DTU

DTU Chemical Engineering
Department of Chemical and Biochemical Engineering

Annual Report 2018

Theme

Sustainable solutions for our industry partners

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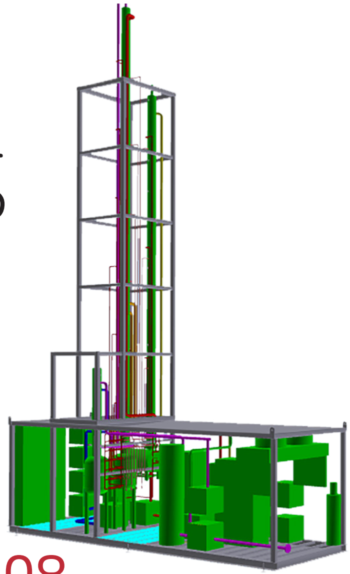
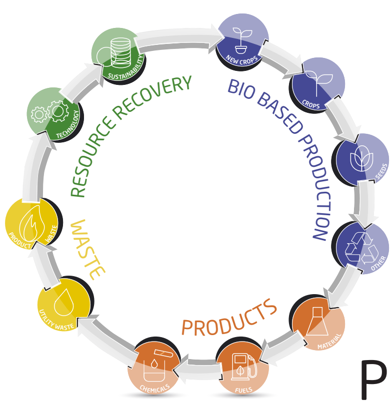
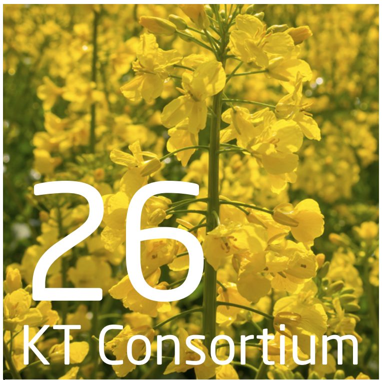






SUSTAINABLE SOLUTIONS FOR OUR INDUSTRY PARTNERS

It has always been a main objective for DTU Chemical Engineering through research and cooperation to find the best solutions, meet today's industrial challenges, and create value through education, innovation, and research.

Over the last decade, sustainability has played an increasingly prominent role for governments, industries, and societies. To ensure commitment, the UN established 17 Sustainable Development Goals that 193 countries joined. DTU has embraced the UN goals to form basis for research, education and innovation—so have we at the department.

In fact, sustainability has been a natural focal point for years at DTU Chemical Engineering, as we continuously strive to find technical solutions to the global challenges—not least the climate challenges. The UN Sustainable Development Goals are therefore already an integral part of our research.

This is also reflected in the theme feature articles where we present some of our many research areas. For example, we capture CO_2 and improve the use of CO_2, set new targets for sustainable coatings, and find green alternatives within the field of plastic. However, having the green story is not enough. It has to make financial sense too. This is why the world's increasing pressure on sustainability motivates many industries to think in new and sustainable solutions. And we support this development.

Traditionally, economic thinking has been linear when it comes to product consumption, i.e. use and disposal. We are now working towards a more circular way of thinking, where the mantra is recycling and reutilization. This angle is highlighted in the theme feature article where we look at a 'waste to value' solution.

"In fact, sustainability has been a natural focal point for years at DTU Chemical Engineering as we continuously strive to find technical solutions to the global challenges, not least the climate challenges. The UN Sustainable Development Goals are therefore already an integral part of our research."

The future chemical engineers will also be affected by the ever-changing sustainable agenda. And as a consequence, our teaching programmes will naturally be influenced by this development—a challenge we at DTU Chemical Engineering meet through continuing adaption of our programmes, organization and facilities. That is why we have strengthened our faculty group with five new members this year, who all will contribute to preparing our students for future challenges.

As our educational focus adapts to future demands, we have, in collaboration with two other DTU departments, created new fermentation technology study programmes with a grant from the Novo Nordisk Foundation.

At DTU Chemical Engineering, we are geared to meet the challenges of today— and tomorrow. Our results speak for themselves, for instance with a record-high number of PhDs researching in current societal concerns.

During 2018, we also broke ground for our new educational and research facilities which will further strengthen our capabilities to provide the best solutions to our students and partners. We expect to take over the building in a year from now.

As the future inevitably will keep bringing about new challenges, we will continuously contribute to setting the agenda when it comes to finding long-term solutions for the benefit of society.

KIM DAM-JOHANSEN
PROFESSOR,
HEAD OF DEPARTMENT

Kim Dam-Johansen
Professor, Head of Department

Photo: Christian Ove Carlsson

KEY NUMBERS **2018**

EDUCATION

306 STUDENTS*

22 SINO-DANISH STUDENTS *

28 COMPLETED BSC PROJECTS

39 COMPLETED BENG PROJECTS

67 COMPLETED MSC PROJECTS

RESEARCH

207 SCIENTIFIC ARTICLES IN WOS-INDEXED JOURNALS

8 CONTRIBUTIONS TO BOOKS AND REPORTS

39 PHD THESES DEFENCES

ORGANIZATION

INTERNATIONAL SCIENTIFIC STAFF (%)

50
TECHNICAL/ ADMINISTRATIVE EMPLOYEES **

83
SCIENTIFIC EMPLOYEES **

106
PHD STUDENTS, INCLUDING 14 INDUSTRIAL PHDS **

239
EMPLOYEES IN TOTAL **

33
FACULTY MEMBERS

INNOVATION

4
PUBLISHED PATENT APPLICATIONS

9
NOTIFICATION OF INVENTIONS

* BASED ON STÅ. ONE STÅ IS THE EQUIVALENT OF ONE STUDENT STUDYING FULL TIME IN A YEAR

** BASED ON FULL TIME EQUIVALENT (FTE)

CO_2 AS A VALUABLE BYPRODUCT FROM BIOGAS

Upgrading of biogas into methane mainly implies removal of CO_2 from the biogas. A project at DTU Chemical Engineering strives to make use of this CO_2.

CO_2 is generally perceived as a greenhouse gas, but can actually be a valuable raw material. For instance, sparkling water and soft drinks are produced by dissolving CO_2 in water, forming carbonic acid (H_2CO_3). Also, CO_2 is in high demand for welding and a range of other industrial processes.

The scope of the project 'BioCO2', coordinated by Associate Professor Philip L. Fosbøl from Applied Thermodynamics—Center for Energy Resources Engineering (AT CERE), DTU Chemical Engineering, is to capture CO_2 during production of biogas and turn it into a product of commercial value.

"For some years now, production of biogas from manure and other agricultural waste products has caught on. Biogas can be upgraded into methane. This upgrading both increases the energy value of the gas and allows for storage of excess gas in the high-standard Danish storage system for methane," explains Philip L. Fosbøl.

Biogas contains roughly 35 per cent CO_2. Removal of this CO_2 will upgrade the biogas to almost pure methane.

"Unfortunately, it is not possible to use the CO_2 from biogas upgrading directly for the various industrial purposes where CO_2 is in demand. If things were that simple, utilization of this CO_2 would already be in place. Each of the purposes in question have their own specifications, but generally the purity requirements are very high. It is a key challenge in the project to meet these specifications in an economically feasible way," says Philip L. Fosbøl.

A portable plant is under construction
BioCO2 is a 3-year effort sponsored by the EUDP programme under the Danish Energy Agency. Besides DTU Chemical Engineering, the Danish Gas Technology Center (DGC), and Pentair are partners to the project. The Danish branch of Pentair, located in Fredericia, specializes in plants for amine-based capture of CO_2.

Together, the BioCO2 partners are to build a portable plant to demonstrate the technology. The plant will be constructed at the premises of DTU Chemical Engineering. After completion it will be installed for periods of operation at two different locations. One location is Mølleåværket—a sewage management plant operated by Lyngby-Taarbæk Forsyning—and the other is a biogas facility at Funen operated by Nature Energy.

"It seems realistic that methane from upgrading of biogas can substitute 5-7 per cent of the current energy consumption in Denmark. If further biomass becomes available, this number could increase further in the future."

"We want to see the technology operated both at a facility with biogas production based on sewage, and at a facility with production based on manure from farms," says Philip L. Fosbøl.

Contributes to Danish energy policy
Besides the new production of high-quality CO_2, Philip L. Fosbøl stresses that BioCO2 will contribute to fulfilment of the ambitious Danish policy on sustainable energy:

"It seems realistic that methane from upgrading of biogas can substitute 5-7 per cent* of the current energy consumption in Denmark. If further biomass becomes available, this number could increase further in the future. Hopefully, BioCO2 will contribute to this development by making biogas upgrading more economically attractive both to farmers and to biogas plant operators."

Although high-quality CO_2 is the main focus of BioCO2, the upgrading of biogas into methane is also revisited.

"Developing a better way to produce CO_2 from the upgrading is important, but obviously one needs to ensure that this doesn't harm the quality of the methane. We need to ensure that the methane quality stays within specifications both for the sake of private consumer safety, and as a precautionary measure for avoiding danger of explosions at industrial facilities," Philip L. Fosbøl explains.

