied Thermodynamics-Center for Energy Resources Engineering

AT-CERE stands for Applied Thermodynamics – Center for Energy Resources Engineering. The AT CERE Research Centre, as part of DTU's Department of Chemical and Biochemical Engineering, is a centre focused in the areas of Applied Thermodynamics, transport properties and processes, materials science, fermentation technology and mathematical modelling with applications to the energy sector incl. petroleum technology, CO_2 capture, utilization and storage, chemical industry as well as biotechnology with emphasis on biorefinery conversions.

AT CERE is associated with the DTU interdepartmental activity CERE, which is Denmark's leading research centre in a wide range of energy resources which, in addition to the above, also include geoscience. AT CERE and CERE host an industry consortium, which includes around 15 companies from all over the world.

AT-CERE is committed to perform high-quality experimental and theoretical research with international impact, in which we often combine the above disciplines in broader projects of interest to chemical, energy and biochemical engineering. Both fundamental and applied research is being conducted. Many of the applied problems are inspired by or based on input from CERE's industrial consortium.

Our History
AT CERE has, in its various forms, a 30+ years history. The centre in its original form (first as a centre in applied thermodynamics, and later, since 1987, in the form of an engineering research centre, IVC-SEP) was established in the early 1980's by Professor Aage Fredenslund, who was succeeded in the leadership in 1994 by Professor Erling Stenby. Since 2009 AT CERE's activities are connected to DTU's interdepartmental activity CERE.

For more information, please visit CERE's website: www.cere.dtu.dk

Main deliverables to the Consortium members
Corporate members of the Consortium can access and obtain all results directly from the Center for Energy Resources Engineering as soon as they become available, usually one or two years before publication. A computer program for Separation and Phase Equilibrium Calculations, SPECS, is made available for members of the Consortium. A wide range of other software tools are also available to member companies as well as access to an electrolyte database and other facilities. Consortium members are offered also favourable prices for PhD courses organized by the centre as well as access to experimental facilities. Also, students and scientists from the Center for Energy Resources Engineering are available for collaboration with consortium members on projects conducted at company facilities.

Progress in anticorrosive coatings

The Hempel Foundation Coatings Science and Technology Centre (CoaST) at DTU Chemical Engineering has made exciting advancements in anticorrosive coatings, particularly focusing on bio-based solutions to advance more sustainable solutions.

Corrosion can cause structural failures with severe consequences for people and the environment. It is important to use anticorrosion coatings to protect metal structures like pipelines, tunnels, ship ballast tanks, containers, and wind turbine foundations from corrosion due to exposure to chemicals during production or harsh marine environments. However, to protect the environment, more sustainable anticorrosive coatings are in high demand and here CoaST is making significant advances in bio-based solutions.

Bio-based binders

The work began in 2020 and set the stage with the use of solid lignin directly as fillers and extraction and chemical modification of lignin molecules into bio-based epoxy binders. Parallel to this, the CoaST group in collaboration with Professor Mats Johansson at KTH, Sweden, demonstrated the potential of Kraft lignin particles in enhancing the chemical resistance and structural integrity of epoxy novolac coatings. Kraft lignin is a by-product generated from the paper and pulp industry after treating lignocellulose materials by the Kraft pulping process. 'Our research emphasized mechanical sieving to obtain fine lignin particles for coating formulations, presenting it as a viable alternative to the conventional solvent fractionation methods for integrating Kraft lignin into coatings', says professor Søren Kiil and continues "we see many opportunities in the field and expect to start several new projects in the coming years".

Sustainable anti-rust pigment

Another bold step forward in bio-based solutions has been introducing bio-char nanoparticles (BCN) as a sustainable, cost-effective, and highly efficient conductive pigment in zinc epoxy primers (ZEPs) (figure 1), which function as an anti-rust pigment.

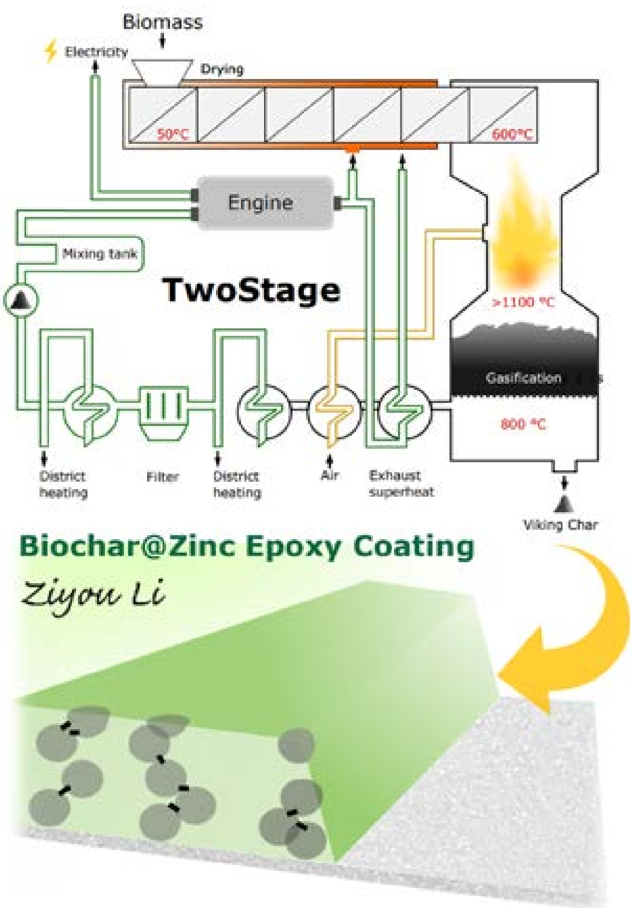


Fig. 1. Schematic illustration of bio-char production for anticorrosive coatings, used in cooperation with the CHEC centre.

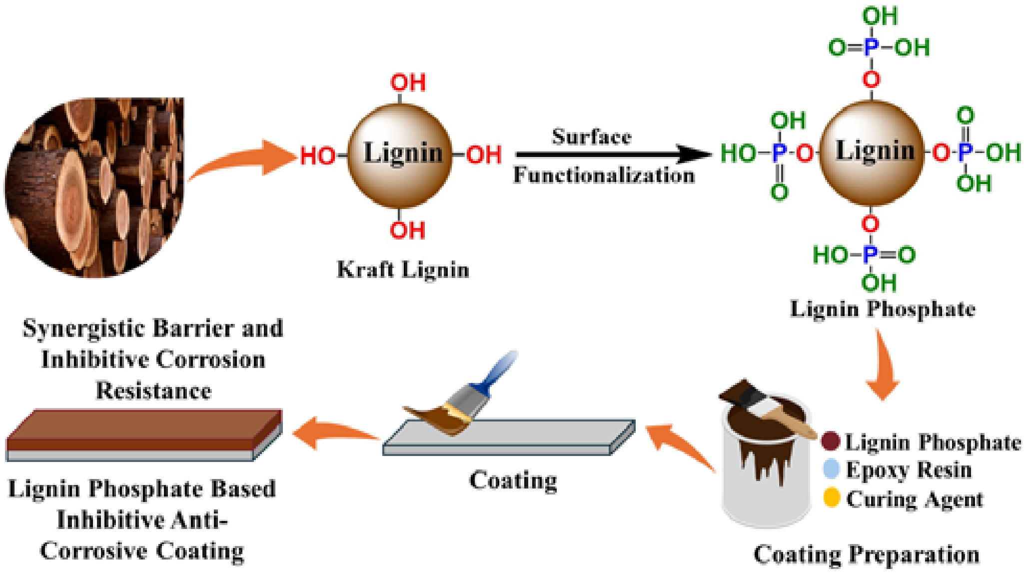
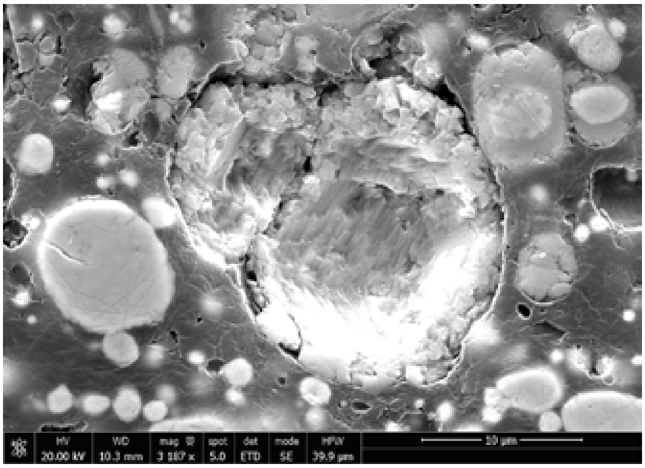


Fig. 2. Lignin phosphate-based inhibitive pigment with synergistic barrier and inhibitive corrosion resistance.

"Through a systematic comparison of ZEPs enhanced with pyrolyzed and gasified BCN, PhD student Ziyou Li has achieved remarkable results," says Professor Kim Dam-Johansen. The modified coatings, with gasified BCN, extended galvanic protection to over 600 hours during the exposure with a reduced zinc content of 30 vol%, compared to just 100 hours for the standard reference. X-ray diffraction analysis confirmed a significant improvement in the utilization rate of zinc within the modified coatings.

"We believe this breakthrough, combined with the exceptional economic and environmental advantages of biochar over other carbon materials, is set to redefine the future of protective coatings", says Professor Kim Dam-Johansen.



Scanning electron microscope image of the biochar-boosted zinc epoxy coatings after 39 days of exposure. Ziyou Li

Inhibitive pigment

Another innovation from the CoaST group is a zinc-free inhibitive pigment made from phosphorylated lignin, offering a bio-based solution for anticorrosive coatings. The reason for wanting a zink-free alternative is to reduce the use of heavy metals to benefit the environment. The research aimed to mimic the inhibitive mechanism of zinc phosphate and to provide a bio-based zinc-free alternative in the domain of inhibitive anticorrosive coatings. Figure 2 illustrates the schematic for the synthesis and incorporation of lignin phosphate in epoxy coating for anticorrosive coating.

Better understanding of bio-based materials

"Collectively, these sub-projects have significantly advanced our understanding of lignin and other bio-based materials potential in anticorrosive applications. Looking ahead, we are initiating a unique approach to convert black liquor from the Kraft process into lignin-based bio-oil for use in coatings," says Professor Kim Dam Johansen.

To achieve this, the group works with specialized reactors, carefully controlling the conditions to optimize each stage of the process. The research also involves detailed analytical testing to monitor the quality and composition of the lignin throughout the process. This approach provides a more efficient and potentially more sustainable way to convert waste into high-performance materials.

"In summary, we are studying lignin in its unmodified form, as chemically modified particles for use as fillers and pigments, and as a potential binder for coatings applications. Additionally, we are exploring new materials, such as bio-chars and converted black liquor, for their use in coatings", Professor Kim Dam-Johansen concludes.

Professor Kim Dam-Johansen

PhD student Alberto Goicoechea Torres preparing black liquor for an experiment. Lisbeth Kirk Mynster

CoaST

The Hempel Foundation Coatings Science and Technology Centre

CoaST is a leading centre for research, innovation, and education in sustainable and primarily organic coatings technologies. CoaST covers coating technologies along the entire value chain from raw materials, over formulation, test and characterization to production and application. In the broad perspective, CoaST activities support development, production, and use of coatings with improved sustainability profiles over the lifetime of the coating.

Coatings for a better future

Coatings are highly complex multicomponent products, which must fulfill many conflicting requirements. Important properties are, for instance, strong adhesion to the substrate or underlying coating layers, adequate viscosity profile, long durability, continuous or durable appealing appearance, and all this at a competitive cost. Functional coatings, in addition, must e.g. provide substrate protection such as resistance against corrosion or biofouling, provide longer escape times during a fire, or remove pollutants through catalytic activity.

