Biobased Chemistry and Technology
Annual report 2016

WAGENINGEN
UNIVERSITY & RESEARCH

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Introduction

It is my pleasure to present to you the annual report 2016 of the Biobased Chemistry and Technology group. In 2016 we strengthened our mission “BCT wants to develop sustainable conversion routes to aid in establishing a biobased economy”. We focused further on our mission by appointing a new tenured track assistant professor dr. Costas Nikiforidis. He will work on developing sustainable biorefineries. He starts from a fundamental point of view and will use the gained insights on interactions between biomass components to develop efficient extraction methods .

https://courses.edx.org/courses/course-v1:WageningenX+BB01x+1T2017/info

Biobased is also gaining in significance within the Wageningen educational ecosystem. The BCT group is heavily involved in the online micromasters “biobased sciences for sustainability” and the application of an on campus master ‘biobased sciences”. In the coming year we will further develop this in collaboration with a number of groups within Wageningen.

For me this was an interesting and exiting year. I hope you feel the same after reading this report.

With kind regards

Prof. J.H. (Harry) Bitter
Chair holder Biobased Chemistry and Technology

Collaborations

The strategy of the BCT group is to develop fundamental insights in processes relevant for biobased conversions. Based on these fundamental insights we also want to suggest improvements in processes in the biobased field. Therefore collaborations with other groups within and outside Wageningen are established. Some of our collaborations are summarized in the table below.
At the end of 2016 the chemistry groups within Wageningen University started closer collaborations within WUR-Chemical Sciences. BCT plays an important role in that e.g. by a positon in the board.

Collaborating group in Wageningen	Topic
Environmental Technology (ETE)	Combining chemo and bio-electro-catalysis Modelling of water-energy-material nexus in industrial and urban environments
Bioprocess Engineering (BPE)	Modeling of algae systems
Wetsus	Waste water treatment and modeling
Organic chemistry (ORC)	Teaching and research proposals
Bionanotechnology (BioNT)	Combining catalysis and NMR in microreactors
Food and Biobased research (FBR)	Different research projects and acquisitions

The BCT group participates within Wageningen in the research schools VLAG and WIMEK and is part of the Netherlands Institute for Catalysis Research (NIOK) and the Institute for sustainable process technology (ISPT). In addition, the group participates in the Working Group on Drying (NWGD), the Dutch Process Control Initiative, the Dutch Institute for Systems and Control (DISC) and WETSUS.
The group collaborates intensively with other academic and industrial groups both within WUR (FBR-Wageningen Research) and outside to address the multi-disciplinary character of the challenges (e.g., within EU projects, STW, BE-Basic, ISPT, Center for Biobased Economy (CBBE) and advisory boards such as the Biorenewables Business Platform).