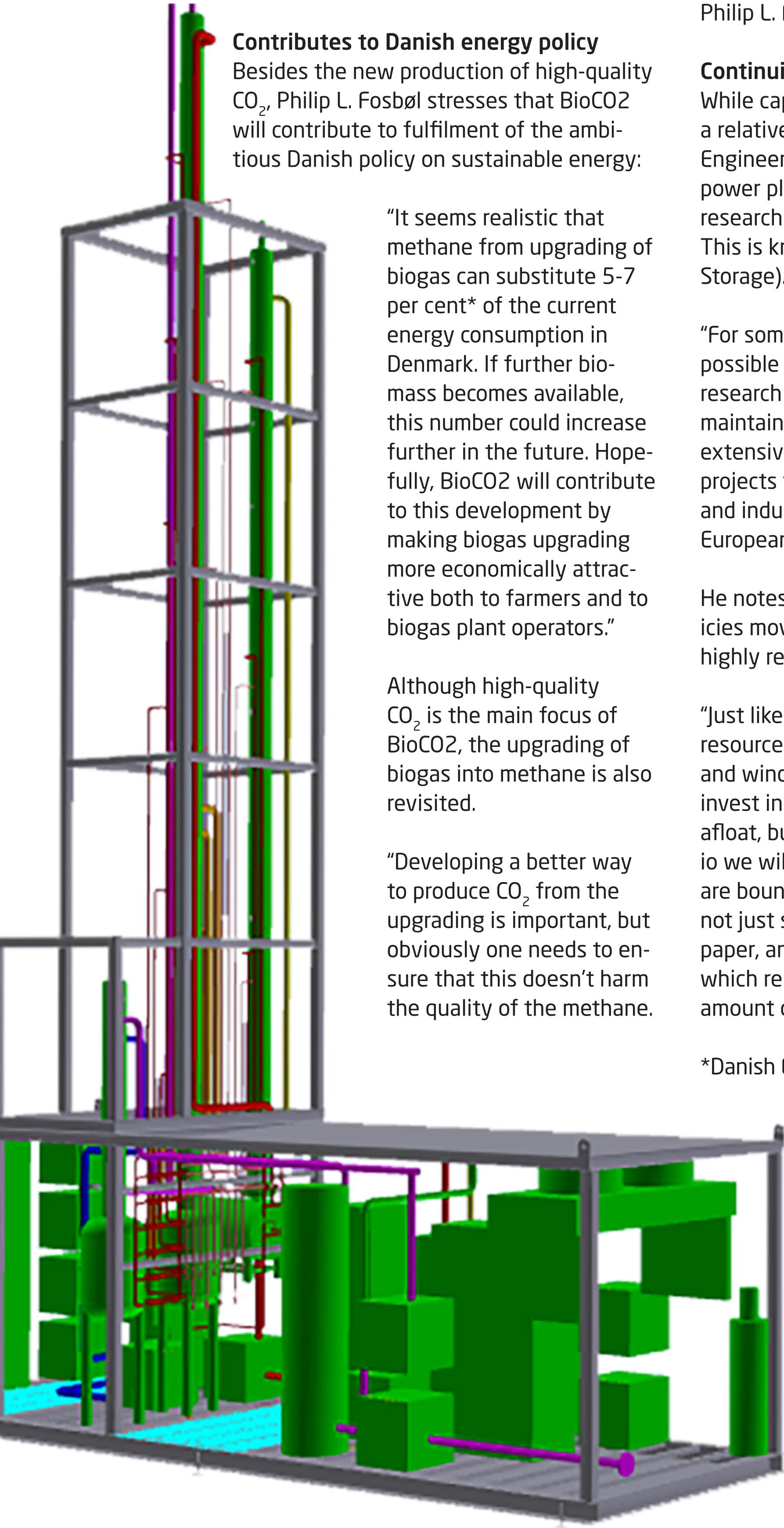
Continuing efforts in carbon capture
While capture of CO_2 at biogas facilities is a relatively new activity at DTU Chemical Engineering, capture of CO_2 from coal-fired power plants has been the subject of vast research efforts over the latest decades. This is known as CCS (Carbon Capture and Storage).

"For some years now, it has not been possible to obtain Danish public funding for research in CCS. However, we have maintained activity in the field through extensive participation in research projects funded by the EU with academic and industry partners from a range of European countries," says Philip L. Fosbøl.

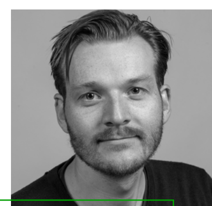
He notes that despite Danish energy policies moving away from coal, CCS remains highly relevant to the Danish society:

"Just like we have invested significant resources into development of photovoltaic and wind turbine technologies, we should invest in CCS. Not to keep our coal facilities afloat, but because in a sustainable scenario we will still need to produce goods which are bound to the emission of CO_2. We cannot just stop using steel, cement, medicine, paper, and similar types of welfare goods which rely on processes that emit a notable amount of CO_2."

*Danish Energy Agency, 2017



BioCO2 is in the process of designing a portable pilot plant for low biogas upgrading to produce clean CO_2.
Credit: Brian Berthelsen, Pentair Union Engineering.



PHILIP L. FOSBØL
ASSOCIATE PROFESSOR

WHY SMOOTH SHIPS ARE MORE SUSTAINABLE

Clever formulation and application of coatings for ships can meet the dual purpose of limiting biofouling in a sustainable way and reducing energy consumption.

The coating of a ship has several purposes besides making the vessel look nice. A key purpose is to control colonization of the surface by organisms present in seawater, also known as biofouling. Conventionally, this is done by adding biocides to a controlled-release coating. However, a promising alternative has been investigated in CoaST (The Hempel Foundation Coating Science and Technology Centre) at DTU Chemical Engineering. CoaST was founded in 2017 based on a donation from the Hempel Foundation.

Instead of using biocides, the biofouling can be combated by creating extremely smooth and flexible surfaces. This may not entirely inhibit the formation of biofouling, but the biofouling may soon be released—unable to stick to the surface, as the ship sails. Fouling-release coatings are presently applied to about 7 per cent of ocean-going ships.

"Notably, a smooth surface will imply a lower drag force, as the ship moves through the water. Therefore, the new anti-fouling strategy also leads to fuel savings and a lower level of harmful emissions, and thus improves transport sustainability," explains Postdoc Xueting Wang, lead researcher in the project.

Significant reduction in drag force

According to experiments and simulations, the average drag force of a state-of-the-art commercial smooth coating is 5.6 per cent lower on average compared with conventional anti-fouling coatings at a simulated sailing speed of 12 knots.

"This level of reduction is so high, that the overall contribution to energy savings and improved sustainability is significant. As an illustration, a reduction in drag force of this magnitude is larger than seen from reducing the height of welding seams, which is another relevant way," notes Associate Professor Søren Kiil.

Xueting Wang evaluating the coating surface on the rotor which was immersed in artificial seawater in a big tank. The rotor is part of the built set-up for drag measurements.

Photo: Thorkild Christensen

“Notably, a smooth surface will imply a lower drag force, as the ship moves through the water. Therefore, the new anti-fouling strategy also leads to fuel savings and a lower level of harmful emissions, and thus improves transport sustainability.”

The team at CoaST has set up lab facilities that allow testing of different coatings under conditions which mimic various physical environments, either natural or artificial. These facilities can also be used for testing the drag force under different welding seam heights or other changes in surface properties.

The key apparatus is a custom-built rotor designed for drag force testing. As the rotor spins, the drag force resembles that of a moving ship. The rotor can be painted with either commercially available products, or lab formulations. Further, a cylindric PVC (poly-vinyl-chloride) rotor with an extremely smooth surface has been manufactured. The PVC rotor will not be painted, but functions as a reference.

White paper on sustainability
The experimental results were a part of Xueting Wang’s PhD project. Further studies in CoaST will involve several scientific disciplines including polymer chemistry, mass transfer and diffusion processes, colloid and surface chemistry, and ship hydrodynamics.

“The project will hopefully lead to further improvements and recommendations for formulation and application of smooth ship coatings for fouling release,” says Søren Kiil.

The project demonstrates a key idea behind the establishment of CoaST, according to Kim Dam-Johansen, Head of Department at DTU Chemical Engineering, and Head of CoaST:

“Covering technologies from raw materials, over formulation, test, and characterization to production and application we take an interest in sustainability over the entire life cycle of a coating.”

By the end of 2018, this focus was put in writing as a white paper on sustainability.

“The quantification of sustainability in the coating industry is still in its infancy stage, mainly due to the absence of global standards between countries, and between the industries involved in the life of a paint,” notes Kim Dam-Johansen.

Extending the life of everyday objects
According to CEPE (European Council of the Paint, Printing Ink and Artists’ Colours) 40 per cent of the environmental footprint of a coating is created in the downstream stage, 10 per cent in the formulation stage, and 50 per cent in the upstream stage. Downstream, the coating industry approaches sustainability by recycling the waste paint, currently applicable for the decorative sector, and by ensuring that the coated substrates can be recycled. And as for formulation, industry can improve sustainability by creating enhanced functionalities of coatings.

“The main purpose of functional coatings is to extend the life of everyday objects, thereby contributing to the preservation of objects, and implicitly to the reduction of CO_2 emissions. Moreover, the functional coatings actively facilitate the sustainability efficacy, when used for green technologies such as wind mills. Last, but not least, upstream, the coating industry may approach sustainability by the selection of raw materials such as alternative pigments or bio-renewable binders,” Kim Dam-Johansen ends.

XUETING WANG
POSTDOC

SØREN KIIL
ASSOCIATE PROFESSOR

KIM DAM-JOHANSEN
PROFESSOR,
DIRECTOR OF COAST
HEAD OF DEPARTMENT

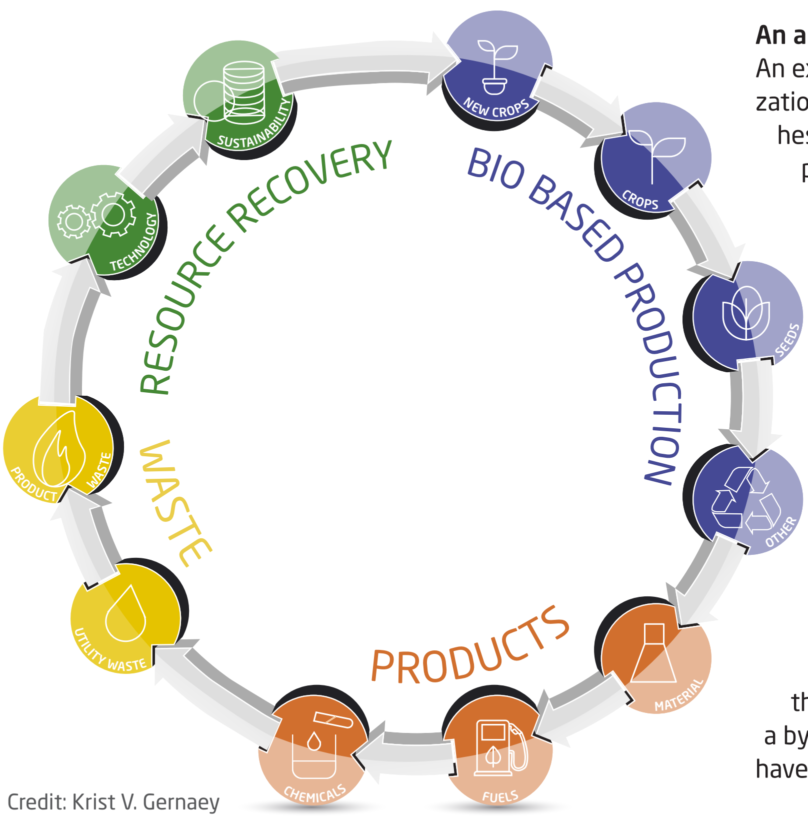
FIND THE JEWELS IN YOUR BIO-WASTE

Researchers at the Process and Systems Engineering Centre (PROSYS) at DTU Chemical Engineering are changing the mindset in the biomass, food, and bio-manufacturing industries, moving away from waste treatment to generating additional revenue streams.