Within the area of sustainable coatings science and engineering, CoaST aim to:

- provide in depth knowledge of current coatings challenges
- understand the fundamental working mechanisms of coatings
- develop mathematical tools that quantify coating behaviour
- design and use equipment for accelerated testing of coatings
- design coatings that set new standards with respect to more sustainable formulations and efficient functionalities

Presently, research activities in CoaST focus on the following areas:

- Sustainable raw materials for coatings
- Coating formulation and production principles
- Fouling control coatings
- Anti-corrosive coatings
- Intumescent coatings
- Other functional coatings

The CoaST research approach is based on classical chemical engineering tools combined with formulation expertise often in close co-operation with industrial partners. CoaST's research covers from basic to applied research and range from laboratory work to model based test programs to natural ageing exposures. CoaST's fundamental coating research supports the traditional more empirical approach of the coatings industry and is focused on improved sustainability profiles.

Promising possibilities with the pyrolysis of biomass

The Catalysis and High-temperature Engineering Centre (CHEC) at DTU Chemical Engineering is actively engaged in multiple research projects focused on the pyrolysis of biomass, with a particular emphasis on optimizing pyrolysis products such as biochar, bio-oils, and gas for various applications.

Pyrolysis process

Pyrolysis is a thermochemical conversion process where solid fuel is heated to temperatures between 400 and 900°C in the absence of oxygen. Under these conditions, biomass decomposes into gas, vapour, and solid products, namely pyrolysis gas, bio-oils, and biochar. Pyrolysis gas and bio-oils can be used on-site for energy production through direct combustion or upgraded for other uses. Pyrolysis gas can serve as a raw material for catalytic methanol synthesis or methane production via biological fermentation (bio-methanation), while bio-oils can be upgraded to liquid fuels.

Biochar, on the other hand, is a promising amendment for agricultural and environmental applications. Approximately half of the carbon in the feedstock is retained in biochar, which, due to high-temperature thermal treatment, becomes a more ordered and stable form compared to the original biomass. This stability makes it difficult for microorganisms to degrade, allowing it to persist in soil for hundreds or even thousands of years, providing a carbon sequestration effect known as biochar carbon removal (BCR). Additionally, biochar can enhance soil health and productivity.

"The potential for all pyrolysis products makes it a very promising field of research for CHEC", says tenure track researcher Giulia Ravenni from DTU Chemical Engineering.

Key projects and collaborations

The centre is involved in two major projects in collaboration with Stiesdal SkyClean. The SkyClean pyrolysis technology utilizes local biomass resources to produce energy, bio-oils, and biochar. These projects aim to support the development and optimization of the technology, paving the way for the widespread implementation of pyrolysis in Denmark, and realize its potential for energy generation and carbon sequestration.

Production of bio-oils

One project aims at producing bio-oils and their potential use as sustainable fuel in the transport sector after catalytic upgrading. Raw bio-oils from pyrolysis are rich in oxygen, relatively low in hydrogen, and tend to be acidic and viscous, necessitating upgrading before being used as fuel. This project investigates the required level of hydrotreatment for mixing bio-oil with heavy fuel oil for marine transport and it is progressing well:

"Our initial results are encouraging, showing that upgraded bio-oils are miscible with heavy fuel oil in some cases and exhibit decreased acid number, water content, and viscosity, along with increased H/C ratio and heating value like we were aiming for", says Giulia Ravenni.

Scaling up the technology

In parallel, CHEC is a partner in a large project

Senior researcher Wolfgang Stelte at the pilot plant in Risø Magnus Møller

financed by the Danish Energy Agency's "Pyrolysepulje," aimed at scaling the pyrolysis technology to a 20 MW size. CHEC's work focuses on operating the 200 kWth SkyClean pilot plant at Risø Campus and characterizing the biomass fuel and biochar product in terms of overall composition and contaminant content. The 200 kWth SkyClean pilot plant, the first prototype for Stiesdal SkyClean pyrolysis technology, began operation in 2019 and has been used primarily for initial development and testing of the pyrolysis reactor design and operation. The researchers will now explore alternative routes for using pyrolysis gas, including testing gas upgrading via partial oxidation and hot char beds to produce methanol or methane to be used various applications.

Ensuring Biochar Safety and Environmental Impact

Given that the primary application for biochar is expected to be in agricultural soils, ensuring its complete safety and the absence of harmful contaminants is crucial. At CHEC, various potential pyrolysis feedstocks have been analyzed and tested in laboratory-scale pyrolysis systems. Biochar samples produced in the laboratory and obtained from the SkyClean plants have also been thoroughly examined to assess their quality. The results have been promising, says Giulia Ravenni:

"Our results indicate that the biochar consistently contains 50% to 90% carbon by weight. Additionally, the detected levels of contaminants, such as polycyclic aromatic hydrocarbons, are sufficiently low to suggest that SkyClean biochar is safe for soil application and biochar carbon removal (BCR) implementation."

Tenure track researcher Giulia Ravenni and Senior researcher Wolfgang Stelte

In addition to the SkyClean projects, the CHEC group is leading a research project from 2024 to 2027, financed by the Danish Environmental Agency (Miljøstyrelsen). This project focuses on evaluating the potential environmental risks of large-scale pyrolysis systems, where biochar is produced for agricultural and environmental management, while other pyrolysis products are utilized as energy carriers. The research will concentrate on pyrolysis feedstocks most relevant to the Danish context, including straw, biogas digestate fibres, and sewage sludge.

This project involves close collaboration with DTU Sustain, Aarhus University, and Roskilde University to evaluate the fate of a wide range of contaminants, including persistent pollutants such as per- and polyfluoroalkyl substances (PFAS), in pyrolysis systems. CHEC's work will also address the safe handling and transportation of biochar, including potential issues related to self-ignition.

CHEC - The Catalysis and High-temperature Engineering Centre

The CHEC Research Centre at DTU Chemical Engineering carries out research in fields related to chemical reaction engineering, with the focus on catalysis and on thermal processes such as combustion, gasification and pyrolysis. The aim is to facilitate the transition to more sustainable and cleaner processes in fuel and chemical production, heat and power production, transportation, energy-intensive industry and agriculture.

Important areas include Power-to-X technologies, development and application of carbon-free energy carriers such as ammonia or metals, use of sustainable resources such as biomass and waste for production of power, fuels and other products such as biochar, and emission control.

CHEC has achieved international recognition through a combination of experiments and mathematical modelling, based on chemical kinetics, chemical reaction engineering, thermodynamics, and fluid dynamics.

Laboratory reactors are used to characterize gas-phase, gas-solid and catalyzed reactions at atmospheric or high pressure in a wide temperature range, sometimes in combination with IR and X-ray spectroscopy. Extrapolation to industrial scale is conducted by use of pilot-scale experiments or full-scale measuring campaigns, often combined with computational fluid dynamics (CFD).

The Role of Hybrid Modelling in Digitalization of Chemical and Biochemical Unit Operations

A key driver in digitalization of (bio)chemical process is the unity of traditional modelling and Artificial Intelligence.

Process modelling is a cornerstone discipline in the field of chemical engineering and is integral when it comes to understanding, designing, optimizing, and operating processes. Traditionally, process modelling has been performed based on physical and chemical understanding and has been heavily reliant on expert knowledge and targeted experiments, and as a result model development has been time-consuming.

Artificial Intelligence (AI) and Machine learning (ML) have yielded tremendous successes in e.g. natural language processing (ChatGPT), image recognition (face recognition, autonomous cars, and cancer diagnosis), and playing games (AlphaGo). Even though AI and ML have proven capable in other fields, they have yet to reach their full potential within process modelling for (bio)chemical processes.

Interdisciplinary approach

In a joint effort, under KT Consortium auspices, the Process and Systems Engineering Center (PROSYS) and the Center for Energy Resources Engineering (CERE) have worked on utilizing AI and ML for process systems engineering (PSE) applications. Developing AI for PSE is a difficult task, as the conventional AI approaches come short when faced with small data quantities, serially correlated data points, and data with low variation, as typically seen in data from the production lines in the (Bio)Chemical industry.

This type of problem calls for an interdisciplinary (hybrid) approach, where process understanding and established mathematical methods are combined with AI, utilizing both expert knowledge and the available process data. Even though the field of hybrid modelling has existed for more than 30 years, it has yet to find its full application in full-scale industrial processes. Collaborations with top experts in the field from Columbia University and Nova School of Science and Technology have been conducted to develop best practices and the proposed methodologies have been showcased using both pilot- and industrial-scale processes.

Hybrid modelling in Industry 4.0

Improved interconnectivity, data acquisition, and cloud computing are all part of the fourth industrial revolution (or Industry 4.0). With these digitalization efforts, process data has become more accessible in the industry. However, the full value of this process data is rarely achieved due to the complexities of developing, integrating, and maintaining hybrid models in full-scale production processes. This can be in part attributed to challenges with developing hybrid models directly for full-scale processes, as it is typically not feasible to experiment in full-scale. Furthermore, the topic is complex and multi-faceted and requires serious educational investments by industries and engineers.

These barriers must be overcome before hybrid models can efficiently be used in industrial processes e.g. for optimization or control applications.

At PROSYS work has been conducted with industrial partners to propose a framework that takes the full lifecycle of hybrid models into account from scoping to model development and model implementation and finally to maintaining the models.

Pilot plant: A digitalization playground

With a recent digitalization upgrade to the DTU Chemical Engineering pilot plant, a unique opportunity for working with data in an industry-like environment has arisen. A range of different unit operations has been connected to a state-of-the-art Supervisory Control and Data Acquisition (SCADA) system with sensor measurements being stored in a central database. Additionally, a Kubernetes cluster has been set up for the pilot plant allowing for process models to be deployed. This new architecture can be used as a digitalization playground for hybrid model development and deployment, and for running these in real-time.

A bubble column aeration system has been used as a case study for the development of digital twins providing accurate forecasting of the aeration.

The work on hybrid modelling will be continued in the future with new cross-centre projects building on the foundations already made by including more complex fluid-separation unit operations from the pilot plant and using the developed models in optimization and control applications. These applications can in the future be used in an educational environment to teach students about hybrid modelling, enabling the upcoming engineers to take full advantage of digital transformation.

Professor Georgios Kontogeorgis

PhD students Mads Stevnsborg and Peter Jul-Rasmussen testing hybrid model implementation for bubble column in DTU Chemical Engineering Pilot Plant. Fiammetta Caccavale

KT Consortium

At KT Consortium we bring together advances and developments made in the area of Process Systems Engineering, Bio-Process Engineering, Applied Thermodynamics and Property Prediction within the Department of Chemical and Biochemical Engineering at DTU and to continuously improve and innovate for a better and more sustainable future.

The KT Consortium is an industry-academia collaboration providing service to company members by fostering a cross-sectorial understanding of (Bio-)Process Systems Engineering and Thermodynamics. The consortium was founded in 2017 based on a long-standing history of collaboration with industry from previous centres and consortia at the Chemical and Biochemical Engineering Department.

We work on developing generic methods and tools using computer-aided systems approach to solve and analyse problems related to product-process modelling, simulation, synthesis, design, analysis, control, and operation for companies within the areas of chemical, pharmaceutical, agrochemical, food, and biochemical industry. KT Consortium is a cross centre activity involving faculty and students from AT-CERE, PROSYS and CHEC research centres. We have close collaborations on a number of projects, work together in funding applications and for supporting our member companies on a wide area of assignments.

As an industrial member of the KT Consortium, one will be provided with state-of-the-art CAPE and PSE methods and tools, the technologies for future chemical and biological processes along with a series of other benefits such as:

1. Participation in the Annual Meeting

2. Web access (via dedicated members site) to:
    - Manuscripts in advance of publication
    - PhD theses (including online defences)
    - ICAS software
    - ICAS training courses
    - Chemical Databases (Electrolyte, IL, organic compounds, etc.)
    - Annual Meetings materials (videos, presentations, workshops)
    - Online seminars (live and recorded) from KT Consortium affiliated staff and faculty as well as invited guests from around the world supported by CERE and PROSYS research centres.