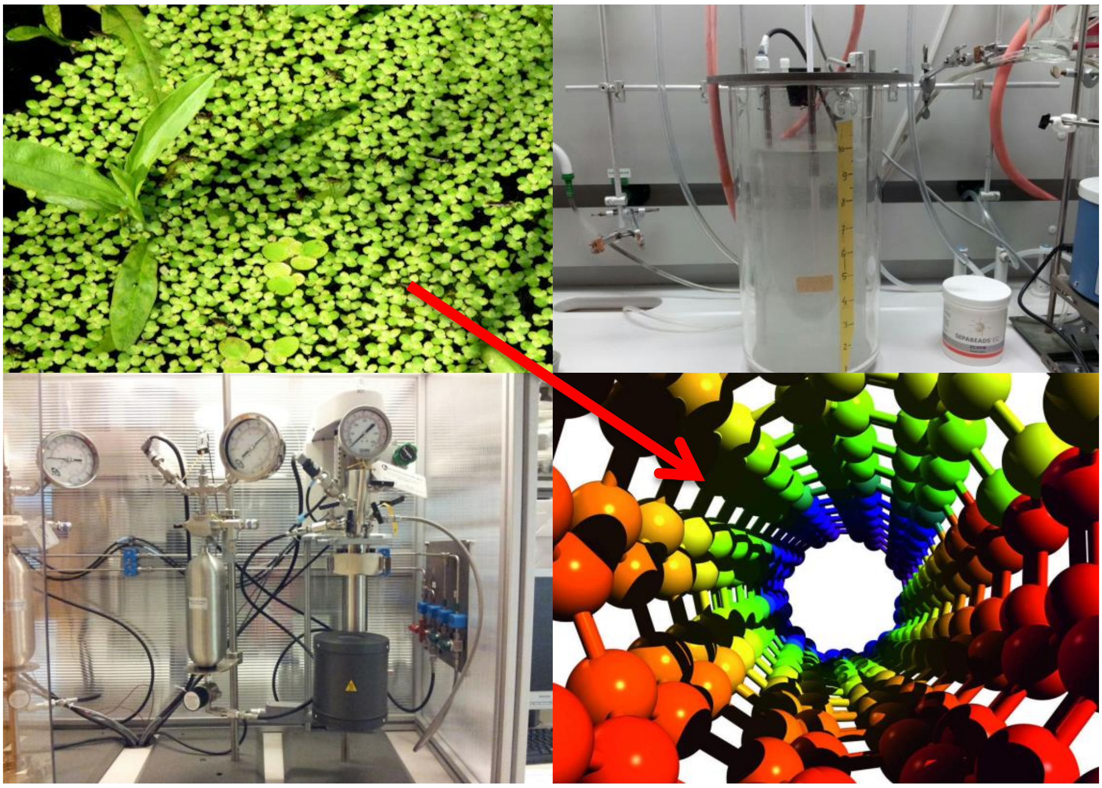
Conversion Group

Staff: Dr. Elinor Scott, Dr. Piet Buwalda, Prof. Harry Bitter, Dr. Costas Nikiforidis
PhD students and post-docs: Piet van der Zaal, Tim Hoogstad (joint technology/conversion), Luana Souza Macedo, Andrada But, Frits van der Klis, Roxani Chatzipanagiotou, Xinhua Goerner-Hu, Gerben Wierda, Evie van der Wijst, Tomas van Haasterecht,
Contact: Elinor.scott@wur.nl

Background and goal
Environmental concerns, fluctuating oil prices and dwindling reserves are leading to the need for the production of biobased chemicals, materials and fuels. In order to achieve this new biomass pretreatments, (bio)chemical conversions and catalyst developments are required. As well as this biobased molecules offer opportunities for the production of novel and functional materials.

Main topics

- Application of homogeneous, heterogeneous and bio-catalysis in biobased reactions
- Developments of non-noble metal based catalysts
- Development of catalysts stable under conditions required for biomass conversion
- Novel functional materials from biomacromolecules (starch, chitin)
- Biorefinery
- Biomass pretreatment and cellulose conversion
- Biomass conversions using catalytic aqueous phase reforming



Selective catalytic transformations of non-edible carbohydrates

Name PhD: Frits van der Klis BSc.
Involved staff members: Prof. dr. J.H. Bitter; Dr. D. S. van Es; Dr. J. van Haveren

Project sponsor: TKI-programs, CatchBio, EU SPLASH

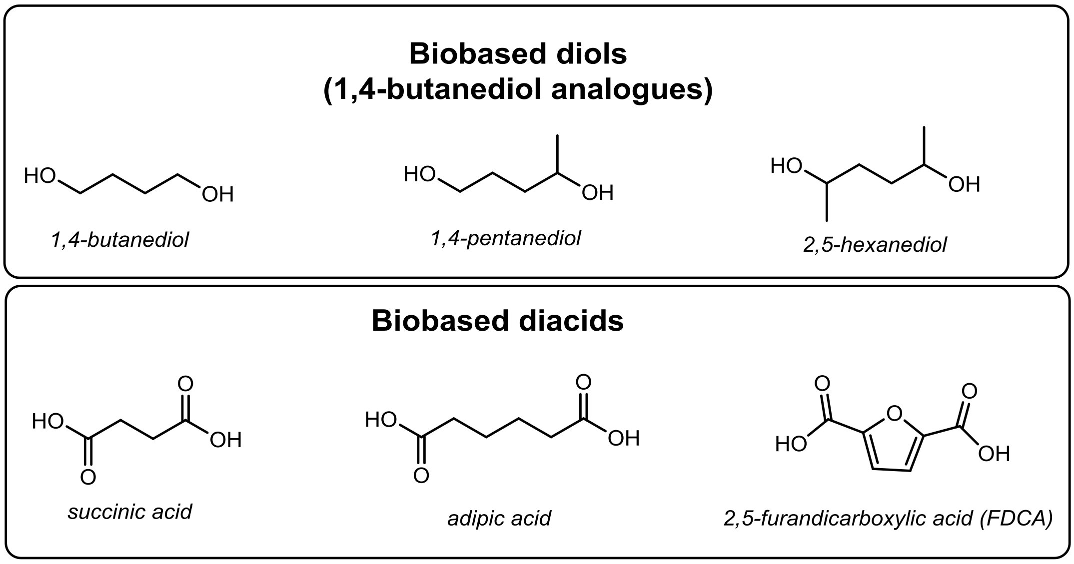
Start/(expected) end date of project: October 2013 – October 2017