To the researchers at PROSYS, 'waste to value' is more than a phrase. Cooperating with companies in the various industries including food and bio-manufacturing industries, they are analysing current waste streams, identifying valuable resources and suggesting techniques to exploit them.

"The application of separation and reaction technologies towards achieving resource recovery and circular economy in bio-based production processes is still minimal, despite their wide use in closely related processes such as dairy production," notes Assistant Professor Seyed S. Mansouri, PROSYS.

"For decades in Danish industry, the main idea has been to treat your waste at a designated facility to reach acceptable levels of certain critical compounds, allowing for safe disposal. Regardless of the many words being spoken about circular economy, it remains difficult to lose this mindset. However, a change in approach is necessary."



Credit: Krist V. Gernaey

An approach of systematic thinking

An extreme example of side-stream valorization in a bio-process is the compound hesperidin. As the market value of this pharmaceutically active compound is more than 170,000 Euro/ton, even tiny amounts in the waste or side-streams may be worth capturing. So, this is truly finding a jewel in one's bio-waste if resource recovery can be justified from a technological, environmental, and societal point of view.

Another example, addressed by the PROSYS team, is continuous removal of lactic acid from fermentation processes. Lactic acid is used in bulk quantities in several chemical industry applications. Thus, the compound—generally regarded as a byproduct in the biotech industry—does have a value in itself.

In a typical scenario, PROSYS may be approached by an enterprise, suggesting PROSYS to take a look at the current streams of waste and byproducts.

"The core of what we do is applying a systematic thinking approach in the context of process engineering which is commonly regarded as Process Systems Engineering (PSE). Firstly, we will try to identify the valuable compounds and their fluxes while quantifying their viability for recovery through techno-economic-sustainability evaluation. Secondly, we will assess which technical solutions can be purchased or developed for the necessary capture of valuable compounds. This is all about managing complexity," Seyed S. Mansouri explains.

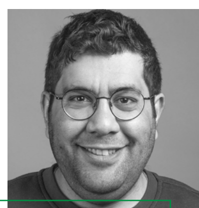
"Only when contributing to an economic or societal perspective, will solutions become operational to the enterprise."

Economic feasibility is crucial
The team is not just looking at recovering resources.

"Only when contributing to an economic or societal perspective, will solutions become operational for the enterprise. At PROSYS we have set up a mixture of expertise to cover the spectrum from economics over general engineering disciplines to specific biotech disciplines such as fermentation and biocatalysis. In our experience, it is preferable to introduce economic calculations as early as possible. This will avoid spending precious time on solutions that will never become applicable," says Seyed S. Mansouri.

Valorization of waste and side-streams has several advantages besides the additional revenue, Seyed S. Mansouri emphasizes:

"Contrary to the earlier image of waste management being unproductive and costly, today we often see the new focus on circular economy as a driver for real innovation. On a larger scale, achieving circular economy is a key opportunity for Denmark. As a small country with large dependency on imports of minerals and other raw materials, it makes a lot of sense to ensure that these streams are used carefully, limiting the need for further imports. And if we look a bit into the future, the day will come when the large raw material consumers have depleted their own resources. This is when they may look to Denmark to be inspired how to manage resources better, and then Danish technologies might become vital."



SEYED S. MANSOURI
ASSISTANT PROFESSOR

Bio-waste related projects in PROSYS

Researchers at PROSYS are involved in several projects aimed at utilizing byproducts and waste streams in the biomass, food, and bio-manufacturing industries.

GREENLOGIC explores mixed microbial culture biotechnology for production of energy-rich biofuels and green chemicals from low-value substrates and waste streams. Besides DTU, the academic partners are Lund University, Delft University of Technology, Technical University Berlin, and University of Queensland. Novozymes participates as industrial end user.

BIOPRO combines the expertise of DTU and University of Copenhagen with the industrial partners Chr. Hansen, CP Kelco, Ørsted, Novo Nordisk, Novozymes, and Xellia Pharmaceuticals, with the aim of bringing new, greener technology into pilot or full-scale application. CAPNOVA is involved to help with transforming research results into new products and startup companies.

REWARD (REuse of WateR in the food and bioprocessing inDustries) proposes the novel idea of applying the successful principles of Process Analytical Technology and Quality by Design to production and cleaning water management in the food and bioprocessing industry.

Further, the centre is involved in R2D2 (Recovery and Reuse through Design and Development), a Postdoc project funded by Carlsberg, and GECKO, a DANIDA funded project in collaboration with Kenya.

HIGHLIGHTS **2018**

1 FEBRUARY
ANNE LADEGAARD SKOV APPOINTED PROFESSOR

Anne Ladegaard Skov was appointed professor at DTU Chemical Engineering. Throughout the years, Anne has researched in new and better silicone elastomers as well as smarter ways to apply them. The focus of her work has been on both chemical and physical/electrical aspects of silicone elastomers and how to produce these. In her professorship, Anne Ladegaard Skov will mainly focus on dielectric elastomers for robots and sensors. On 25 May, Anne held her inaugural lecture: 'Pride and Prejudice in Electrical Fields: Dielectric Silicone Elastomers'.

6 FEBRUARY
VISIT FROM THE HEMPEL-DTU AWARD WINNER

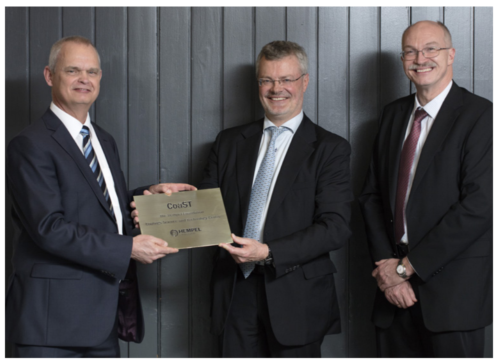
As winners of the Hempel-DTU award, HTX Holstebro's students paid a visit to our department. The students were shown around the large-scale experimental facilities at our Pilot Plant, introduced to the amazing world of coatings, and got an understanding of how the structure of water can serve as a driving force for innovation.

26-27 FEBRUARY
INDUSTRIAL PHD STUDENT WINS PRESTIGIOUS AWARD

Industrial PhD student Valeria Chiaula won the Best Poster award at the 12th World Congress on Pharmaceutical Sciences and Innovations in Pharma Industry in London, UK. She presented her work on glycerol containing elastomers with improved moisture handling properties. Her aim is manufacturing glycerol-silicone elastomers to help wound healing process in chronic wounds.

14 MARCH
FIRST ANNUAL MEETING AND INAUGURATION OF COAST

Our new research centre CoaST, The Hempel Foundation Coatings Science and Technology Centre had its very first annual meeting and, on top of that, was officially inaugurated.



Professor Kim Dam-Johansen, Director of CoaST. Richard R. Sand, Chairman of the Hempel Foundation. Anders O. Bjarklev, President of DTU. Photo: Mikael Schlosser

22 MAY
GROUNDBREAKING CEREMONY

The design of our new Building 228A is moving forward. In May, we celebrated the groundbreaking of the new state-of-the-art facilities which will mainly contain laboratories and pilot halls.

11 JUNE

GEORGIOS M. KONTOGEORGIS SELECTED FOR THE 2018 DISTINGUISHED LECTURE IN THERMODYNAMICS

The European Federation of Chemical Engineering's Working Party on Thermodynamic and Transport Properties nominated Professor Georgios M. Kontogeorgis for his outstanding contributions to the generation, application, and dissemination of knowledge and the technical advancement of the field through industrial cooperation.

18-20 JUNE

CERE DISCUSSION MEETING 2018

The annual Discussion Meeting had 23 participants from the Consortium and 28 participants from other research institutions, contributing to the record overall participation of 117. The meeting was partly overlapping with the annual meeting of the KT Consortium specializing in process simulation.

19-21 JUNE

KT CONSORTIUM ANNUAL MEETING

This year's KT Consortium Annual Meeting 2018 included 20 industrial participants from almost as many companies in intense discussions over a 3-day period with approx. 40 researchers from DTU Chemical Engineering.

22 JUNE

GREEN CHALLENGE

In this year's DTU Green Challenge (Grøn Dyst), students from all over the world participated—all sharing their green projects. Seventeen Sino-Danish Center (SDC) students from our MSc programme in Beijing participated in the Green Challenge with four projects: 'Extraction of CO_2 from shale gas mixture by Ionic Liquids', 'A techno-economic evaluation of treatment of brewery wastewater by symbiosis of algae and bacteria', 'Post-combustion CO_2 capture by biomass/waste chars' and 'Biomass-based Intumescent Coatings'.

29 JUNE – 27 JULY

SUMMER UNIVERSITY 2018

78 students from the US, 1 from India and 17 students from the Sino-Danish Center (SDC) for education and research participated in this year's annual Summer University for international students. Here students spent about four weeks in and around the department's Pilot Plant facility where they gained valuable insights into the challenges of real industrial challenges.