3. Access to collaboration and research from:
    - Student projects
    - Visiting PhD students
    - Joint Research Projects

4. Access to know-how and influence on the research programme.

If you are interested to join KT Consortium or know more about, please contact Professor Georgios M. Kontogeorgis.

Digitalization for (bio) manufacturing

The digitalization of (bio)manufacturing presents challenges that call for significant research and preparation before implementation as the work in the Process and System Engineering Center (PROSYS) at DTU Chemical Engineering shows.

The integration of digitalization into industrial environments, as exemplified by Industry 4.0, has paved the way for the adoption of advanced technologies such as Digital Twins (DTs), Internet of Things (IoT), Artificial Intelligence (AI), and big data analytics.

Increased digitalization and automation offer the potential for significant efficiency and productivity improvements, as well as improved sustainability and competitiveness. The implementation of digitalization within (bio)manufacturing is not without challenges, and a significant research effort is often required in preparation for implementation.

"Traditionally, digitalization has focused on data and models to translate such data to useful information. We support that development by participating in several research activities, often with special focus on biomanufacturing", says Professor Krist Gernaey, head of the PROSYS centre at DTU Chemical Engineering. He offers several examples of their current research activities within this field.

Simulation tools for chromatography

Chromatography is an essential operation in downstream processing of pharmaceutical products. Traditionally performed in batch mode, continuous operation of chromatography offers numerous advantages, including enhanced process control, increased capacity utilization, reduced utility consumption, and improved product purity and yield. Purification of pharmaceuticals can be achieved with greater efficiency by shifting to continuous chromatography. The centre develops simulation tools and shortcut design methods for continuous chromatography processes such as simulated moving bed (SMB), in close collaboration with experts from Forschungszentrum Jülich in Germany.

Energy storage

The intermittent nature of most renewable energy sources is unsuited for today's demand-driven energy market. Therefore, chemical energy storage through PtX technologies is required to support the green energy transition. The main challenge of PtX technologies is handling the highly fluctuating power supply from renewables, as traditional production plants for compounds such as methanol and ammonia, rely on a stable power source (usually natural gas). Consequently, for PtX there is a need to define entirely new operating strategies enabling operation over a broad operating window ranging from 10% to 130% of the nominal plant load. This is for example addressed through rigorous modelling of the PtX plants. Specifically, for a Power-to-Ammonia case study, plant dynamics and operating limits are identified through static and transient simulations across the plant operating window.

"We perform plant-wide steady-state optimization across the operating window and formulate a control strategy for achieving optimal and robust plant operation under dynamic operation with a fluctuating power supply," explains Krist Gernaey.

Component properties

The ability to evaluate pure compound properties of various molecular species is an important prerequisite for process simulation in general and in particular for computer-aided molecular design (CAMD). Current techniques rely on group-contribution (GC) methods but suffer from drawbacks such as the absence of contributions for specific groups. To overcome some of these drawbacks, the PROSYS centre has successfully deployed graph neural network (GNN) models for describing a wide range of pure component properties. A GNN uses a graph representation of the molecule as input, where nodes correspond to atoms and edges correspond to the bonds linking the atoms.

Digitalization relies on data

The success of digitalization efforts is to a large extent dependent on the availability of informative data. At industrial scale, the number of available measurements is usually rather limited, especially in stainless steel bioreactors that undergo thorough sterilization as part of the regular cleaning procedures. For aerobic fermentation, for example, the standard measurements include dissolved oxygen, pH, temperature, etc., whereas essential variables such as substrates and products are only measured sporadically in the lab, by analyzing samples collected on the bioreactor.

At PROSYS, the researchers investigate the development of improved measurement devices to yield more informative data in a fermentation broth, in collaboration with DTU Nanotech.

"More specifically, we have developed patent-pending 4th generation electrochemical sensors for measurement of glucose and lactate in a fermentation broth. Electrochemical sensors for the measurement of glucose – also called biosensors – have been around for a long time. The novelty is that

PhD student Fiammetta Caccavale at work: Development of digital teaching methods, including use of AI-driven tools to enhance student learning experiences. Ulrich Krühne our technology – called SmartSens – is not based on an immobilized glucose oxidase enzyme, but on immobilized nanomaterials that interact with the compound to be measured. Or in other words, the biological element in the traditional biosensor has been eliminated, leading to better thermal stability of the sensors," says Krist Gernaey.

This novel approach to quantifying glucose and lactate has already drawn interest from large players in biomanufacturing and bioreactor equipment manufacturing, and the centre is now working towards the establishment of a startup.

Professor Krist Gernaey

PROSYS

Our main purpose is to perform research and teaching that will contribute to developing technologies for future more sustainable chemical and bio-based production processes.

Furthermore, our activities include digitalization of production processes as well as societal challenges by addressing several Sustainable Development Goals (SDGs), most importantly sustainable production and consumption (SDG12), climate action (SDG13) and affordable and clean energy (SDG7).

Our research work, often in collaboration with industrial partners, involves three main components: **Process systems engineering (PSE), Bio-based transformations (biocatalysis, fermentation) and Separation processes (Downstream processing).**

We develop computer-aided tools for a broad range of processes including food and pharma production, manufacturing of chemicals and wastewater treatment/resource recovery. We work with mathematical modelling and simulation, optimization, process synthesis and design, etc. In recent years, Life Cycle Analysis (LCA) has developed into an important tool complementing traditional techno-economic analysis of process alternatives.
We perform experimental and theoretical work that spans from microscale over lab and pilot-scale to full-scale activities, also including digitalization of the systems studied.

Within fermentation, we work with pure and mixed cultures, and we have also developed activities involving scaling up/scaling down, computational fluid dynamics, and development/test of novel online sensors.

In biocatalysis, multi-step biocatalysis and in-situ product removal (ISPR) are investigated, as well as oxygen supply methods for bio-oxidations. Enzymes investigated include alcohol oxidases, carbohydrate oxidases, cytochrome P450s, Baeyer-Villiger monooxygenases, dehydrogenases, peroxidases, laccases, and transaminases.
Within downstream processing, we cover a broad range of unit operations (e.g. distillation, crystallization, extraction, chromatography), for example investigating methods to obtain improved control of such processes, and have detailed expertise on different applications of membrane processes, particularly classical liquid operations—from microfiltration to reverse osmosis—and use of membranes for enzyme immobilization.

Collaboration is key to our existence, and therefore PROSYS has many international academic partners, and participates in a broad range of industry collaborations.
At the Department, we have frequent collaborations with the department's pilot plant..

Microbes Assisting the Green Transition

The Biological Conversions group (BioCon) research group at DTU Chemical Engineering is pioneering a novel platform for designing microbial consortia tailored to specific processes.

Microbes have been a fundamental part of our planet's ecosystem for over 3.8 billion years. With more than one trillion species, the vast majority of these microorganisms are beneficial and hold immense potential for addressing current biosphere challenges. These microbes harbour crucial genes that can be harnessed for a myriad of processes, offering a unique and substantial opportunity to tackle environmental issues.

Harnessing microbial potential

Microbial technologies present a significant potential for addressing the pressing challenges of our biosphere.

"When we explore the microbial pan-genome and achieve a comprehensive understanding of whole-cell metabolism, we can develop novel bioproducts and processes. Currently, many of the products and chemicals we use are derived from fossil resources," says Professor Irini Angelidaki. However, microbes can catalyze processes that produce these chemicals from biomass technologies. This includes the production of plant growth promoters, improvement of soil fertility, reduction of biodiversity losses, mitigation of pollution, and substitution of plastics with bioplastics. These applications are just the beginning, as ongoing research and gene mining continue to reveal new possibilities.

Current exploitation and future potential

Despite the vast potential, the exploitation of complex microbiomes for the production of specific chemicals is still in its early stages. Professor Angelidaki believes there is an urgent need to advance these technologies to address planetary challenges effectively. Waste and wastewater, for instance, can be converted into high-value products through bioconversion reactions catalyzed by microorganisms. The use of waste biomass requires mixed culture fermentations, which are increasingly important in industrial and environmental biotechnology, as well as in global carbon capture and recycling, where anaerobic microbes play a dominant role.

Innovative approaches at DTU Chemical Engineering

The BioConversion (BioCon) research group at DTU Chemical Engineering, are pioneering a novel platform for designing microbial consortia tailored to specific processes, based on the genetic information of anaerobic microorganisms. This innovative technology leverages advances in multi-omics and automation, such as metagenomics and microfluidics, to develop knowledge-based approaches grounded in genetic data.

"Our multi-step approach begins with deciphering complex microbiomes, establishing crucial microbial interactions, and identifying and modelling key microbes for specific processes. This is followed by isolating often unknown microbes and constructing active microbial consortia for targeted bioprocesses", professor Irini Angelidaki explains.

Advancing microbial consortia design

The traditional method for creating microbial consortia for mixed culture fermentations has been largely random, influenced by environmental variables such as temperature and substrate composition. The approach at BioCon is more systematic and informed by genetic insights. By understanding and manipulating the genetic and metabolic interactions within microbial communities, the researchers at BioCon can design consortia that are optimized for specific bioconversion processes. This not only enhances the efficiency and effectiveness of these processes but also opens up new avenues for sustainable production and environmental management.

Irini Angelidaki concludes: "The potential of microbes in assisting the green transition is vast and largely untapped. At DTU Chemical Engineering, we are at the forefront of this exciting field, developing innovative technologies and approaches to harness the power of microbes. Our work is paving the way for a more sustainable future, where microbial technologies play a crucial role in addressing environmental challenges and promoting a greener planet."

Professor Irini Angelidaki

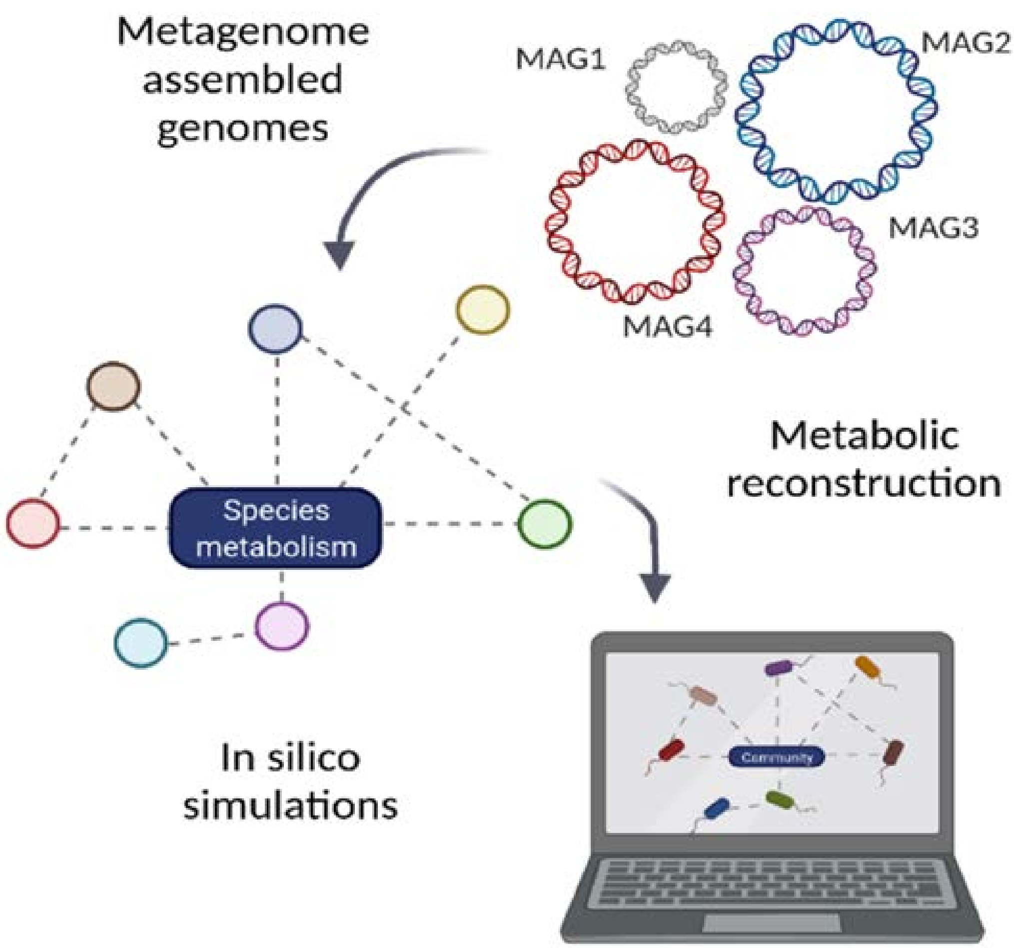


Figure 1: Illustration of microbial interactions of the metagenome assemble genomes (MAGs)

BioCon

In the Biological Conversions group (BioCon), our goal is to develop and validate novel technologies exploiting microorganisms as tools to transform organic waste and wastewater into useful bioproducts, biofuels, and bioenergy.