Background and goal of project

Carbohydrates are excellent starting materials for a wide variety of biobased chemical building blocks like diols and di-acids, which can be used in polyester synthesis. In this part of my project, a series of novel biobased polyesters from 1,4-butanediol-analogues and biobased diacids was prepared, and the influence of Me-substituents on the glass transition temperature and crystallization was investigated.

Highlight of the past year

Methyl-substituted analogues of 1,4-butanediol were investigated: 1,4-butanediol (0 x Me), 1,4-pentaandiol (1xMe) and 2,5-hexaandiol (2xMe). From these diols, three series of polyesters were prepared using the following diacids: succinic acid, adipic acid and furan-2,5-dicarboxylic acid (FDCA).



The obtained polyesters were analysed for molecular weight, and thermal properties. We found that in all series the glass transition temperature (Tg) increases with the number of Me-groups. All building blocks can be prepared from renewable resources, and the possibility to influence the Tg inspires to develop novel (biobased)polyesters.

Type of student projects envisioned

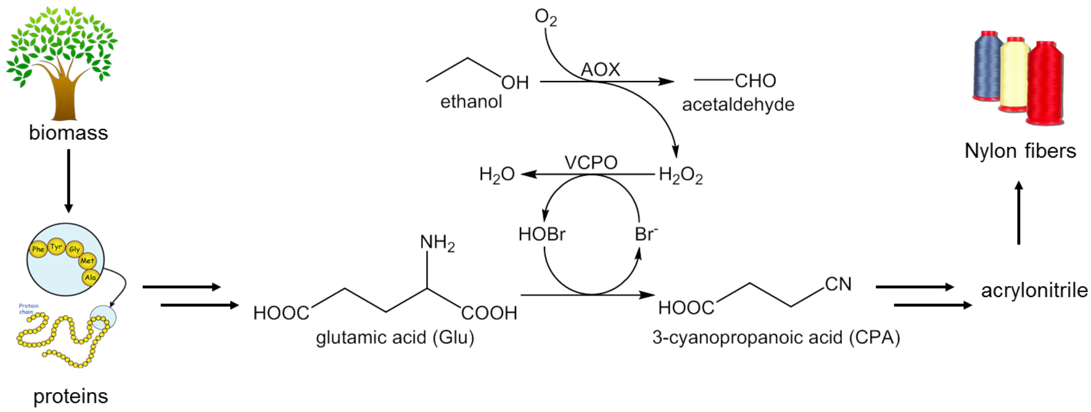
Student projects all involve organic chemistry and/or catalysis orientated lab work, focused on the conversion of carbohydrates. Standard analysis during synthesis includes NMR, GC-MS, IR and HPLC. Catalysts will be analyzed by TEM, XRD, chemisorption and physisorption.

Biocatalytic Formation of Industrial Nitriles from Biomass

Name PhD: Andrada But
Involved staff members: Elinor Scott, Johan Sanders, Harry Bitter
Project sponsor: Wageningen University
Start/(expected) end date of project: 11.06.2012-10.06.2016

Background and goal of project

Introduction of functionality into hydrocarbons to produce functional chemicals is energy intensive. This is especially true for nitrogen containing chemicals where ammonia is used. Research is focusing on the transformation of amino acids from protein-rich waste streams into bulk chemicals. One example is glutamic acid (Glu) – a versatile starting material for the syntheses of N-succinonitrile and acrylonitrile *via* 3-cyanopropanoic acid (CPA). A viable conversion of Glu to CPA is *via* enzymatic oxidative decarboxylation using HOBr generated using vanadium chloroperoxidase (VCPO) with H_2O_2 and NaBr. For this reaction dilute streams of H_2O_2 from the antraquinone process are traditionally used. This involves sequential concentration and dilution steps of H_2O_2 which would result in an inefficient use of energy due to sequential concentration and dilution steps. Therefore, the in situ production of H_2O_2 is desired. This can be carried out using an alcohol oxidase (AOX) which converts alcohols and molecular oxygen into (volatile) aldehydes and H_2O_2.