16-23 AUGUST

BIOPRO WORLD TALENT CAMPUS

This year, 25 participants from 19 of the world's best universities met up at Sorø Science Center for the annual BIOPRO World Talent Campus. Here they were presented with current real life cases from companies in the biotech industry, including, to name a few, Novozymes, Novo Nordisk, Chr. Hansen, CP Kelco and Xellia Pharmaceuticals, all of which they also got to visit during the week. The week also included social events in order to support the making of a global network.

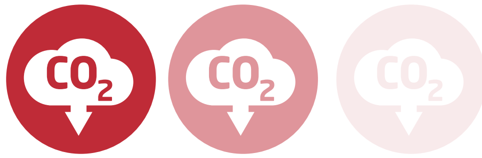
24 AUGUST
RESEARCH DAY—MISSION (IM)POSSIBLE

Presentation techniques were on the agenda at this year's Research Day. Prior to the event, PhD students had participated in workshops on how to present their research via visual, journalistic storytelling by using smartphones only. PhD student Francois Krüger took home best video with his 'Mission Impossible'-inspired video on thermodynamics of petroleum fluids relevant to subsea processing. Runner-up was PhD student Anna B. Figols with her video about production of polyhydroxyalkanoates from crude glycerol.

Photo: Francois Krüger

14-16 SEPTEMBER
KT-IPE SEMINAR IN CHINA

The annual KT-IPE seminar was held in the SDC building in Beijing—with 14 participants from DTU Chemical Engineering and around 25 participants from the Institute of Process Engineering (IPE). Here, the participants from the two departments presented their work while also discussing education and research collaboration. The final day included a visit to the IPE pilot facilities as well as their laboratories.



27 SEPTEMBER
COLLABORATION WITH FLSMIDTH AND ROCKWOOL ON SUSTAINABLE PROCESS TECHNOLOGIES

CHEC at DTU Chemical Engineering, in collaboration with FLSmidth and ROCKWOOL, received DKK 20 million from Innovation Fund Denmark to develop sustainable process technologies, which will enhance the use of alternative fuels as well as reduce the emission of CO_2.

12 OCTOBER
NORDIC WORKSHOP ON PHARMACEUTICAL CRYSTALLIZATION PROCESS DEVELOPMENT AND SCALE-UP

As part of the ProPharm project, funded by the Danish Council for Independent Research, PROSYS organized and hosted the first Nordic Workshop on Pharmaceutical Crystallization Process Development and Scale-up. This was for scientists interested in learning and sharing in the field, and case-studies were presented by international peers from related academia and 42 industrial participants including Novo Nordisk, Leo Pharma, Xellia Pharmaceuticals, Arla Foods, Lundbeck, Novozymes, and many more.

NEW FACULTY MEMBERS

This year, five new faculty members have joined the department to further support our increasing educational activities: Assistant Professor Seyed S. Mansouri, Assistant Professor Huichao (Teresa) Bi, Associate Professor Martin Andersson, Senior Scientist Jesper Ahrenfeldt and Senior Consultant Khosrow Bagherpour. We are confident that they will all contribute to the educational as well as the research environment for many years to come.

26 OCTOBER

PROSYS ANNUAL RESEARCH SEMINAR

The PROSYS Annual Research Seminar was organized for 91 participants (> 30 external). PROSYS PhD and postdocs presented their most recent research achievements, and three industrial speakers highlighted different perspectives of industrial development and industry-academia collaboration.

Photo: Birgitte Røddik

26 OCTOBER

DTU YOUNG RESEARCHER AWARD TO SARA LINDEBLAD WINGSTRAND

Former PhD student Sara L. Wingstrand recognized that the key to improving polymer fibre strength lies in an understanding of the relation between molecular orientation in the spinning process and the morphology of the final fibre product.

13 NOVEMBER

CHEC ANNUAL DAY

75 participants, of which 20 were industrial partners, attended this year's CHEC Annual Day. The programme included presentations from PhD students about the various research activities with industry.

20 NOVEMBER

WORKSHOP ON SUSTAINABLE AVIATION FUELS

Speakers and representatives from producers, developers and academia were present at the workshop, discussing how the Nordic countries can lead in finding solutions, developing technologies and producing sustainable aviation fuels. DTU Chemical Engineering was well-represented due to the potential technologies and new solutions that the department possesses and would like to pursue further. DTU Chemical Engineering was co-organizing the workshop together with Nordic Initiative for Sustainable Aviation (NISA) and Nordic Energy Research (NER).

SIX DEPARTMENTAL SEMINARS

At our department we always want to learn about and share new research and ideas. Therefore, it is well received by everyone at the department when Associate Professor Ioannis V. Skiadas invites scholars from around the world to give departmental seminars. This year, the seminars were given by Professor Jay H. Lee from KAIST (Korea Advanced Institute of Science and Technology), Dr.-Ing. Christoph Held from TU Dortmund University, Prof. Dr. Volker Hessel from Eindhoven University of Technology, Associate Professor Luis Ricardez-Sandoval from University of Waterloo, Ontario, Professor Teofil Jesionowski from Poznan University of Technology and Professor Benoit Chachuat from Imperial College London.

Photo: Christian Ove Carlsson

Photo: Openhouse


Photo: Mikkelsen Arkitekter

BUILDING
FOR THE FUTURE

This year, we broke ground on our new 6,000 m^2 building which will include laboratories for teaching as well as research, and a significant expansion of our existing pilot hall, making it available for large-scale experiments on biomass, particle technology, fermentation based manufacturing, coating production and tests, etc.

The new facilities will make it even more exciting for both students and researchers to employ their skillsets as they invent and develop tomorrow's research based solutions for industrial application, further consolidating DTU Chemical Engineering as one of the world's leading university departments in Chemical and Biochemical Engineering.

We look forward to inaugurating the new facilities in 2020 and thus strengthen our mission to develop and utilize knowledge, methods, technologies, and sustainable solutions for the benefit of society.

A NEW ERA OF BIO-BASED POLYMERS

In a world of scarce resources, bio-based polymers have entered the scene, offering interesting new functionalities.

As crude oil resources are slowly drying out, interest in producing bio-based polymers is rising accordingly. However, we should not only aim for direct substitution, but also take advantage of the new functionalities. This is according to Anders E. Daugaard, Associate Professor with the Danish Polymer Centre (DPC) at DTU Chemical Engineering:

"We do see new developments within fossil-based polymers from time to time, but these are mainly hybrids of well-known systems. We hadn't seen truly new polymer systems for several decades, until the bio-based polymers began entering the scene. This is really exciting, especially if you keep an open mind to their new functionalities."

Photo: Christian Ove Carlsson

"Some customers may want to buy a polymer just because it is bio-based, but overall only having 'the green story' will not be enough. Once you can show better properties, things will really take off."

The most prominent example is FDCA (2,5-furan-di-carboxylic-acid). FDCA is not a new substance but only within the last decade has this organic chemical compound become of industrial relevance. FDCA can substitute terephthalic acid (PTA), one of the widely used building blocks for production of polyesters and other polymers. Plastic bottles and wrapping products made from FDCA are already in production.

"The interesting thing for us is that as this business case has become relevant, the FDCA monomer will be produced in much larger quantity, leading to lower prices. This opens the field for other new business cases from this polymer system," says Anders E. Daugaard.

Having 'the green story' is not enough

In other words, the DPC researchers are not only focusing on how well a bio-based polymer like FDCA can match the properties of a fossil-based polymer like PTA—but also on the properties that are different. For instance, the gas-barrier properties of FDCA are actually better than those of PTA. This means that a FDCA container is more effective in preventing leaks of gasses and thereby also leaks of smell.

"This is where things become interesting. Some customers may want to buy a polymer just because it is bio-based, but overall only having 'the green story' will not be enough. Once you can show better properties, things will really take off."

Another example of different properties is the stability. Bio-based polymers are generally less stable than fossil-based, but this can actually be an advantage:

"For instance, at a football stadium you can serve all food and beverages at plates and cups made from a bio-polymer, and later process the leftovers, plates and cups into compost—saving the resource consumption for rinsing and separation. This would not be possible if the polymer was fossil-based," explains Anders E. Daugaard, noting that the example is from the US:

"The concept conflicts with current Danish waste treatment, but such regulations could be altered in the future."

Part of the circular economy

On the same note, bio-based polymers could be introduced for some hardened polymer products.

"If you look solely at properties like stiffness, stability, and mechanical strength, bio-based polymers may not be able to compete with fossil-based polymers. However, as interest in circular economy is growing, the perspective begins to change. It could be a better option overall to have a less stabile product, if the reusability is much better."

Besides FDCA, several other bio-based polymers are being developed for a range of applications. For instance, the DPC researchers have an ongoing collaboration with Haldor Topsøe on preparation of functional polyesters.

"Currently, polyesters are produced from cleaner raw materials such as sugars, but it will become possible to instead produce it from straw and other types of biomass which are currently seen as agricultural waste materials. Again, this is really exciting from a perspective of using the world's scarce resources in a sustainable manner," says Anders E. Daugaard.

Enzymatic polymerization is highly specific

Bio-based monomers are generally more fragile and cannot tolerate the same harsh processing as can fossil-based. However, this does have an upside. Enzymatic polymerization is not only gentle, but also more specific, meaning the products may become of excellent purity and can have a much higher degree of functionality compared with polyesters prepared by classic methods.

"As enzymes cannot tolerate high temperatures, they may not be fit for production of bulk quantities of polymers and can 'only' contribute to substances like additives. Still, this will be a valuable contribution to transition to a sustainable use of resources," says Anders E. Daugaard, summing up:

"The really uplifting thing is that the new bio-based polymer systems are coming. There is no doubt about it. So, as polymer scientists we have a unique chance to investigate all the new functionalities and at the same time contribute to sustainability."

DPC PROJECTS ON BIO-BASED POLYMERS

Researchers at DPC are engaged in a range of projects focusing on different types of bio-based polymers. Titles of some of the most recent scientific publications indicate the scope of the research:

'Highly Branched Bio-based Unsaturated Polyesters by Enzymatic Polymerization'
Polymers, 2016. Funded by Innovation Fund Denmark, and enzymes were supplied by Novozymes.

'Synthesis of a Novel Polyester Building Block from Pentoses by Tin-containing Silicates'
RSC Advances, 2017. Collaboration with Haldor Topsøe, enzymes were supplied by Novozymes.