Utilizing our expertise in biochemical engineering, we develop new technologies to upcycle nutrients from residual resources. We start from basic science, uncovering the mechanisms behind microbial processes, and we continue to apply research towards the development of new biotechnological solutions in pilot scale.

Our experience in biological biogas upgrading (biomethanation) can serve as a perfect example of the development of environmentally and techno-economically sustainable solutions at pilot-scale.

Biomethanation activities aim to develop and demonstrate at operational environment advanced, automated, and consolidated concept for CO_2 capture and utilization by exploiting synergies with excess renewable electricity (e.g. from wind turbines, photovoltaic plants) to produce high-grade biomethane equivalent to natural gas (>95% CH_4) for grid injection. Demonstrating an efficient and high-rate CO_2 capture, utilization and storage technology can markedly combat global warming. In accordance with the European Green Deal to transform EU to climate neutral in 2050, biomethanation can attract growing attention as it can strongly reduce greenhouse gas emissions from industry and energy sectors.

Our ongoing research on biomethanation is focused on increasing biogas production capacity, accelerating start-up period and avoidance of lag phase, revealing proper stand-by mode strategy, unveiling proper dosage, and trickling of nutrients using digested residual resources. In addition, we have increased focus on new reactor configurations, dynamic modelling, and microbial resource management.

The activities are conducted in strong collaboration with wastewater treatment and biogas plants where the biological methanation is evaluated as an alternative methodology to improve economy and sustainability.

NNF WeArAble team observing the actuation performance of silicone dielectric elastomer fibers
Thomas Steen Sørensen

Transforming the future of soft wearables

Soft wearables are poised to revolutionize the way we interact with technology. At the Danish Polymer Centre (DPC) at DTU Chemical Engineering, they are realizing the transformative potential of soft wearables and their positive impact on the future.

The pursuit of good health and well-being is a crucial aspect of sustainable development goals, aiming to create a more sustainable and equitable future. It is important to ensure that this future is accessible to all individuals, including those with physical differences or disabilities. The quality of life for these individuals greatly depends on innovations in the field of wearable actuators and exoskeletons. However, current exoskeleton technology often consists of bulky and heavy materials, posing challenges for integration into everyday life.

User-friendly exoskeletons

DPC is committed to developing lightweight, user-friendly, and textile-based exoskeletons that can be easily integrated into society. They are exploring the use of soft, high-energy density actuators based on novel silicone elastomers developed at DPC to achieve this goal.

"The project goes beyond the development of new materials for soft robotics. It aims to gain a fundamental understanding of the structure-property relationships across multiple length scales, from DNA to textile suits," says Professor Anne Ladegaard Skov.

This is achieved through the hierarchical integration of proteins and silicone elastomers into stable electro-mechanical fibers, embedded in yarns and textiles, to create versatile actuators. This approach allows for the full exploitation of the materials' synergistic potential and the mitigation of any shortcomings.

Danish-Swiss collaboration

The WeArAble Project is a collaboration between the Danish Polymer Centre at DTU and the Soft Transducers Lab of École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland. DPC focuses on understanding the silicone polymer structure to increase energy density and electro-mechanical properties, while EPFL concentrates on actuator design that fully embraces the material's properties.

"We collaborate daily by exchanging ideas and expertise in respective research fields, which I am convinced will result in great advancements in soft robotics by the end of the project", Anne Ladegaard Skov says.

Muscle-like motion

Over the years, DPC has gathered extensive knowledge of silicone materials being used as dielectric elastomer actuators (DEA). Even though these materials have been proven to be a great candidate for novel soft actuators, many of the intrinsic properties need to be further optimized.

The strain performance of the dielectric elastomer actuator depends on factors such as the dielectric permittivity of the medium, its Young's modulus, thickness and applied voltage. Additionally, the actuator shape plays a role, with fiber-shaped DEAs showing the biggest potential for resembling muscle-like movement.

In the pursuit of addressing the dependency parameters, our researchers have undertaken diverse approaches. Notably, they are dedicated to enhancing the medium dielectric permittivity through the development of innovative high-permittivity ionic liquid grafted silicone fillers that seamlessly integrate into the polymer matrix. Furthermore, the integration of proteins, particularly collagen fragments, is being explored to customize the mechanical properties of the silicone matrix based on the processing temperature. In addition, efforts are underway to enhance silicone by rendering it more hydrophilic and incorporating diverse moieties.

Woven into textiles

Another significant initiative involves curing silicone material in a high electric field to align polymer chains and orient fillers, thereby improving the electro-mechanical properties of the actuator. Moreover, the intrinsic softness of silicone is being refined through the synthesis of highly entangled

Weaving process of silicone fiber actuator Thomas Steen Sørensen and bottle-brush elastomers from precursor polymers. This optimized silicone matrix is poised to be leveraged for the fabrication of fibres that can be woven and embedded into electrically operated active textiles.

The project is paving the way for groundbreaking advancements in the field of soft robotics. The ongoing research and innovations in material science and actuator design are poised to enhance the quality of life for individuals with physical differences or disabilities, contributing to the overarching goal of sustainable and equitable development.

WeArAble
Time frame: 2023-**2028**
Total budget: 48 m DKK
DTU budget: 29 m DKK

Professor Anne Ladegaard Skov

The Danish Polymer Centre

The Danish Polymer Centre aims at being at the forefront of the synthesis and characterization of novel polymer materials with a special emphasis on silicone polymers and sustainable polymers. Currently, most focus is directed towards sustainable polymers, plastics, and elastomers for use in a variety of applications, such as commodity plastics, advanced electronics, and soft robotics.

The main objective of the research area is to lead the way toward more sustainable materials. We aim to take part in the transition at all levels of materials development from the fundamental synthesis of new bio-based polymers, across various recycling pathways and toward industrial implementation.

In society, we are targeting a more sustainable use of all materials and plastics in particular. There are a number of pathways towards reaching this – both from a materials sourcing point of view, as well as through conservation of the materials we have and using them in the best possible way. In our efforts to contribute to this challenge in society, we collaborate across the relevant disciplines to take part in the development of the new systems that we require as tomorrow's materials.

Specifically, we currently have research activities in the areas of greener production, using both enzymes as well as classical synthetic methods to prepare polymers from new sources of raw materials. By exploiting waste materials or bio-based raw materials, we target the preparation of materials with a lower impact. Through collaborations, we exploit both chemical, biological, and mechanical recycling to prepare new products or materials that enable easier recycling and permit either simpler or direct recycling of materials. This also encompasses the synthesis of additive components to enable systems to be recycled directly and to simplify these systems to increase their value in a circular economy context.
These activities are supported through our strong chemical synthetic and characterization platform, which we exploit across a broad range of products both in collaboration with other academic institutions as well as with industry.

Highlights **2024**

8 MARCH
DTU OPEN HOUSE EVENT
2000 visitors attended the DTU Open House which included an education fair. The DTU President, Anders Bjarklev, came by the department's stand and tried out the interactive VR training course at our Pilot Plant. To cite the president: "So you can learn about and practice safety in advance before you get started? That's smart." Many potential students also visited our stand and tried the VR equipment assisted by Assoc. Professor Ulrich Krühne.

18 MARCH
VISIT FROM DTU PRESIDENT
DTU President Anders Bjarklev visited the Department of Chemical and Biochemical Engineering to discuss the mid-term evaluation of DTU's strategy, "2020-2025 - Technology for People." The President provided a brief overview of the key conclusions from the evaluation, followed by a presentation from our Head of Department highlighting the main successes and areas of focus related to the implementation of DTU's strategy. The meeting ended with a discussion about the strategy.

Birgitte Hannibal

25 MARCH
TOP PRIZE AT SPIE NDE 2024
Professor Anne Ladegaard Skov and her team won the prestigious first prize for their fiber actuators at the "EAP in action" which shows the latest capabilities and applications of Electroactive Polymers (EAP) materials. The results displayed at the SPIE NDE conference are part of the WeArAble project. They have developed a method to make long artificial muscle fibres that can be incorporated into textiles and figured out how to produce these muscle-like actuators by the metre. This creates the potential for making clothes that can assist people in lifting heavy objects.

SPIE NDE

24-25 APRIL
COAST ANNUAL EVENT AND WORKSHOP
The Hempel Foundation Coatings Science and Technology Centre, CoaST, hosted its 7th Annual Event highlighting the latest advancements in coating research. The event featured a broad range of contributions from the international research community, including a presentation by Professor Serge Bourbigot from the University of Lille. 32 CoaST Postdocs and PhD students presented their projects with individual fast-paced poster pitches followed by a poster session. The event was attended by 50 internal and 48 external participants. On the second day participants from 12 European universities and other research institutions joined a workshop facilitated by CoaST to kickstart the collaboration within a new European coatings network.

Christian O. Carlsson

30 APRIL
10 MILLION EUR INNOVATION ACTION "SEAFAIRER"

SEAFAIRER is a 4-year Horizon Europe Innovation Action with Assoc. Professor Seyed Soheil Mansouri as Principal Investigator. From sourcing sustainable feedstock to performing a real-world trial in an ocean vessel – the SEAFAIRER project sets a course to strengthen the European biofuel ecosystem.

6-8 MAY
QUANTUM COMPUTING WORKSHOP

The workshop, titled Solving Challenges in the Chemical and Biological Processing Industries, brought together scientists and engineers at all career stages in academia, industry, and startups from the rapidly growing field of quantum computing. A range of top researchers gave presentations on quantum generative AI, and emerging trends in quantum computing.

28 MAY
DFF GRANT TO PROFESSOR MANUEL PINELO

Nine DTU researchers received DKK 55 million in total from the Independent Research Fund Denmark under the DFF-Research Project 2 initiative. Professor Manuel Pinelo received a grant for the project "Pioneering Cell-Like Technology to Overpower Traditional Chemical Synthesis: Engineering Intelligent Microenvironments with Innovative Materials for Sequential Enzyme Reactions". With the grant, he will be able to pursue his most innovative ideas and promote innovative Danish research.

4 JUNE
NEW PRESIDENT OF EURECHA

Assoc. Professor Seyed Soheil Mansouri was appointed the new President of EURECHA (European Committee for the Use of Computers in Chemical Engineering Education). He will lead EURECHA's efforts in advancing chemical engineering education through innovative use of technology.