Highlight of the past year

In the last part of this project, the in situ production of H_2O_2 by AOX was investigated. The peroxide produced by AOX in the first reaction, reacts further in the second reaction with NaBr under the catalysis of VCPO and forms the oxidizing agent HOBr. It was found that when HOBr is immediately used by a third reaction involving a fast halogenation step, such as the bromination of monochlorodimedone, the three reactions are possible in one pot. However, when HOBr was used to convert glutamic acid to 3-cyanopropanoic acid the two enzymes had to be separated in two reaction vessels to avoid inactivation of AOX by HOBr.

Type of student projects envisioned

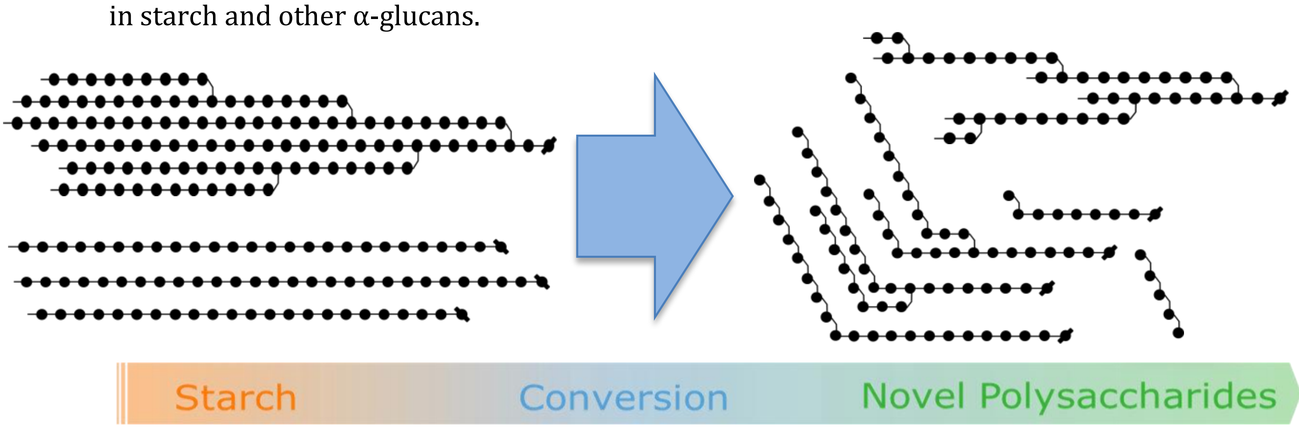
The typical work within this project involves lab experiments (enzymatic reactions) and analytical studies (spectrometry, HPLC, others).

Isomalto/malto-polysaccharides from starch

Name PhD: PH van der Zaal MSc
Involved staff members: dr. PL Buwalda, prof. dr. JH Bitter
Project sponsor: TKI/AVEBE (CCC-B)
Start/(expected) end date: 01-10-2013/01-10-2017

Background and goal of project

Starch is used in a wide range of applications due to its inherent functionality. The functionality of starch depends on its natural properties and these natural properties vary per starch source. In order to broaden the spectrum of starch functionality, it is often modified. This can be done in planta, chemically, physically and enzymatically. Recent trends in sustainable processing have sparked more interest in the enzymatic modification of starch. Traditionally, starch bio-catalysis is focused on breaking down specific linkages with glucanohydrolase enzymes. However more recently, starch is also modified with glucanotransferases. Instead of solely breaking down, glucanotransferase enzymes are capable of modifying starch by adding, deleting and shuffling the linkages in starch and other α-glucans.



4,6-glucanotransferase (GTFB) is a glucanotransferase, capable of converting α-1,4 linked glucans, such as starches, into α-1,6 linked glucans. This conversion of starch results in the formation of isomalto/malto-polysaccharides (IMMPs).
IMMPs can be considered as a new generation of polysaccharides with potential for products in and outside the food industry, such as: prebiotics, food fibers, texturizers, replacement of synthetic polymers and for biomedical materials.

Highlight of the past year

The preparative fractionation of IMMPs has resulted in a deeper understanding of the GTFB mechanism. With the use of ^{1}H NMR and methylation analysis it was determined that GTFB transferase activity is dependent on the linearity of the substrate. Produced IMMPs rich in linear alpha-1,6 linkages were also classified as slowly-fermentable fibers with prebiotic potential.

Type of student projects envisioned

- Structural characterization with the use of enzymatic fingerprinting; controlled hydrolysis of IMMPs with glucanohydrolases.