'Hybrid Poly(lactid acid)/ Nano-cellulose/ Nano-clay Composites with Synergistically Enhanced Barrier Properties and Improved Thermomechanical Resistance'
Polymer international, 2016. Funded by the Marie Curie International Training Network under the EU FP7.

'Investigation of Curing Rates of Bio-based Thiol-ene Films from Diallyl 2,5-furandicaboxylate'
European Polymer Journal, 2018. Frontpage of the issue. The project was funded by DTU.

ANDERS E. DAUGAARD
ASSOCIATE PROFESSOR

A NOVEL CONCEPT FOR BIO-FUEL PRODUCTION

Catalytic hydro-pyrolysis is a strong candidate for conversion of biomass into liquid fuels for vehicles and airplanes. The technology can be viewed as part of the solution to the renewable energy storage challenge.

Current state-of-the-art methods for production of liquid fuels from biomass involve fermentation or other intermediate steps which have low energy efficiency and possibly create waste. A new technology investigated in a joint industry project at DTU Chemical Engineering offers direct production of bio-gasoline or bio-diesel, and methane. The main side-product is char which is also useful—either as a fertilizer if returned to the field or as a source of more gas.

The process in question is catalytic hydro-pyrolysis. Biomass pyrolysis is a well-established process, where the biomass is heated rapidly in an anaerobic atmosphere resulting in a mixture of char, bio-oil, and methane. However, the bio-oil will contain considerable amounts of both water and a range of oxygen-containing organic compounds. The water content reduces the energy potential of the oil, while the oxygen-containing organic compounds make the oil less stable and thus hamper the potential for storage. Also, the oil is highly acidic, which is a risk factor for corrosion in fuel systems. Therefore, bio-fuel produced through pyrolysis may need post-treatment by hydrogenation. Reheating the oil for hydrogenation, however, may cause operational problems due to the reactive

Photo of the bench scale catalytic hydropyrolysis set-up at DTU Chemical Engineering.
Photo: Thorkild Christensen

"We strive to make our results available to as wide an audience as possible, not least since the method is a potential solution to a large societal challenge."

nature of the oil. The idea behind catalytic hydro-pyrolysis is to produce the desired end-products in one step.

"Producing the end-products directly reduces energy consumption and costs. And most importantly, the direct approach causes less operational issues. We have shown the feasibility of the method," states Professor Anker D. Jensen from CHEC at DTU Chemical Engineering.

Highly relevant for Denmark
The core of the system is a catalyst-loaded fluid bed reactor. The biomass is fed into the reactor and fluidized by hydrogen. Hereby, the oxygen-containing organic components react with hydrogen at the catalyst surface, and they are thus pacified before they polymerize and cause the catalyst to deactivate.

"We have demonstrated that the conditions for maintaining the efficiency of the involved catalysts are actually much better in the direct process" says Anker D. Jensen.

The process produces a mixture of oxygen-free bio-hydrocarbons in the gasoline and diesel boiling point range along with a very clean water phase. Therefore, the produced biofuel has a high energy content and may be stored just like fuels produced from fossil feedstock.

"The technology is generally applicable, and is highly relevant for a country like Denmark. The produced methane can be used directly in our natural gas distribution system, and we have a large production of sustainable energy, mainly power from wind turbines. In windy periods we actually have excess wind power. This could be used to produce hydrogen." notes Anker D. Jensen. "Furthermore, DTU Mechanical Engineering, which was partner in the project, has shown that the process has a very high energy efficiency, making the process look even better."

Strives to publish results
Entitled 'Hydrogen assisted catalytic pyrolysis'—or H2CAP for short—the 4.5-year project was initiated in 2014 on a grant from The Strategic Research Council. At that time, ideas of commercialization were still in their infancy. This may soon change, as several large energy corporations such as Shell and Phillips 66 are looking at various catalytic hydro-pyrolysis designs with an eye to commercialization.

"We strive to make our results available to as wide an audience as possible, not least since the method is a potential solution to a large societal challenge", says Anker D. Jensen. "Besides biomass, the process also has potential using waste plastics as feedstock converting it into fuels or monomers that could be recycled. This is something we would like to investigate in future projects."

He is pleased to note that no less than ten articles are in the pipeline for scientific publication from the H2CAP project, while several others have already been published, including a large review article in the prestigious journal Progress in Energy & Combustion Science.

Besides the group at DTU Chemical Engineering, the H2CAP project involves DTU Mechanical Engineering, Stanford University (USA), Karlsruhe Institute of Technology (Germany), and the catalyst producer Haldor Topsøe.

ANKER D. JENSEN
PROFESSOR

CHEMICAL ENGINEERING TOOLS FOR GREEN OILS

The properties of oil produced from biological feedstock are very different from fossil-based oils. A consistent effort in the KT Consortium assists in providing the necessary methodology for bio-refining.

While refining crude oil into a variety of useful products has been around for more than a century, the processing of oil from canola and other biological raw materials is a much younger discipline. Therefore, this emerging industry branch finds itself in need of both chemical engineering models and experimental data in order to perform at a level similar to that of traditional refineries.

“The faculty of the KT Consortium was approached by one of our industry members, Alfa Laval, and we were happy to set up a joint effort,” explains Georgios M. Kontogeorgis, Professor at DTU Chemical Engineering and chairman of the KT Consortium.

Alfa Laval is a world leader within technologies based on heat transfer, fluid handling and separation processes. During the last couple of decades, edible oil systems have been of rising importance to the corporation.

“The long-standing cooperation with Alfa Laval on edible oil systems is a fine example of how industry and academic competences can move things forward.”

Photo: Colourbox

New property models for bio-oils
After more than a decade of joint research, including several PhD projects, a lot of progress has been made. First of all, the collaboration has resulted in property models and databases based on the relatively scarce experimental data published in the open literature. This has been supplemented with in-house comparison with Alfa Laval plant data. Further, experiments designed to result in new data in order to verify the models and know their limitations and the uncertainties involved are continuously set up.

Currently, the collaboration includes a PhD project by Olivia A. Perederic, DTU Chemical Engineering, on 'Systematic computer aided methods and tools for lipid processing'. The project is sponsored by Alfa Laval.

The main KT Consortium deliverable is the ICAS (Integrated Computer Aided Systems) software.

"According to feedback from of our industry members, they consider ICAS to be at least as good and possibly better than commercially available process simulation tools," says Georgios M. Kontogeorgis. "In relation to bio-oils, the combination of software and experimental results will often allow a company to do a preliminary design. Generally, this will be enough to establish the commercial potential of a given process and rank design alternatives."

Strong participation from industry
The KT Consortium is focused on process simulation, has software as its main deliverable and has mainly chemical, pharmaceutical and biotech participants.

Besides the ongoing joint projects and contacts, the industry members are invited to participate in the KT Consortium annual meeting. As always, the 2018 version was well attended by 17 different industrial companies. This year, several presentations involving biotechnology—for instance enzymatic processes for production of chemicals from biomass, conversion of biomass into biofuel, and conversion of biogas into bio-methane—were part of the programme.

"We are pleased by the strong involvement from our industry members. The annual meeting is a truly inspiring venue for direct discussions involving both industry and DTU Chemical Engineering researchers," Georgios M. Kontogeorgis states.

"The long-standing cooperation with Alfa Laval on edible oil systems is a fine example of how industry and academic competences can move things forward."

GEORGIOS M. KONTOGEORGIS
PROFESSOR
CHAIRMAN OF KT CONSORTIUM

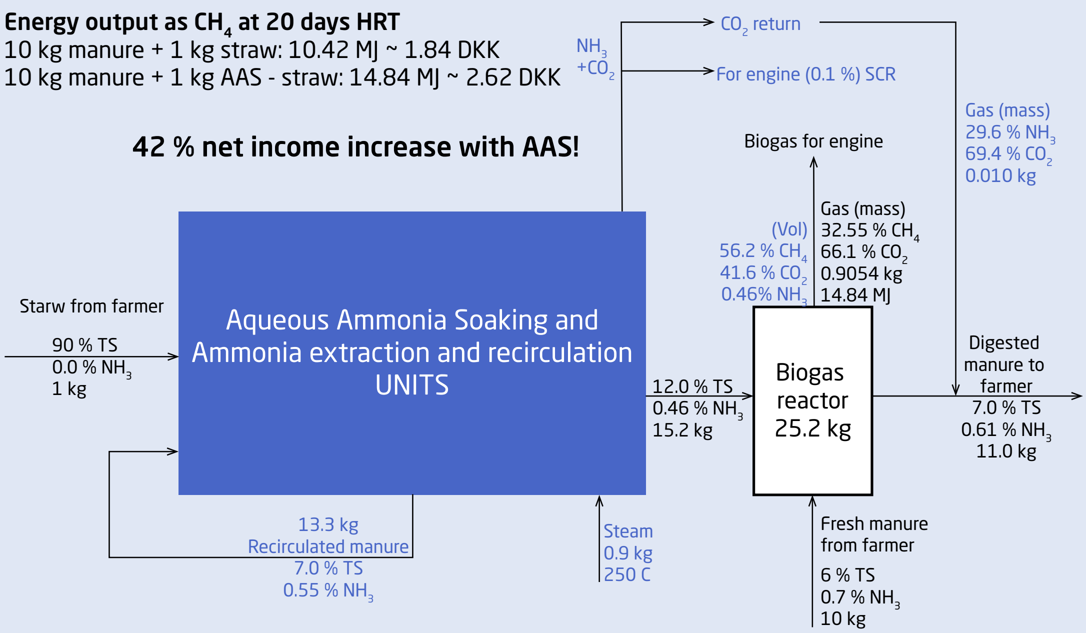
BOOSTING THE EFFICIENCY OF BIOGAS PLANTS

Laboratory experiments have shown pretreatment with ammonia able to increase methane production from manure fibres by more than 200 per cent. Pilot Plant tests will take the method close to full-scale implementation.

The amount of methane produced from the solid fraction of swine manure has been increased three-fold under lab conditions at DTU Chemical Engineering. In collaboration with a range of Danish biogas industry operators and consultants, the cross departmental Pilot Plant facility at DTU Chemical Engineering is about to make the method operational.