14 JUNE
POSTER PRIZE WIN AT NORDIC POLYMER DAYS

Virginia Celestre won the poster prize in Helsinki at the Nordic Polymer Days. She won it for the poster "Repolymerization of TA hydrolysates into PET". The Nordic Polymer Days is a long-standing tradition (>50 years) of sharing research in the field of polymers across the Nordic countries.

Arianna Rech

18-21 JUNE
CERE DISCUSSION MEETING AND KT CONSORTIUM ANNUAL MEETING

For the first time, the CERE Discussion and KT Consortium Annual Meetings were combined. 109 members of the CERE industry consortium and 50 members of the KT Consortium met to discuss the wave of transition in the energy resources sector with a focus on thermodynamics and CO_2 capture as well as bio-process systems engineering.

1 JULY
TWO NEW FACULTY MEMBERS

Magdalena Maria Skowyra and Narayanan Rajagopalan were appointed as Assistant Professors: Bothe were recruited internally at the department.

Magdalena holds an M.Sc. in Medical Physics from AGH University of Science and Technology om Krakow, Poland and a PhD from DTU Nutech. She came from a Postdoctoral position at DPC where she specializes in polymers and elastomers. Narayanan has an M.Sc. in Chemistry and a PhD in Metallurgical Engineering & Materials Science from the Indian Institute of Technology Bombay in Mumbai, India. He came from a position as Tenure-track Researcher at CoaST, specializing in material structure-property relations, coating formulations, functionalization (surface & chemical), and coating degradation mechanisms.

Highlights **2024**

1-25 JULY

SUMMER UNIVERSITY

In July, as always our department was full of American students attending our Summer University. This year 66 students attended the course within large-scale chemical unit operations designed for international and non-DTU students.

Steen Larsen

8 JULY

VISIT FROM HIGH SCHOOL STUDENTS

65 high school students from across Denmark visited KT as part of the UNF Chemistry Camp. They toured the Danish Polymer Centre's laboratories, learning about polymers.

Malthe Petersen

12 JULY

ERC PROOF OF CONCEPT GRANT TO PROFESSOR GEORGIOS KONTOGEORGIS

The European Research Council recognized the excellent research developed during Prof. Georgios M. Kontogeorgis' ERC Advanced Grant project "New Paradigm in Electrolyte Thermodynamics", and awarded him a Proof of Concept project for further work to enable the progress from ground-breaking research towards innovation.

AUGUST

UNDERWATER SOLAR CELLS

Professor Søren Kiil and Assoc. Professor Narayanan Rajagopalan published "Self-sustaining antifouling coating for underwater solar cells" in Progress in Organic Coatings with remarkable results on their collaboration with US Navy on transparent anti-fouling coatings from the Maritime Test Centre in Hundested. The results drew attention and was mentioned on several international Tech sites in e.g. the US, Italy, and the Netherlands.

5-16 AUGUST

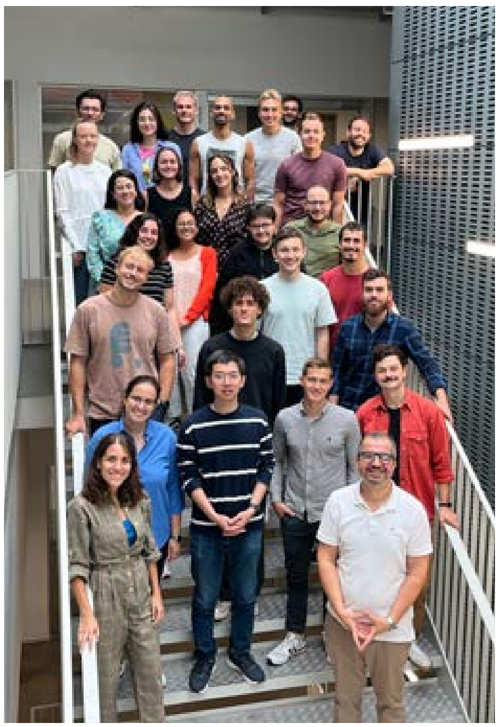
PHD COURSE ON THERMODYNAMIC MODELS

The PhD course "Advanced Course on Thermodynamic Models: Fundamentals & Computational Aspects" attracted 29 participants, including five industry professionals.

18-23 AUGUST

SUMMER SCHOOL

Professor Gurkan Sin held his annual week-long summer school on Uncertainty and Sensitivity Analysis of Model Output in Engineering Applications for 25 PhD students.



Reza Boskabadi

23 AUGUST
KT RESEARCH DAY 2024
For this year's edition, the annual department research event had three internal speakers, Assoc. Professors Philip Loldrup Fosbøl, Jakob Kjøbsted Huusom and Hao Wu. The program also featured a pitch and poster competition. The pitch winner was PhD student Joshua Anani from CoaST and PhD student Fiametta Caccavale from PROSYS won the poster competition.

Birgitte Hannibal

5 SEPTEMBER
BEST PRESENTATION AWARD AT IFQ2024
PhD student Jakob Meister received the Bryers Award for Best Presentation at the 29th International Conference on the Impact of Fuel Quality on Power Production and the Environment in Garmisch-Partenkirchen, Germany.

9-13 SEPTEMBER
EUROPEAN SUMMER SCHOOL ON MICROFLUIDICS
Assoc. Professor Ulrich Krühne participated as a teacher in the 5th European Summer School on Microfluidics at the University Magna Graecia in Catanzaro, Italy. The 6th edition of the Summer School will take place on October 13-17, 2025, at the Department of Chemical and Biochemical Engineering.

Microfluidics

26 SEPTEMBER
VILLUM EXPERIMENT GRANT
Professor Manuel Pinelo and Tenure-track researcher Antonio Grimalt Alemany each received a Villum Experiment grant from the Villum Foundation. Antonio Grimalt-Alemany's grant supports his project titled "MicrobesTALK – Talking Microbes into Biofilms." Meanwhile, Manuel Pinelo's project focuses on the use of novel supports for laccase immobilization, specifically polymer membranes embedded with next-generation inorganic powders and metal-organic frameworks (MOFs).

30 SEPTEMBER
DPC ANNUAL POLYMER DAY
The DPC Annual Polymer Day was attended by 110 participants. Professor Karin Odelius, KTH, gave the plenary talk on the recycling of polymers. The centre's PhD students presented their work as either talks or posters.

3 OCTOBER
NEW DFF GRANT TO PROF. GEORGIOS M. KONTOGEORGIS
Prof. Georgios M. Kontogeorgis received funding from the Danish Council for Independent Research (DFF) for the project "Investigation of the anomalous behavior of water using a new hypothesis". The grant supports investigations into the origins of water's unique behaviors, aiming to develop advanced thermodynamic models based on the two-state theory.

10 OCTOBER
CHEC RESEARCH CENTRE ANNUAL DAY
The Annual Day was an informal networking event with guest speakers from CrossBridge Energy, Elcogen and Valmet. The 98 participants from industry and academia shared a range of research highlights from activities within catalysis and high-temperature processes.

Highlights **2024**

11 OCTOBER
PROSYS ANNUAL RESEARCH SEMINAR
The 8th PROSYS Annual Research Seminar was an informal networking event where 140 participants shared the latest developments from the research activities at PROSYS. These included biocatalysis, fermentation technology, downstream processes, mathematical modelling, computational fluid dynamics (CFD), and Process Systems Engineering (PSE).

14 OCTOBER
A PAPER IN A NATURE FAMILY JOURNAL
PhD student Rasmus Fromsejer and his supervisors Bjørn Maribo-Mogensen, Georgios M. Kontogeorgis, and Xiaodong Liang have published the paper "Accurate formation enthalpies of solids using reaction networks" in npj Computational Materials, and it marks the first paper of the group's first paper in a Nature Family journal.

21-23 OCTOBER
ESBES 2024
The ESBES 2024 symposium was held in DR Byen for 245 participants, with Assoc. Professor Ulrich Krühne and Professor Krist Gernaey as two of the main organizers. The event was combined with the one-day FBM Symposium (70 participants). The scientific program included sessions on biocatalysis, biotechnology and metabolic engineering, digitalization, upstream and downstream processing, circular bioeconomy and processing. In total the scientific program covered about 90 oral presentations and close to 100 poster presentations. Our PhD Student Marc Lemperle won first prize in the poster competition.

Pedram Ramin

30 OCTOBER
PROFESSOR KRIST GERNAEY TAKES A SEAT ON RESEARCH COUNCIL
The Board of Directors of the Independent Research Fund Denmark appointed new members to its five research councils. Among the appointees was Professor Krist Gernaey, Head of PROSYS, who joined the Council for Technology and Production on 1 January 2025. He will help allocate risk-tolerant funds, amounting to approximately DKK 1.9 billion in 2024.

16 NOVEMBER
YOUNG RESEARCHER OF THE YEAR AWARD
PhD student Randi Neerup received one of the six prestigious Young Researcher of the Year Awards 2024 at DTU. She won it for her PhD thesis "Large CO_2 Pilot: Energy Consumption, Emission, and Corrosion" concerning pilot-scale carbon capture at Amager Bakke (ARC). During her thesis, she published eight articles and succeeded in reducing energy use by 20% compared to existing technology in the carbon capture field.

Christian O. Carlsson

18 NOVEMBER

KT INNOVATION SEMINAR

At the department's Innovation Seminar, experts from both inside and outside KT discussed topics related to commercialization for KT researchers. The researchers listened to presentations on IP licensing agreements and strategies, as well as the legal aspects of publishing and sharing code and software.

20-22 NOVEMBER

3-DAY EVENT ON CARBON CAPTURE

BioCon hosted a 3-day event for a consortium of European companies and universities focused on CO_2 capturing technologies in an EU project. The event included workshops on biogas upgrading and featured participants from VEOLIA (NL and FR), CETAQUA (ES), UVIC (ES), TERRAWATT (FR), UGENT (BE), CRYOINNOX (BE), DBFZ (DE), and SINTEF (NO). It concluded with a visit to our department's laboratories.

21 NOVEMBER

ULRICH KRÜHNE RECEIVES DTU'S TEACHING AWARD 2024

Assoc- professor Ulrich Krühne, head of studies at the Bachelor of Science in Chemistry and Biotechnology and Chemical Engineering and International Business – was honored with DTU's Teaching Award 2024 for his innovative work on integrating digital tools into teaching: "Ulrich Krühne receives the teaching award because he shows us exemplary examples of how teachers can use digitalization to strengthen students' learning and skills - and at the same time free up important time for teachers," said Dean of Education and Study Environment, Lars D. Christoffersen.

Mikal Schlosser

2-4 DECEMBER

Professor Manuel Pinelo organized the 20th Nordic Filtration Symposium in Aalborg together with Aalborg University. The symposium brought together experts, researchers, and industry professionals to discuss the latest advancements in filtration technology.

Christian O. Carlsson

3 DECEMBER

ERC CONSOLIDATOR GRANT TO DR. XIAODONG LIANG

The European Research Council awarded an ERC Consolidator Grant to Assoc. Professor Xiaodong Liang on "Revolutionizing Molecular Thermodynamics by Water and Electrolytes (REMOTE)". The project aims to deepen our fundamental understanding of the underlying physics – specifically, the relationships between structures, interactions, and properties – while laying the groundwork for a paradigm shift in molecular thermodynamics. The project's central hypothesis is primarily inspired by the anomalous properties of water and the complex behaviours of electrolyte solutions.

6 DECEMBER

KT CHRISTMAS SEMINAR AND LUNCH

The department's festive day began with centre presentations highlighting the scientific achievements of 2024, followed by Per Falholt sharing his personal journey over 40 years in Chemical Engineering. The day ended with a traditional Christmas lunch for 200 employees from the department.