- In depth chemical analysis of IMMPs, including; molecular weight, ratio of α-1,4: α-1,6 linkages and directed (enzymatic) modification.

Non noble metal carbides and phosphides to be developed in Brazil and the Netherlands to replace heterogeneous noble metal based catalysts

Name PhD: Luana Souza Macedo
Involved staff members: Harry Bitter, Victor Teixeira da Silva
Project sponsor: UFRJ (Brazil) and Wageningen University
Start/(expected) end date of project: March 2014 – March 2017

Background and goal of project

Noble metals are widely used in industry as catalysts for many reactions such as hydrogenation, hydrolysis and Fischer-Tropsch synthesis. However, noble metals are scarce therefore more readily availbe replacements are desired. Transition metal carbides and phosphides revealed to be efficient catalysts for reactions that involve the transfer of hydrogen, such as ammonia synthesis and decomposition, hydrogenolysis and hydroprocessing. Thus they are a potential replacement of noble metals. In spite of the increasing number of reports showing the potential of transition metal carbides and phosphides as catalyst for many reactions, they are not widely used for commercial applications due to the restriction of the complete control and understanding of their structure and physical chemical properties. Thus, understanding fundamental aspects of this new class of catalysts is paramount to spread its use.

Highlight of the past year

Depending on the synthesis method (carburization and carbothermal reduction) and consequently on the C/Mo ratio available on Mo_2C/CNF synthesis, alpha or beta phase of Mo_2C/CNF can be formed.

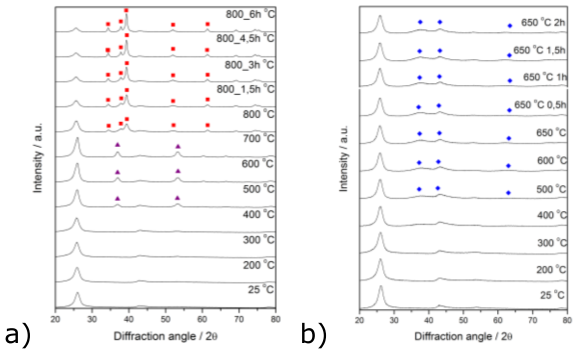


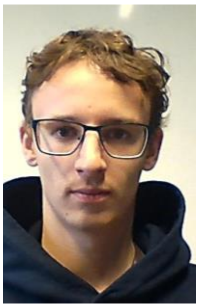
Figure 1. In situ XRD for 7.5 wt% Mo_2C/CNF synthesized via a) carbothermal reduction with argon and b) carburization with 20% CH_4/H_2 gas mixture
■ hexagonal β-Mo_2C ▲ MoO_2 ♦ cubic α-MoC_{1-x}

α-MoC_{1-x}/CNF catalyst has better performance compared to β-Mo_2C/CNF for stearic acid hydrodeoxygenation at 350 ^{o}C and 30 bar H_2, what can be attributed to its higher amount of active sites and of Mo atom terminated sites compared to β-Mo_2C/CNF. In addition, the higher HDO conversion over α-MoC_{1-x}/CNF can be related to the bigger distance between the active sites in α-MoC_{1-x}/CNF, which leads to a higher availability of simultaneous adsorption of stearic acid molecules on the catalyst sites during reaction.

Type of student projects envisioned

This project involves mostly lab work, what includes synthesis and characterization of catalysts added to batch catalytic reactions. As characterization techniques we use mostly N_2 physisorption, microscopy and gas chromatograph analysis.

Real time monitoring of reactions with micro NMR spectroscopy

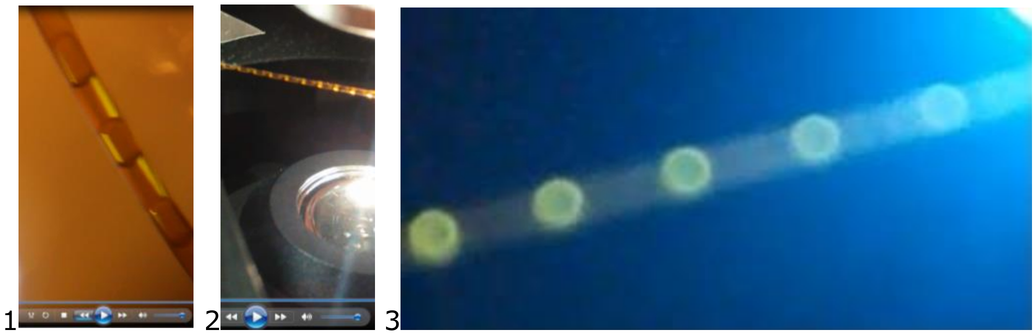


Name PhD: Gerben Wierda
Involved staff members: Prof. dr. Harry Bitter, Prof. dr. Aldrik Velders, Dr. Elinor Scott
Project sponsor: VLAG Graduate School
Start/(expected) end date of project: September 2015 – September 2019