"Upscaling the process from lab scale to full-scale is by no means straightforward. Ammonia is a pollutant. In the lab it is easy to handle ammonia, but in full scale with much larger amounts of ammonia involved, this is more challenging. Here, we see the value of having pilot plant facilities," says Associate Professor Ioannis V. Skiadas, heading the new project DEMONIAGAS (Demonstration of enhanced methane production from ammonia-pretreated biomasses in biogas plants) for DTU Chemical Engineering. The project is funded by the Danish Energy Agency through EUDP (Energy Development and Demonstration Program).

While swine manure is available in large quantity in Denmark, the methane potential of the manure is too low for economically



Potential outcome from DEMONIAGAS project. Credit: Hariklia N. Gavala, DTU and N.B.K. Rasmussen, DGC

"In the lab, it is easy to handle your ammonia, but in full scale with much larger amounts of ammonia involved, this is more challenging. Here, we see the value of having pilot plant facilities."

feasible biogas production. This has been addressed by mixing manure with other biomasses with a higher methane potential such as slaughterhouse wastes, energy crops, and fish oil. However, increased demand for biomass feedstock for other applications has raised prices of these types of biomass. Therefore, it is highly desirable to utilize the methane potential of the manure by making the fibre content already present in the manure available to the biogas producing microbes.

Preparing a meal for microbes

In the DEMONIAGAS project, the fibres are pretreated with ammonia.

"In analogy, if we as humans were to eat paper, we wouldn't achieve any nutritional benefit. This is because, unlike cows for example, we lack the biological mechanisms necessary to digest cellulose fibres. But if the paper is suitably pretreated, sugars can be produced from the cellulose and these will have nutritional value for us. What we are doing in the project is basically the same thing, only are we pretreating the fibres to make them available for microbes to digest," explains Associate Professor Hariklia N. Gavala, responsible for the bio-process engineering component.

Photo: Colourbox

The researchers have named the process Aqueous Ammonia Soaking (AAS). In a previous research project, the methane yield of manure fibres was increased almost 200 per cent in less than 20 days digestion at 37°C. The project also looked at adding extra sources of cellulose, primarily wheat straw. By subjecting the straw to ammonia treatment, its methane potential was raised by 50 per cent.

"So, this is very encouraging, as straw is a cheap feedstock. However, there is a limit to how much straw you can introduce. If one adds solid material in too large quantity, the slurry becomes difficult to pump," says Ioannis V. Skiadas, noting that the project will also demonstrate a more economically feasible way to run the process. "Unlike in the lab, a full-scale process should preferably run continuously. Also, continuous production is more economical because stops between batches are avoided, just as are the start-up procedures for production of the next batch."

A model to assist decisions by operators

Finally, the precise pretreatment needs to be adjusted for the type of biomass added to the sludge.

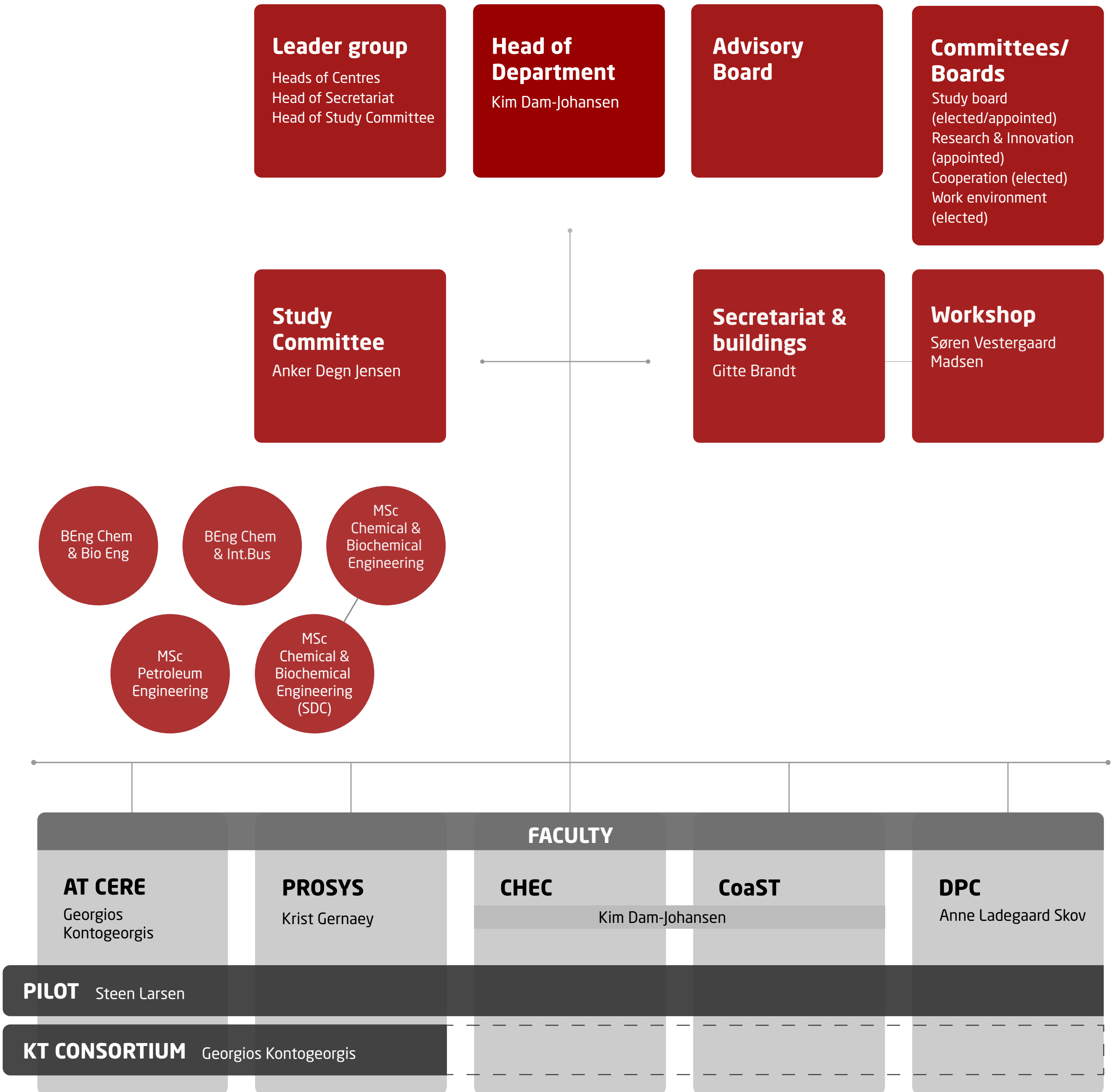
"Conditions such as temperature, duration, ammonia concentration, and solid/liquid ratio should be optimized for the biomass type. We plan to develop a model capable of telling the operators which parameter values to select," Hariklia N. Gavala informs. "Further, the model will tell you what the maximum methane production could be in each case. This may assist business decisions by the plant operator."

External partners in the DEMONIAGAS project are Madsen Bioenergi, Danish Gas Technology Center (coordinator), EnviDan, and Lundsby Biogas. The demonstration project follows up on a recently completed research project, AMMONOX, coordinated by DTU Chemical Engineering and funded by Energinet.dk.

HARIKLIA N. GAVALA
ASSOCIATE PROFESSOR

IOANNIS V. SKIADAS
ASSOCIATE PROFESSOR

ORGANIZATION



RESEARCH CENTRES

DTU Chemical and Biochemical Engineering is home to five research centres and one cross departmental Pilot Plant facility – each focusing on their area of expertise. Below you can get a quick overview of the centres and their respective research areas.

AT CERE

In Applied Thermodynamics–Center for Energy Resources Engineering (AT CERE), we focus on applied thermodynamics, transport processes and properties, mathematical modelling, materials science, petroleum technology, enhanced oil recovery, CO_2 capture, and gas hydrates and energy resources.

CHEC

In Combustion and Harmful Emission Control (CHEC), we focus on catalysis, inorganic chemistry, combustion and flue gas cleaning, diagnostics, gasification, pretreatment of biomass and pharmaceuticals.

DPC

At Danish Polymer Center (DPC), we focus on polymer technology, polymer chemistry, rheology, filament stretching rheology, surface modification, silicone polymers and elastomers.

COAST

The focal points in The Hempel Foundation Coatings Science and Technology Centre (CoaST) are on sustainable coatings technologies including raw material engineering, smart formulation and production principles, application, testing and tailor-made functionalities.

PILOT PLANT

The cross-departmental Pilot Plant facility focuses on designing and building large-scale plants to perform, teach and develop unit operations, industrial chemical processes, operational experience, design of components, plant safety, and good manufacturing practice.

PROSYS

Process and Systems Engineering Centre (PROSYS) is focused on developing state-of-the-art Process Systems Engineering (PSE) methods and tools, as well as to develop and demonstrate novel technologies for future more sustainable production processes.

To learn more about our research, recent results, or current projects, please visit **www.kt.dtu.dk/research.**

THE FACULTY **2018**

SCIENTIFIC

Jens Abildskov
Associate Professor

Martin Andersson
Associate Professor

Huichao (Teresa) Bi
Assistant Professor

Jakob M. Christensen
Associate Professor

Jesper Ahrenfeldt
Senior Scientist

Kim Dam-Johansen
Professor,
Head of Dept.

Anders E. Daugaard
Associate Professor

Philip L. Fosbøl
Associate Professor

Hariklia N. Gavala
Associate Professor

Krist V. B. Gernaey
Professor

Peter Glarborg
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Jakob K. Huusom
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Martin Høj
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Manuel Pinelo
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Alexander A. Shapiro
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Gürkan Sin
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Associate Professor

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Professor

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Associate Professor

Kaj Thomsen
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Stig Wedel
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John Woodley
Professor

Hao Wu
Assistant Professor

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PILOT PLANT

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PILOT PLANT

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Senior Consultant
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John Villadsen
Professor Emeritus

Lars G. Kiørboe
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Karsten H. Clement
Professor Emeritus

Ole Hassager
Professor Emeritus

Hanne Østergård
Emeritus

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LARS BANG
EXECUTIVE VICE PRESIDENT,
H. LUNDBECK A/S

"Implementing manufacturing of new medicines and continuously exploiting innovative new technologies to optimize manufacturing is key to the competitiveness of Lundbeck. Through a long-term partnership with DTU Chemical Engineering, we are working together with a world-class research group. It has significantly increased our technological competences and capabilities. At the same time it has improved our network and thereby the basis for attracting the right new engineers to drive further progress."