Cooperating companies

2

21st.Bio

3

3V TECH EQUIPMENT & PROCESS SYSTEMS

A

AGC Biologics
Air Products
Alfa Laval
Algiecel
ALK Abello
AquaGreen
Aquaporin
ARC
ARKEMA FRANCE
Arla Foods Ingredients Group
AVEVA
Avista Green
AWAPATENT
Axens

B

Babcock & Wilcox Vølund
Baker Hughes
BASF
Bayer
BioHalo
BioInnovation Institute
BioLean
Biomar
BioMia
Biopharm Services
Bioscavenge
Biosyntia
BP
BTG Bioliquids

C

Calsep
Carbfix
Carlsberg Research Laboratory
Centro Tecnológico Componentes
Chreto
Chromologics
Ckj Steel
C-LEcta
Covestro Deutschland
CP Kelco
Cysbio

D

Dall Energi
Dalum
Dampskibsselskabet Norden
Danfoss
Danish Technological Institute
Dansk Gasteknisk Center
Dan-Unity
DHI
DSM Firmenich
Dyadic

E

ECCO
Elkem
EnCoat
Enduro
Engineering Consulting Corporation
ENI
EnviDan A/S
Equinor
ESSS North America
Estech

F

Finnsementii
FLSmidth
Fluor Corporation
Freesense
Fuji Pharma
FUJIFILM

G

G2B Biosolutions
GEA Process Engineering
Geminor
GR3N SAGL
Green2X
Greenlab Skive
Grundfos

H

H&M - HENNES & MAURITZ GBC
Hafnium Labs
Harper & Vedel
Harriot Wiat
HCS
Hempel
Henkel
Hillerød Forsyning
Holm Christensen Biosystemer
Hundested Havn
Hutchinson

I

IFP Energies nouvelles
IFPEN
INNARGI
Innosyn
Insatech

J

Janssen - pharmaceutical company of Johnsson & Johnson

K

Kaffe Bueno
Kalundborg forsyning
Karup Kartoffelmelsfabrik (KMC)
KBC
KMT Cables
Koppers

L

LactoLink
Landbrug & Fødevarer
LEGO
Lemvig Biogas
Leo Pharma
Linde
LiqTech International
Lucent Petroleum
Lundbeck Pharma
Lundsby Biogas

M

Madsen Bioenergi
MAN Energy Solutions
Mash Makes
MediaMedic
Metricorr
Microsoft
Mitsubishi Chemical Corporation
Momentive
Mölnlycke

N

NEO GROUP
Neste Corporation
New Energy Coalition
Nilpeter
Nopa
Nordic Sugar
Nova Pangeae
Novo Nordisk
Novonesis

O

Octarine Bio
OMV Petrom

P

ParticleTech
Pharmacosmos
Polyloop
Pond
Process-design
PROCESSI INNOVATIVI
Processium

Q

Q-Interline

R

Rambøll
Resino
Ringsted Forsyning
River Stone Biotech
Rockwool
Roxtec

S

SaltPower
Sartorius
Schlumberger
Scienciox
Scott Sports
SemperCycle
Shell
Sinopec
Skanderborg Forsyning
Skovgaard Engineering
SMK - Statens Museum for Kunst
Stiesdal Fuel Technologies
SYNESIS
Syngenta

T

Technaro
Teknologisk Institut
Tetrapharm
Topsoe
TotalEnergies
Tårnby Forsyning

U

Unibio
Unilever
Union Engineering
US Navy

V

Valmet AB
Vandcenter Syd
Viegand & Maagøe
Viking Malt

W

Waste Plastic Upcycling
Wetsus

X

Xellia Pharmaceuticals

Ø

Ørsted

Aa

Aalborg Portland

Strengthening KT Students

The student organization at DTU Chemical and Biochemical Engineering, KT Students, aims to create an engaging study environment for students through social and professional activities. In 2024, KT Students has aimed to encourage social interactions among students and strengthen knowledge regarding opportunities within the department as well as in the industry.

The year 2024 has been an active year for KT Students with huge developments within the organization and events hosted by KT Students.

In the spring of 2024, the focus of KT Students was to arrange PhD talks at DTU, as well as arranging a company visit to Amager Ressourcecenter (ARC), where students learned about their carbon capture and storage technology, among other things.

"KT Students wants to create connections for the students to the chemical and biochemical industries, creating valuable opportunities for collaboration between academia and the professional world. This relationship benefits students by providing insights into potential career paths, while also allowing companies to be inspired by the next generation of engineers," says Mathilde Munch Jensen, Vice Chairperson of KT Students.

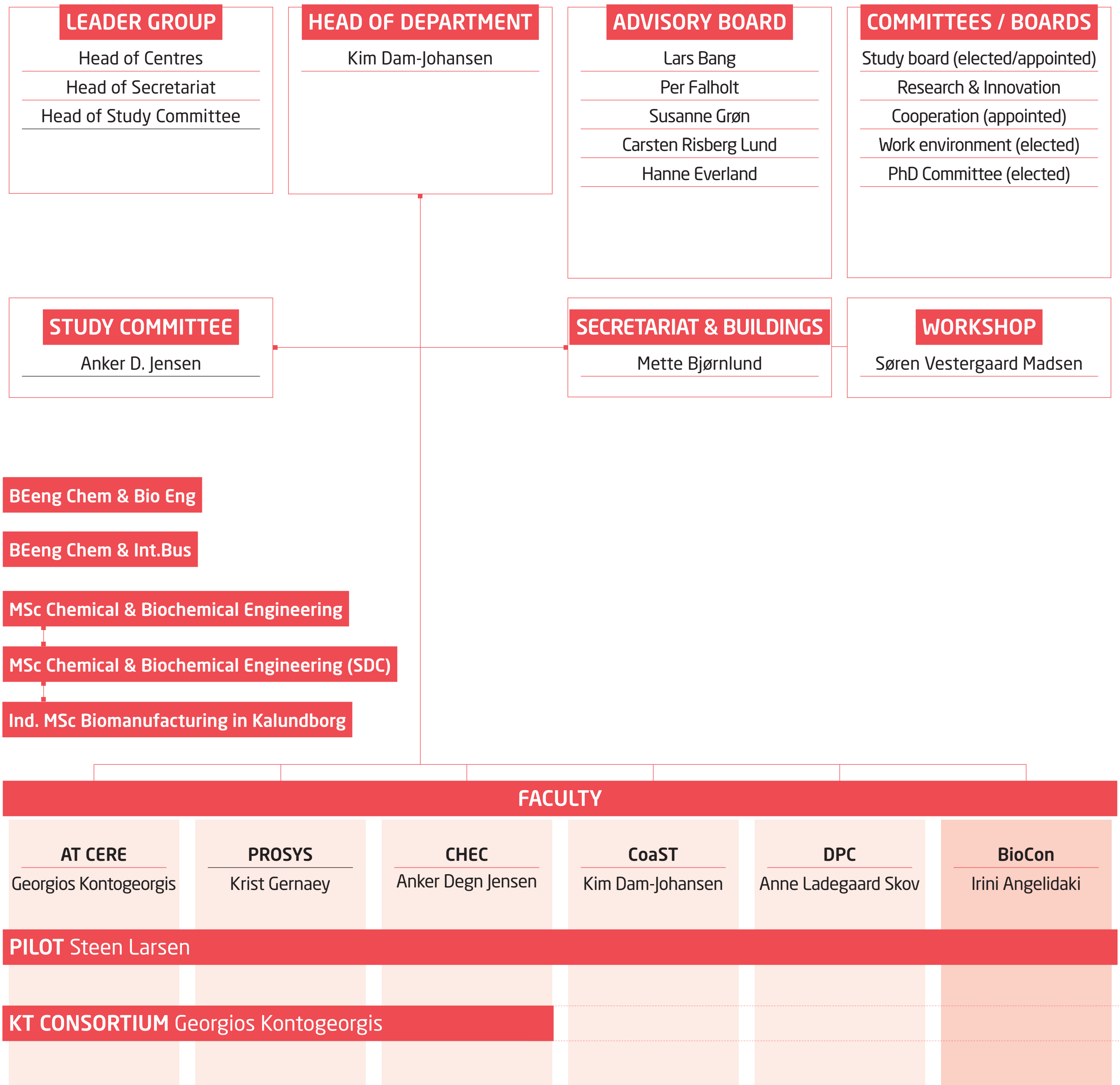
Additionally, the organization placed a strong emphasis on organizing social events for students within the department, as we believe that building friendships and networking across different year groups is both valuable and essential for personal and professional growth.

The Autumn of 2024 had a great start, with company visits to Copenhagen Atomics and the Statens Museum for Kunst (SMK) laboratories, where students had the chance to learn about pigment dating and characterization. Another visit to CP Kelco was also arranged later in the autumn. In October 2024, members of the board attended the NKK (Nordic Chemical Engineering Conference) student event in Trondheim. This is a unique opportunity, taking place every year, for chemical engineering organizations from across the Nordic region to gather to collaborate, network and share ideas.

The organization has seen significant growth in terms of membership over the past year, though still primarily consisting of master students. As a result, KT Students is eager to welcome more bachelor and bachelor of engineering students to join the organization, which continues to be one of our main ambitions. DTU's global reputation for excellence motivates us to uphold the same high standards within our student organization. With more members on board, we aim to expand our impact by offering more academic content and organizing even more engaging social events for students at KT, setting the bar even higher for what we can accomplish together.

Most of KT Students board. From left to right, top then bottom: Emil Hansen, Kasper Jørgensen, Aske Hansen, Ida Overgaard, Emilie Andresen, Laura Karlsmose, Dalimil Ott, Nikolaj Falkenberg, Janie Andersen, Mathilde Jensen, Melissa Jensen, and Cecilie Juhl
Christian O. Carlsson

Organization



The Faculty **2024**

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
Associate 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


Magdalena Skowyra
Assistant Professor


Manuel Pinelo
Professor


Martin Høj
Associate Professor


Narayanan Rajagopalan
Assistant Professor


Nicolas von Solms
Professor


Peter Szabo
Associate Professor


Peter Glarborg
Professor


Philip L. Fosbøl
Associate Professor


Seyed S. Mansouri
Associate Professor


Søren Kiil
Professor


Ulrich Krühne
Associate Professor


Xiaodong Liang
Associate Professor

TECHNICAL AND 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


Stig Wedel
Associate Professor
Emeritur

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
PRINCIPAL INVESTIGATOR
NOVO NORDISK FOUNDATION

"Climate change, food waste, global health, and the overuse of antibiotics and pesticides are pressing issues that society and industry must address to shape a more sustainable future. Biosolutions often hold the key to solving these severe challenges of the green transition. Through engineering science and deep skills in biomanufacturing, we can bring these solutions to scale faster and more safely. This will enable us to combat climate change, safeguard biodiversity, protect the environment, and secure sustainable food production for a growing population. At Novo Nordisk Foundation, we are positioned to drive positive change and address these challenges. The Department of Chemical and Biochemical Engineering, as a close partner, is uniquely situated to provide innovative solutions and strong engineering candidates contributing to this essential purpose."

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."

Teaching

KT considers research based and industrial inspired education and teaching our most important contribution to society and we are involved in:

- The BEng programmes "Chemical and Biochemical Engineering" and "Chemical Engineering and International Business".
- The BSc programmes in "Kemi og Teknologi", "General Engineering", and a new digital education taught in Danish, DTU Chemical Engineering are contributing with the specialization in Power-to-X.
- The MSc programmes in "Advanced and Applied Chemistry", "Chemical and Biochemical Engineering", "Sustainable Energy" (with special focus on Bio-Energy), as well as the N5TPolymers MSc programme. MSc in Chemical and Biochemical Engineering, Study line in Biomanufacturing (Industry MSc in Engineering, Kalundborg), 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 modelling, process and product design.