THOMAS VIDEBÆK
CHIEF OPERATING OFFICER,
NOVOZYMES A/S

"At Novozymes, we aim at finding biological answers, for better lives, in a growing world. Fermentation technology holds enormous potential and every day we work together with partners around the world to improve chemical processes. Thereby reducing the need for scarce resources for the benefit of consumers, our partners, as well as the planet."

BJERNE CLAUSEN
PRESIDENT & CEO,
HALDOR TOPSØE A/S

"Topsøe's solutions within catalysis help solve some of the world's most serious challenges. In order to develop our products and meet future needs, our close partnership with DTU Chemical Engineering is indispensable. We aim for the same high scientific and quality standards, and in Topsøe we are greatly inspired by the remarkable knowledge, drive, and curiosity of the students and candidates from DTU Chemical Engineering."

LARS PETERSSON
CHIEF OPERATING OFFICER,
EXECUTIVE VICE PRESIDENT,
HEMPEL A/S

"At Hempel, we strive every day to solve the challenges of our customers by providing coating solutions which protect their assets, lower their impact on the environment, and enhance their performance. In that quest for solutions, DTU Chemical Engineering is an invaluable partner for us to tap into the latest research within the fields of formulations, processes, and sustainability. Cooperating with DTU Chemical Engineering also creates an excellent opportunity for attracting talent and developing future and existing Hempel employees."

HANNE EVERLAND
VICE PRESIDENT TECHNOLOGY,
GLOBAL R&D, COLOPLAST A/S

"The best results are never achieved alone. For Coloplast, performance and collaboration go hand in hand. Working together with colleagues, customers, and partners, we share knowledge and explore new possibilities. That's what moves things from what they are, to what they could be. It is our mission to always be at the forefront of new technology and innovation within medical devices for people with intimate healthcare needs and therefore we have this partnership with DTU Chemical Engineering. The polymer research and education as an integrated part of Chemical Engineering is important not only for Coloplast, but for the medical device industry in Denmark in general."

COOPERATING COMPANIES

Addifab
Akzo Nobel
Alfa Laval
Applied Chemicals and Materials Division, NIST
Aquaporin
Arkema France
Arla Foods Ingredients Group
AstraZeneca
AVEVA Software
AWA Denmark
Babcock & Wilcox Vølund
BASF
Bayer
Biomar
Bioscavenge
Biosyntia
BP
Burkert
BW Scandinavian Contractor
Carlsberg Research Laboratory
Centro Tecnologico Componentes
Chevron
Chr. Hansen
Chreto
Ckj Steel
C-LEcta
Coloplast
Conocophillips
CP Kelco
Dansk Gasteknisk center
DHI
DSM
DSM Nutritional Products
DuPont Nutrition and Biosciences Denmark
Electrochaea
Encoat
Engineering Consulting Corporation
EnviDan
Equinor
Esbjerg Farve- og Lakfabrik
Evonik
ExxonMobil
Firmenich
FLSmidth
Fluidan
Fluor Corporation
Freesense
Fujifilm Diosynth Biotechnologies
GEA
GlaxoSmithKline
GLYCOM Denmark
Gr3n Sagl
Grundfos
H. Lundbeck
Haldor Topsøe
Hempel
Hennes & Mauritz GBC
Hess
HOFOR
Holm Christensen Biosystemer
Hwam
IFP Energies nouvelles
Innosyn
Insatech
Janssen pharmaceutical company of Johnsson & Johnson
Jiangsu Industrial Technology Research Institute
Kalundborg Forsyning
KBC
Landbrug & Fødevarer
LEAP Technology
LEGO
Leo Pharma
Linde
LiqTech International
Lundsby Biogas
Madsen Bioenergi
Maersk Oil
MAN Energy Solutions
Microsoft
Mitsubishi
MOL Group
Mærsk Line
National Oilwell Varco
NEO GROUP
Neptune Energy
Neste Jacobs Oy
Nordic Sugar
Nouryon
Nova Pangeae
Novo Nordisk
Novozymes
ParticleTech
Petrobras
Pharmacosmos
PHX Innovation
Process Design
Processi Innovation SRL
Processium
ProSim SA
Q-Interline
Radiometer
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SBM Offshore
Schlumberger
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Sinopec
SmartMotion Technologies
Solchroma
SYNESIS
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TOTAL
Umicore Denmark
Unibio Group
Unilever
Union Engineering
Wacker
Welltec
Wintershall
Xellia Pharmaceuticals
Ystral
Ørsted

GUESTS

From 17 different countries

50 Guests*

29 Research institutions

* PHD, POSTDOC, GUEST RESEARCHER AND PROFESSOR.

KTSTUDENTS BRINGS INDUSTRY AND STUDENTS CLOSER TOGETHER


Photo: Christian Ove Carlsson

From left to right: Monica Abildgaard, Helena Thøgersen, Anna Stærmose, Binoy Shah, and Jeska Naujoks.

The student organization KTStudents is much more than organizing social events. In fact, most of the time is spent on company visits and organizing in-house presentations from various industries and alumni.

Among the more popular events this year was a visit to GEA. Another popular event was the in-house presentation by Haldor Topsøe.

"We think it is extremely important for students to get an idea of what will meet them workwise at the end of their studies. That's why we arrange these events so that they get to know the chemical and biochemical industry. Furthermore, attending our events will give the students an opportunity to develop strong networks, too", says Anna Stærmose, Chairman of KTStudents.

The activities run by the KTStudents contributes to giving students insights into current and future industry challenges that they will be solving in the future. They also serve as a means to building valuable liaisons.

Contact KTStudents on **KTSO@kt.dtu.dk**

TEACHING

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

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

COURSES

1 SEPTEMBER 2017 – 31 AUGUST 2018

PHD COURSES

28904	Polymer Physics
28905	Advanced Topics in Process Systems Engineering
28908	Rheology of Complex Fluids (heavy)
28909	Thermodynamic Models, Fundamentals and Computational Aspects
28917	Statistical Thermodynamics for Chemical Engineering
28923	Uncertainty and Sensitivity Analysis of Numerical Models
28927	Advanced Topics in Process Technology
28928	Electrolyte Solution Thermodynamics
28930	Advances in Chemical and Biochemical Engineering
28931	Biorefinery and Sustainability
28932	Process Engineering Laboratory

SINO-DANISH CENTER (SDC) COURSES

88700	Industrial Reaction Engineering
88701	Transport Processes
88703	Laboratory Experiments
88704	Progress in Research
88705	Process Design – Principles & Methods
88707	Energy and Sustainability
88710	Combustion and High Temperature Processes
88711	Industrial BioReaction Engineering
88713	SDC Green Challenge
88714	SDC Summer School in Unit Operations
88715	Biorefinery

COURSES

MSC, BSC, AND BENG COURSES

Below, course numbers and names are shown for 2018, 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.

SPRING-SEMESTER

28012 Chemical and Biochemical Process Engineering (62) **(B)**
28016 Mathematical Models for Chemical and Biochemical Systems (43) **(B)**
28020 Introduction to Chemical and Biochemical Engineering (64)
28022 Unit Operations of Chemical Engineering and Biotechnology (49) **(B)**
28025 Bio Process Technology (88)
28121 Chemical Unit Operations Laboratory (5)
28157 Process Design (39) **(B)**
28160 Mathematical Models for Chemical Systems (37)
28212 Polymer Chemistry (41)
28214 Polymer Synthesis and Characterization (13)
28221 Chemical Engineering Thermodynamics (48)
28231 Laboratory in Chemical and Biochemical Engineering (23)
28322 Chemical Engineering Thermodynamics (41) **(B)**
28342 Chemical Reaction Engineering (53) **(B)**
28344 Biotechnology and Process Design (43) **(B)**
28345 Chemical Reaction Engineering (47)
28346 Advanced Fermentation Technology Practicum (11)
28350 Process Design: Principles and Methods (58)
28352 Chemical Process Control (33) **(B)**
28361 Chemical Engineering Model Analysis (49)
28415 Oil and Gas Production (24)
28423 Phase Equilibria for Separation Processes (18)
28434 Membrane Technology (60)
28443 Industrial Reaction Engineering (39)
28451 Optimizing Plantwide Control (20)
28535 Rheology of Complex Fluids (light) (3)
28811 Polymers in Processes and Products (6)
28850 Quality by Design (QbD): Integration of Product and Process Development (75)
28855 Good Manufactoring Practice (93)
28864 Introduction to Matlab Programming (23)
28871 Production of Biofuels (20)
28885 Technology and Economy of Oil and Gas Production (20) **(B)**

Courses given in cooperation with other departments:
12701 Introduction to Living Systems (61)
26317 Instrumental Chemical Analysis (30)
41683 Materials Science (48) **(B)**