Courses

1 SEPTEMBER 2023-31 AUGUST 2024

PHD COURSES

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 Analyses of Numerical Models
28927	Advanced topics in process technology
28928	Electrolyte Solution Thermodynamics
28932	Process Engineering Laboratory
28933	Introduction to Chemical Modification of protein therapeutics
28934	Automation and control of yest fermentation
27828	Upstream Process Development

SDC course

88704	Progress in Research
88701	Fluidization and Multiphase Flow
88710	Combustion and High Temperature Processes

Courses

Master's and bachelor courses

Below, course numbers and names are shown for 2023-2024, 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

28010 Products and Processes – Introduction to Chemical Engineering (70)
28012 Chemical and Biochemical Process Engineering (63) **(B)**
28016 Mathematical models for chemical and biochemical systems (65) **(B)**
28020 Introduction to Chemical and Biochemical Engineering (49)
28022 Unit Operations of Chemical Engineering and Biotechnology (55) **(B)**
28121 Chemical Unit Operations Laboratory (21)
28125 Chemical Unit Operations Laboratory (14)
28140 Introduction to Chemical Reaction Engineering (44)
28150 Introduction to Process Control (38)
28157 Process and Product Design (58) **(B)**
28213 Polymer Technology (35)
28233 Recovery and Purification of Biological Products (188)
28242 Chemical Kinetics and Catalysis (49)
28244 Combustion and High Temperature Process (49)
28311 Chemical and Biochemical Product Design (51)
28315 Colloid and Surface Chemistry (33)
28316 Laboratory Course in Colloid and Surface Chemistry (9)
28322 Chemical Engineering Thermodynamics (59) **(B)**
28342 Chemical Reaction Engineering (25) **(B)**
28344 Biotechnology and Process Design (16) **(B)**
28352 Chemical Process Control (37) **(B)**
28412 Advanced Chemical Product Design (21)
28420 Separation Processes (64)
28455 Process adaptation in fermentation based biomanufacturing (76)
28485 Biobusiness and Process Innovation (242)
28530 Transport Processes (27)
28720 Downstream Processing (6)
28745 Industrial cell-based reaction engineering (7)
28761 Mathematical modelling for industrial applications (7)
28831 Computational Fluid Dynamics in Chemical Engineering (14)
28845 Chemical Reaction Engineering Laboratory (22)
28852 Risk Assessment in Chemical Industry (36)
28857 Good Manufacturing Practice – Practical version (47)
28864 Introduction to Matlab Programming (17)
28870 Energy and Sustainability (143)
28872 Biorefinery (57)

COURSES GIVEN IN CO-OPERATION WITH OTHER DEPARTMENTS:

12701 Introduction to Living Systems (102)
26010 Introductory Project in Chemistry (52)
27020 Bioengineering (Polyteknisk grundlag) (383)

SPRING SEMESTER

28010 Products and Processes – Introduction to Chemical Engineering (69)
28020 Introduction to Chemical and Biochemical Engineering (47)
28025 Bio Process Technology (39)
28121 Chemical Unit Operations Laboratory (8)
28157 Process Design (42) **(B)**
28160 Mathematical Models for Chemical Systems (36)
28212 Polymer Chemistry (59)
28214 Polymer Synthesis and Characterization (9)
28216 Organics Coatings Science and Technology (14)
28221 Chemical Engineering Thermodynamics (13)
28271 Thermal gasification and sustainability (16)
28342 Chemical Reaction Engineering (48) **(B)**
28344 Biotechnology and Process Design (33) **(B)**
28345 Chemical Reaction Engineering (91)
28346 Advanced fermentation technology practicum (22)
28350 Process Design: Principles and Methods (62)
28352 Chemical Process Control (43) **(B)**
28361 Chemical Engineering Model Analysis (72)
28423 Phase Equilibria for Separation Processes (15)
28434 Membrane Technology (59)
28443 Industrial Reaction Engineering (29)
28451 Optimizing Plantwide Control (37)
28737 Applied Chromathography Project (6)
28811 Polymers in Process and Products (8)
28850 Quality by Design (QbD): Integration of Product and Process Development (136)
28855 Good Manufactoring Practice – Theoretical version (123)
28864 Introduction to Matlab Programming (23)
28871 Production of Biofuels (31)

COURSE GIVEN IN CO-OPERATION WITH OTHER DEPARTMENTS:

26280 Chemistry and Physics in CO2 Storage (8)
26317 Instrumental Chemical Analysis (46)
27020 Bioengineering (Polyteknisk grundlag) (374)
27455 Microbial adaptation to industrial processes (69)
27828 Upstream Processs Development (5)
41686 Materials Science (74) **(B)**
47213 Introduction to Power-to-X (Online) (23)
47334 Carbon capture, utilization, and storage (58)

BACHELOR OF ENGINEERING DEGREES

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

Analysis of machine learning models for performance prediction of membrane separations (**Jonas Røkke Bjørnsson**)
Advanced process understanding of a reaction step in industrial API manufacturing (**Bryndís Kristjánsdóttìr**)
Computational modelling of a CCUS cycle with focus on optimization (**Jonas Vestergaard Kristensen**)
Biosimilars process design and optimization (**Esben Buch Andersen**)
Design of innovative electrochemical cell for carbon capture (**William Rørbech Øgaard Pedersen**)
Reverse osmosis digital twin for permeate return (**Kasper Hartung Damsgaard**)
Experimental determination of solid-liquid equilibrium of advanced solvents for CO_2 capture (**Hend Osama Marak**)
Enzymatic microreactors (**Jonas Brems Kristensen**)
Enhancing Wastewater Treatment Efficiency: A Sewnsor-Based Approach for optimizing Phosphorus Removal (**Michelle Charlotte Zingenberg Salewski**)
Formulation of Redispersible Powder Coatings (**Mohamed Jamal Eddin Dakak**)
Fouling mitigation methods in the submerged ceramic membrane bioreactor (**Thor Peter Nyhegn Kistrup** and **William Nielsen**)
HMFO stability study in a bubble column (**Kasper Holmberg Christophersen**)
Influence of epoxy coatings surface roughness on dirt pick-up (**Ncklas Johnsen Petersen**)
Induction heating of feedlance in spraydrying plant (**Nicklas Plum Toft**)
Kinetics measurements of innovative CO_2 capture solvents (**Bjarke Mads Tind**)
Modeling of absorption and desorption systems (**Jens Thomas Davison-Grevsen**)
Modeling and analysis of electricity consumption of a power station (**Andreas Sulaj Kloppenborg** and **Jakob Skytte Brodersen**)
Optimization of Absorption Refrigeration Processes (**Mathilde Lisberg Schmidt**)
Optimization of steam usage in sugar production (**Alperen Gökmen**)
Optimizing tablet manufacturing through a comprehensive FMEA study of compression process risks and mitigation strategies (**Jeppe Nikolai Holm Madsen**)
Oxidation of CO by N_2O (**Rasmus Hafel**)
Periodic stripping (**Visti Skjøttgaard Jensen** and **Lene Gunnø**)
Process economic development of biosimilars (**Minda Troung** and **Julie Ida Schak Laursen**)
Scaling up the production process of a fermented broad bean sauce (**Magnus Bækgaard Andersen** and **Lucas Hother Hald**)
Reduction of compressor network energy consumption (**Nikolas Vengberg Aggelis**)
Structure-property relationship of epoxy-amine coatings for cargo hold application (**Malek Rafea Al Ahmad**)
Synthesis of acrylic polymers for applications in production of optical fibers (**Andre Kappe Larsen**)
Technical and economic evaluation of low and high temperature electrolysis for green ammonia production (**Rebecca Rhein Larsen** and **Julie Spühler Riber**)
Development of a FT-IR method (ATR) for identification of Novo Nordisk packaging materials containing polymers (**Marcus Harder Birkeslund**)
Development and characterization of novel trickle bed reactor system for syngas biomethanation (**Hassan Fahim Yousif**)
Validation of a sterile filtration system for use in pharmaceutical production (**Anna Mathiasen**)

BACHELOR OF SCIENCE DEGREES

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

Evaluation of possible reaction mechanisms for catalytic ammonia synthesis (**Eva Filippa Scott Johansen** and **Ida Lindhardtsen**)
Stabilization of biomass pyrolysis oils (**Ida Schiødte Overgaard**)
Exploring sensor design for continuous monitoring in bioreactors (**Mateo Schiopetto**)
Molten salt reactor fluids and exposure to ambient conditions (**Dylan Connor Bailey**)
Analysis of NH_3 low-pressure premixed flames (**Mette Kjærgaard Thorup**)
Deposit formation by kaolinitic clays in flash calcination (**Nicolaj Jonathan Jensen**)
Combustion properties of binders used in stone wool products (**Agnete Rytter Munk**)
Understanding and modeling the expansion behavior of intumescing alkali silicate particles: A parameter study (**Ida Kastrup Hemberg**)
Preparation of Styrenic Monomers from Zosteric Acid and Evaluation of their Polymerization (**Jens Lyhne Olsen**)
Hybrid modeling of mixed-substrate succinic acid fermentation by Actinobacillus succinogenes (**Adam Maxwell Bilde**)
Catalytic Removal of N_2O from Ship Flue Gas using Ammonia as Fuel (**Rasmus Kold**)
Artificial muscle fibers from silicone (**Mathilde Lei**)
Linear polymers with hydrolysable inkers targeting simple cleavage under mild conditions (**Julie Bøye Larsen**)
Modelling gas diffusion in solid oxide electrolysis cells (**Emilie Normann Langhorn** and **Nathalie Kay Christiansen**)
Modeling, analysis and design of absorption and desorption systems (**Viktor Fraenkel**, **August Holm Johannsen**, **Tobias Bæk**)
Optimal feed rate to induce Crabtree effect (**Kasper Weinreich Rask** and **Tom Schmidt Hansen**)
Synthesis and characterization of a novel pigment for anti-corrosive coating (**Khalil Ahmad Othman**)
Development of a novel trickle bed reactor system for syngas biomethanation (**Sarah Liselotte Krarup**)
Development of continuous mode fermentation with electrochemical *in-situ* product recovery for succinic acid production (**Oliver Berg Fiehn**)
Studies on the effect of additives on the thermal stability of titanium dioxide based SCR catalysts (**Astrid Mantzius Jepsen**)
Modelling, optimisation and control of an adiabatic quench cooled reactor for power to ammonia (**Anton Østdal**)

MASTER OF SCIENCE DEGREES

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

Additives and their influence on thermal and mechanical properties of bacterial polyesters (PHAs) (**Sara Soledad Abarca De Las Muelas**)
Analysis of increasing the production capacity at Chr. Hansen (**Trine Badsberg Christiansen**)
Application of optimization algorithms for the development of multi-step chromatographic processes for synthetic peptide purification (**Amalie Elsborg Andersen**)
Biomass measurement and overflow metabolism analysis in *saccharomyces cerevisiae* fermentation for improved pharmaceutical production (**Joan Cortes Gimeno**)
Sustainable power-to-ammonia production (**Georgios Balamotis**)
Sustainability assessment of syngas biomethanation (**Maria Samara**)
Computational Fluid Dynamics Simulation of CO_2 Ingress Container Closure Integrity Tests (**Martin Montero Grande**)
CFD simulation of a mixing tank of 200 l for fully formulated biologics solution (**Jens Winther Hartvig**)
Co-culture of komagataeibacter xylinus with pseudomonas putida in ocean water for enhanced bacterial cellulose production (**Patricia Brito Diaz**)
Combination of two complementary enzyme immobilization strategies for CO_2 capture and conversion: PE-based supports in enzymatic membrane reactors (MBR) and encapsulation in metal organic framework (MOF) structures (**Gustav Hausting Balslev Jørgensen**)
Degradation of waste polyethylene terephthalate by metal-free deep eutectic solvent with low usage of methanol (**Chunrui Rong**)
Dynamic and discrete events in biopharmaceutical production planning in a CDMO company (**Emil Graahede Sandoy**)
Acetic acid production from $CO2_2$ and CO gas streams (**Anastasia Rovithi**)
Effect of CO_2-switcheable surfactants on foam quality with an application to underground CO_2 storage (**Khaled Abdallah T Alturkey**)
Efficient synthesis of aromatic amines via selective hydrogenation of nitroaromatics over Pd1+C/TiO_2-Ov dual-site catalyst (**Yuxi Wang**)
Experimental investigation of foam produced by CO_2-switchable surfactants for application in underground CO_2 storage (**Theodoros Argyrelis**)
A modelling approach for scale-up of new technologies in API manufacturing processes (**Nanna Mortensen**)
Energy optimization – pinch study of the crude distillation preheat train of Kalundborg refinery (**Georgios Theocharous**)
Enzyme membrane reactor simulation and optimization for controlled preparation of oligodextran (**Dan Wang**)
Improving the bonding strength in apple-based leather materials (**Eleftheria Gitsouli**)
Improving carbon capture in power-to-x electrochemical cells through focused solvent testing (**Ward Peeters**)
Enhancing stereolithography (SLA) 3D printing with cellulose-based UV-curable resin (**Jan-Philipp Kruse**)
From surfactant free to apollonian emulsions: preparation and destruction (**Siméon Henri Emmanuel Charriau**)
Investigation and modeling of unified drag in gas-solid two-phase flow (**Yuxuan Zhou**)
Investigation of machine-learning force fields for ionic liquids and their property prediction (**Yaxi Yu**)
Recovery of cell walls from green algae for sustainable materials design (**Pia Juste Boeschen**)
Characterizing biofilm formation in syngas biomethanation processes (**Kayla Alexandra Buch**)
Characterization and testing of bio-oils from slow pyrolysis (**Manali Mahesh Kulkarni**)
Catalysts for ammonia cracking (**Mikkel Heskjær Danmark Strandberg**)
Condensation polymerizations of aromatic monomers under microwave irradiation (**Andreas Vahr Holm**)
Improvement of chromatography resin life-time (**Rasmus Thomas Rohde Nielsen** and **Peter Dines Arndal Fiil**)
Membrane filtration of bioprocess broth for active pharmaceutical ingredient (API) production (**Harsh Madhukar Parab**)
Mini pilot work on CO_2 capture with electrochemical PtX solvent regeneration (**Mateusz Zbigniew Zalewski**)
Modelling CIP systems in pilot-scale manufacturing of pharmaceutical products (**Bao Ngoc Vu** and **Nikolai Asbjørn Jessen**)
Modelling of catalyzed hardware in a lab reactor (**Heiðar Snær Ásgeirsson**)
Modeling kinetics and deactivation in the methanol-to-hydrocarbon process over zeolite-based catalyst (**Theis Steffen Hansen**)
Multivariate statistical process control of multi-phase fermentation process (**Anmol Tandon**)
Monitoring of metabolites in fermentation broth – a comparison of technologies (**Meryem Irem Sipahi** and **Maria-Eleni Mazaraki**)
Numerical simulation of multiphase reactors and the use of PIV for validation (**Vojtech Kunc**)
Next generation electrolysis system as hydrogen source for ammonia production (**Ida Levin Andersen**)
Biogas conversion by methanotroph-microalgae co-cultivation to proteinous biomass production (**Lucrezia Tesei**)
Optimal cost and energy production using simulation of parallel CO_2 capture plants (**Valdemar Emil Rasmussen**)
Optimization of the measurement angle in the fluorescence of crude oil solutions and dispersions (**Aapo Dahir Osman**)
Flow reactor oxidation of NH3/H2 (**Anna Ronalda Nord Brodersen**)
Thiol-enes with highly porous structures as membrane materials (**Alexandra Maria Tsitseli**)
Process design, modeling and validation of batch crystallizations (**Steffen Domy**)
Process optimization through hybrid modelling (**Brynjolf Bennicke Ernstsson**)
Production of volatile chemicals by Parageobacillus thermoglucosidasius (**Margarita Balampanou**)
Redispersible polymer powders (**Laura Csakvari**)
Regulating the composition of SAM to broaden the open circuit voltage of FA0.8Cs0.2Pb(I0.8Br0.2)2 solar cells and enhance stability (**Renlong Hao**)
Removal of CH3Cl from incondensable gases by absorption with activated carbon in the process for pyrolysis of rural living garbage (**Yande Cai**)
Removal of microplastics from water environments using nitrogen-rich layered carbon materials (**Xu Feng**)
Role of cell-to-cell communication mechanisms triggering biofilm formation in microbial communities (**Ingvild Straumøy**)
Simulation of continuous recovery process for biopharmaceuticals (**Andrea Castaneda Tena**)
Performance simulations and analysis of low and high temperature electrolysis technology for green ammonia production (**Daniel Calvo Blazque**z)
Stabilization of biomass pyrolysis oils (**Hannah Abildgaard Sløk**)
Study on Effect of Battery Configuration on Mechanisms of Energy Storage (**Zijiu Ma**)
Experimental and modeling investigation on condensed-phase sulfation of ash deposits (**Knut Ibæk Topp Lindenhoff**)
Synthesis of Aromatic Polyesters Based on 4-Hydroxyphenylacetic acid (HPA) with Varied Hydrolytic Stability (**Elias Kjær-Westermann**)

Synthesis of acid-base bifunctional catalysts for catalytic cracking of cyclohexane (**Zhen Xu**)
Technoeconomic Performance of Alternative Carbon Capture Solvents (**Shai Hvid Shiv**)
The design, synthesis, and application of photocatalysts in the field of photocatalytic CO_2 reduction (**Xiaoxue Xi**)
Time-scale and sensitivity analysis of microbial conversion from gaseous carbon sources to valuable products (**Deborah Pfaff**)
Exploring enhanced coating properties of intumescent coatings (**Marina Stähle**)
Harnessing green chemistry for valorization of enzyme production byproducts using advanced membrane technologies (**Niels Alexander Møller**)
Development of an object-oriented fermentation modelling platform at Novozymes; Opportunities and challenges in digital process characterization and scale up (**Erik Neesgård Stavad**)
Investigation of the influence of feed-composition on distillation processes in biomanufacturing (**Rolf Hoel**)
Exploring the thermostability of biphasic human insulin at elevated storage temperature (**Deeptha Sri Shammugam**)
Investigation and Selection of Candidates for non-fluoro hydrophobic coatings, for the protection of Hearing Aids (**Ameya Rajendra Jagtap**)
Carbonation of minerals to mitigate CO_2 emissions (**Nikolaos Kavros**)
GHG emission reductions in drilling activities (**Stanislaw Witold Wlodarczyk**)
Feasibility and performance comparison of edible oil refining using membrane technology and traditional refining, focusing on coffee oil (**Sergio Vinagre Madrid**)
Nitrous oxide mapping and control in the Novozymes industrial wastewater treatment plant (**Jaime Whale Obrero**)
Model and experiments of solvent degradation from large scale CO_2 pilots (**Shruti Guha**)
Model-based process understanding of industrial continuous centrifugation in an API recovery facility (**Maria Lindegaard Nissen**)
Drying Process Optimization by integrating digital twin technology (**Luna Frederikke Okkels** and **Amanda Fryland**)
High pressure oxidation of hydrogen by nitrous oxide (**Eva Maria Fabricius-Bjerre** and **Tor Kristian Joensen**)
Production and characterization of biochar for construction materials (**Sunna Liv Stefánsdóttir**)
Kinetic measurements and modeling for next generation CO_2 capture solvents (**Evelyn Namuga Kasule**)
Techno-economic and Life Cycle Assessment of a production process for Sustainable Aviation Fuels (SAF) from H_2 and CO_2 (**Pierre Jean Eugene Guillioteau**)
Techno-economic assessment of Fischer-Tropsch process technology for jet fuels (**Alberto Santos Sanz**)
Extending ranges of property prediction methods using machine learning (**Yitong Yang**)
Development of an open-source platform for compartment and kinetic modelling in bioreactors for vaccine production (**Noah Bastian Christiansen** and **Sebastian Lund Jensen**)
Development of an open-source platform for compartment and kinetic modelling in bioreactors for vaccine production (**Maximilian Leon Hans Werner Klein**)
Use of membrane technology for production of green energy via pressure retarded osmosis (PRO) (**Mie Thoendal Pedersen**)
Cultivation of methane oxidizing bacteria (MOB) for conversion of biogas to proteinous biomass (**Aljosha Rizvic**)
Effect of biochar on the biogas process (**Ioana-Laura Dudu**)
Experimental membrane optimization of electrochemical gas cleaning cells (**Stine Vrist Jepsen**)
Estimation of properties of production chemicals and their influence on produced water management (**Melpomeni Charisi**)
A comparative study of compositional and black-oil reservoir modeling with focus on consistent fluid modeling (**Christoffer Brustad Duus**)
Methane Eradication Photochemical System: A roadmap for commercialization (**Esther Lynn Kühlmann**)
Hybrid Machine-learning strategies for monitoring production of biological products (**Amirkiarash Ehtesham**)
Chemically Modified Lignin based Anti-corrosive Coatings (**Arvind Ramesh Kulkarni**)
Maximizing performance of immobilized enzymes through microenvironment control in mixed-matrix membranes (**Shantanu X**)
Mathematical modeling approach for solid-liquid separation by flocculation and centrifugation (**Magnus Tørrild Thorbek**)
Nanofiltration used for electrochemical CO_2 capture and Power-to-X technologies (**Theodora Dragani**)
Novel membrane-based capture methods for biopharmaceutical downstream processing (**Carlos Bierkens Limia**)
High-pressure oxidation of ammonia in the presence of additives (**Anna Tveen Trap**)
Pigmentation of self-stratifying fouling control coatings (**Nagashravan Praveen Hemadri**)
Protein precipitation modeling in downstream biological product purification (**Zeina Aref Abdul Hamid**)
Strategies for Preservative Loss in Pharmaceutical Manufacturing: Study of Phenol Diffusion in Silicone Tubing (**Jinyuhan Wang**)
Transdermal patches for efficient drug delivery (**Kristina Gabriele Jazbutis**)
Guard-bed development for vegetable oil in HDO application (**Hidde Oberon Machiel** and **Jan van den Brekel**)
Development of Novel Sunscreen Products (**Helga Sigrún Hermannsdóttir**)
Investigation on the discoloration of lead white in old master drawings at the National Gallery of Denmark (**Bianca Moretti**)

SDC MASTER DEGREES

Chlorine removal from the pyrolysis gas of municipal solid waste (MSW) (**Yande Cai**)
Analysis of Mesoscale Markers for Gas-Solid Heterogeneous Drag (**Yuxuan Zhou**)
Preparation of high value products by electrochemical reduction of CO_2 (**Xiaoyue TU**)
Synthesis of zeolite IM-5 and its catalytic performance for cracking naphthene (**Zhen Xu**)
Study on design, preparation and application of graphitic carbon nitride based photocatalyst (**Xiaoxue XI**)
Prepare cyclohexylamine by hydrogenation of Nitrobenzene with Pd1-Run/d-BN catalyst (**Luxi Wang**)
Filtration of microplastic spheres by biochar and catalytic removal of pollutants (**Xu Feng**)
α-Fe_2O_3 Photocatalytic reactions of different crystal faces (**Shijun Yu**)
Wide bandgap perovskite solar cells for calcium silicon stacked materials (**Renlong Hao**)
Influence of battery configuration on the mechanisms of energy storage (**Zijiu Ma**)
The construction and property study of ionic liquid machine learning force fields (**Yaxi Yu**)
Simulations and Optimization of Enzyme Membrane Reactor for Controlled Preparation of Oligodextran (**Dan Wang**)
Methanolysis of Polyethylene terephthalate (PET) at Low Temperature (**Chuirui Rong**)

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