FALL-SEMESTER

28001 Introduction to Chemistry and Chemical Engineering (70)
28012 Chemical and Biochemical Process Engineering (97) **(B)**
28016 Mathematical Models for Chemical and Biochemical Systems (51) **(B)**
28022 Unit Operations of Chemical Engineering and Biotechnology (61) **(B)**
28121 Chemical Unit Operations Laboratory (33)
28125 Chemical Unit Operations Laboratory (14)
28140 Introduction to Chemical Reaction Engineering (44)
28150 Introduction to Process Control (61)
28157 Process and Product Design (29) **(B)**
28213 Polymer Technology (41)
28233 Recovery and Purification of Biological Products (61)
28242 Chemical Kinetics and Catalysis (76)
28244 Combustion and High Temperature Process (39)
28246 Applied Enzyme Technology and Kinetics (62)
28247 Advanced Enzyme Technology (17)
28310 Chemical and Biochemical Product Design (64)
28315 Colloid and Surface Chemistry (71)
28316 Laboratory Course in Colloid and Surface Chemistry (13)
28322 Chemical Engineering Thermodynamics (49) **(B)**
28342 Chemical Reaction Engineering (45) **(B)**
28344 Biotechnology and Process Design (29) **(B)**
28352 Chemical Process Control (34) **(B)**
28420 Separation Processes (43)
28515 Enhanced Oil Recovery (23)
28530 Transport Processes (77)
28831 Computational Fluid Dynamics in Chemical Engineering (21)
28845 Chemical Reaction Engineering Laboratory (17)
28852 Risk Assessment in Chemical Industry (70)
28864 Introduction to Matlab Programming (45)
28870 Energy and Sustainability (90)
28872 Biorefinery (50)

Courses given in cooperation with other departments:
23522 Rheology of Food and Biological Materials (16)
26010 Introductory Project in Chemistry (65)
36004 Health, Diseases and Technology (62)
41683 Materials Science (33) **(B)**

BACHELOR OF ENGINEERING DEGREES

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

Optimization of indicator stick for lactate dehydrogenase measurement in milk
Release of Active Ingredients from Silicone Membranes
Investigation of the effect Polyaluminium Chlorides have on Flocculation (2 students)
Design of cyclically operated reactive separations
Dispersion techniques in coating production
Preparation and characterization of skin adhesives
Optimization and Validation of Continuous Filterdryer (2 students)
Development of new resin formulations for additive manufacturing
Thermodynamic Modeling of Heavy Metal Salts in Ash from Sewage Sludge
Decomposition of urea (2 students)
Optimizing management of solvent waste from industrial amphotericin B purification (3 students)
Ozone Gas Solubility and Stability in Edible Oil Mixtures for Medical Treatment (2 students)
Numerical and experimental investigation of a bioreactor
Experimental pilot campaign and design of a mobile demonstration unit for biogas upgrading
Production of pure phosphate product from incinerated sewage sludge
Sealing as a remediation method in PCB-contaminated buildings (2 students)
Chemical Properties of CO_2 Solvents with Additives, Experimental Work and Modelling
Emulsions as formulation format for enzymes (2 students)
Optimization of process equipment for roasting coffee using fluidized bed technology
Use of keratin protein hydrolysate for the cost-effective microbiological production of 1,3-propanediol (1,3-PDO) from crude glycerol by the beterolactiv bacterium *Lactobacillus diolivorans*
Preparation of antimicrobial polymer surfaces
Corrosion analysis of transformer stations
Extraction of valuable substances from ash from biomass combustion
Development and formulation of Cleansing Balm for GOSH Donoderm Skincare
Development of crystallization process for Amphotericin from dimethyl sulfoxide solvent system
Combustion behavior of raw and pelletized wood at suspension-fired conditions
Numerical fluid dynamic investigation of a chemical reactor with anchor shaped impeller
Direct membrane filtration (DMF) for treatment of wastewater
Modelling mass transfer and diffusion into medical containers
Recovery of ammonia from aqueous ammonia-soaked biomass as a method to increase the methane productivity in biogas plant
Development of pretreatment methods of lignocellulosic biomass for production of second generation biofuels

BACHELOR OF SCIENCE DEGREES

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

Synthesis of Antimicrobial Polymers and Anchoring on Surfaces
Development and test of a compartment model for a wood burning stove
Economic Analysis of Separations Technology
Chromatographic column characterization and modeling (2 students)
Dielectric elastomers in optical applications (2 students)
Optical surfaces from PDMS
Quantification of adsorption rates of dispersion agents on pigments
Scalable coating processes for perovskites solar cells
Micro-imprinting of silicone elastomers
Foam as material for robot skin
Analysis of industrial pressure filtration processes

Design an interactive thermodynamic modelling system in MATLAB and EXCEL
Ionic Liquids-based Electrolyte for Lithium Battery
Energy Storage in Phase Change of Inorganic materials
Modelling of heavy metal salts in solutions of ash from biomass
Poisoning by SO_2 and regeneration of Rh/ZSM-5 catalysts for methane oxidation
Model for urea decomposition
Development of a more active ammonia catalyst
Separation of phosphorus from heavy metals in biomass ash (2 students)
Gas-induced degradation of protective coatings in extreme conditions
Investigation of cracking of glucose for production of chemicals
Recombinant Enzyme Evaluation Studies for Biocatalysis
The kinetics of the Claus process with addition of sulfuric acid
Enzyme reaction and process optimization for CE15 carbohydrate esterases
Investigation of alternative catalysts for the oxidation of methanol to formaldehyde

MASTER OF SCIENCE DEGREES

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

Study of Mixing, Peeling and Polysaccharides for the Pharma Industry
Reservoir-well Interaction
Modelling the BAWAT Ballast water Treatment System
Modelling of dealumination in the catalysts for the MTG process
Modeling and simulation study of a disposable bioreactor for cultivating mammalian cells
Calculations and experiments concerning scaling/corrosion
Numerical investigation of the fluid dynamic conditions of the Lysefjord (Norway)
Surface modification of polysulfone hollow fiber membranes
Numerical modelling of DME-enhanced water injection in heterogeneous chalk reservoirs
Optimization of protein recovery from keratin rich slaughterhouse waste
Characterization of product gas from gasification of straw in an LT-CFB gasifier for the catalytic conversion of tar to bio-oil
Hydraulic fracturing in layered media
Numerical study of the effects of CO_2 and water on oil recovery in chalk
Dynamic modeling of a Continuous Freeze-Drying Process
Dynamic modeling of separation of fermentation liquids
In-line dispersion techniques for efficient coating production
Quality control for efficient in-line coating production
Thermodynamic analysis of chalk-brine-oil interactions
Biomethanation of syngas in attached growth bioreactors
Periodic Reactive Separation
FCA controlled nutrient addition during microbial fermentations
Development of polycaprolactone-based scaffolds for biomedical applications
Modeling and characterization of pH in *Bacillus licheniformis*
Selective non-catalytic reduction of nitric oxide by ammonium sulfate
Extensional Rheology of Polymer Melts
Synthesis of novel curing systems for silicones
Well Spacing Optimization under Subsurface Uncertainty for Tight Carbonate Reservoirs
Oxidative leaching of chalcopyrite particles. Experimental investigations and modelling aspects
Field scale long term optimization of a gas lift system
Thermodynamics of petroleum fluids relevant to subsea processing
Chromatographic column characterization: Experiments and simulation
Computer-Aided Molecular Design for Solvent Selection using Group-Contributions
Preparation and testing of FDCA based nanocomposites
Quantification of leveling in conventional antifouling coatings

Diffusion of OH solvents in organic coatings
Fermentation of crude glycerol to ethanol in lab and pilot-scale
Optimization of an enzyme purification process
Extraction of alginate from brown algae
Techno-economic assessment of production of lactic acid using 3rd generation biomasses
Catalytic deoxygenation of biomass pyrolysis vapor model compounds with zeolites
Synthesis and test of modified SUZ-4 catalysts for the MTO reaction
Recovery Process Optimization
Cracking of sugars for production of chemicals
Recycle option for chromatographic separation
Thermodynamic modeling of the solubility of pharmaceuticals with the PC-SAFT EOS
Feasibility of membrane technology in resource recovery from bio-based production processes: a techno-economic decision
Preparation of novel membrane systems for enzyme immobilization
Functionalization of silicone elastomers for improved electrical properties
Experimental investigation of dairy fouled membrane cleaning with help of ultrasound
Techno-economic assessment of methods for calcium precipitation from dairy ultrafiltration permeates
Monoamine oxidase-based biocatalysis for pharmaceutical synthesis
Chemo-enzymatic reactions for pharmaceutical synthesis
Systematic decison-making framework for resource recovery in bio-based industry
Mass transfer from nano bubbles for anti-bacterial applications
Periodic separation
Highly Sensitive and Flexible Pressure Sensor Based on Popous Dielectric Elastomer Conductive Filler
Synthesis and characterization of amphiphilic diblock copolymer brus films by metal-free SI-ATRP
Determination of relative permeabilities from steady-state and transient experimental data
Development of ceria-based electrodes for low-temperature solid oxide electrolysis cells
Modelling hydrate formation for hydrate mitigation during oil and gas production
Modelling and simulation of gas diffusion in polymers
Commissioning, test and evaluation of low-tar biomass gasifier for rural applications
Mechanistic modeling and monitoring of API production fermentation
Preparation and testing of reactive bio-based polyesters
Development of a precipitation software tool for improved fermentation design
Syngas conversion to C_2-oxygenates over rhodium-based catalysts
Geothermal heat production in low permeable fractured reservoirs

SDC MASTER'S DEGREES

13 students finished their research projects for the MSc Degree/Double degree. The project titles are listed below:

Acceleration of the iron cycle for a Fenton-like reaction by a porous β-cyclodextrin polymer
Adsorption of volatile organic compounds in multistage fluidized bed
The diversity of organophosphorus pesticide degrading bacteria and its influence factors in vegetable phyllosphere
A green catalytic synthesis of N-containing compounds
Catalytic systems for hydrogenation of ethylene carbonate to produce methanol and ethylene glycol
Conversion of 2,5-furandicarboxylic acid from 5-hydroxymethylfurfural
Multi-scale simulation of dense gas-fluidized beds with binary particles mixtures
Carbon dioxide capture from flue gas using ionic liquids-based solutions
The role of graphene in multifunctional membrane preparation
Smart and self-healing hydrogels derived from catechol modified chitin nanofibrils
Studies on the aldol condensation of formaldehyde and propionaldehyde using bifunctional catalyst
Synthesis and property study of Tz-TzII (Thiazol-thiazolisoindigo) based derivatives
Investigation on the phenolic bio-oil etherification

WoS PUBLICATIONS

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Department of Chemical and Biochemical Engineering
Technical University of Denmark
2800 Kgs. Lyngby
Denmark

Phone +45 4525 2800
Email kt@kt.dtu.dk
Web www.kt.dtu.dk

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