Background and goal of project

Inside a plug flow reactor concentrations of products and reactants change as function of the position along the reactor due to conversion. In my project I will study the chemical composition of a reaction mixture as function of position in a wall-coated heterogeneous catalytic reactor by using NMR spectroscopy. Insights in how the conditions influence catalyst performance inside the reactor are anticipated.

Fused silica tubes were coated with AlO(OH) on which nanosized Pt particles were deposited. The hydrogenation of mesityl oxide (MO) to methyl isobutyl ketone (MIBK) at mild temperatures is used as first show case. In a later stage a solid base catalyst will be added to also make MO by the self-condensation (and dehydration) of acetone.



Slug-flow (Taylor flow regime) established in a reactor capillary at acetone flow speed 33 μL/min and H_2 flow speed 100 μL/min (picture 3) Recordings credits to Tomas

Highlight of the past year

- Microreactor set-up preparation and slug-flow tests. (see figure)
- Batch reactor catalytic tests and reactant characterisation.

Type of student projects envisioned

A student on this project could work with microreactors, using supported metal catalyst nanoparticles. The design, preparation and characterisation of the coated reactor can have unexpected results.
Would you work on the frontier of catalysis research in Wageningen? Send an e-mail to gerben.wierda@wur.nl

Combining *Chemo-* and *Bio-* electro-catalytic synthesis of chemicals

Name PhD: Konstantina Roxani Chatzipanagiotou, MSc
Involved staff members: prof. dr. Harry Bitter (BCT), prof. dr. ir. Cees Buisman (ETE), dr. ir. David Strik (ETE)
Start/(expected) end date of project: March 2015/March 2019

Background and goal of project

Carbon dioxide (CO2) is the primary contributor to climate change. One way to mitigate the problem is by using CO2 and renewable electricity to produce chemicals. In Microbial Electro-Synthesis (MES, Figure 1), bacteria use electricity to convert CO2 in useful organic molecules. A key challenge for up-scaling MES is to improve the electron transfer between the cathode and bacteria. Metal particles have been previously shown to improve the attachment of bacteria on the electrode, and facilitate the electron transfer [1,2]. This project aims to investigate the addition of metals to MES bio-cathodes as a way to improve electron transfer and CO2 reduction rates.

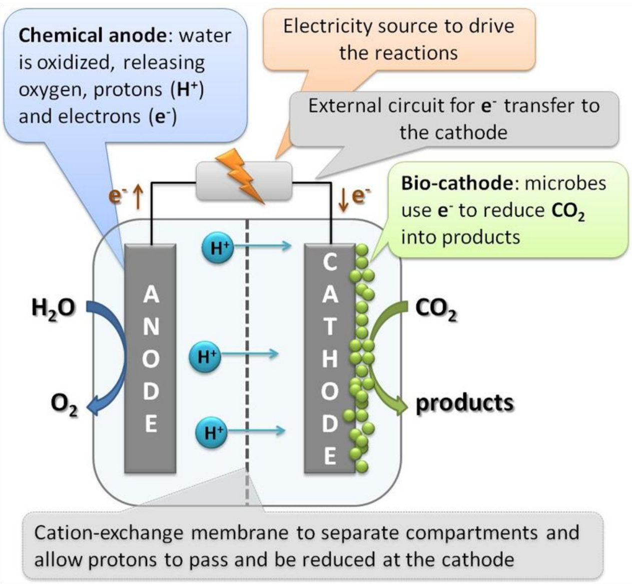


Figure 1: The MES cell schematic.

Highlight of the past year

Adding nickel on an acetate-producing MES bio-cathode has been previously shown to increase acetate production by more than a 4-fold, operating at -0.6 V vs. Ag/AgCl cathode potential [1,2]. As can be seen in Figure 2, at more negative potentials (-1.06 V), we found that nickel enhances hydrogen production by more than a 3-fold, compared to the control reactor. At the same time, the acetate yield decreases by 50% compared to the control reactor (Figure 2). Thus we can tune the activity of the system to either hydrogen or acetate production by adding a nickel catalyst and changing the applied cathode potential.

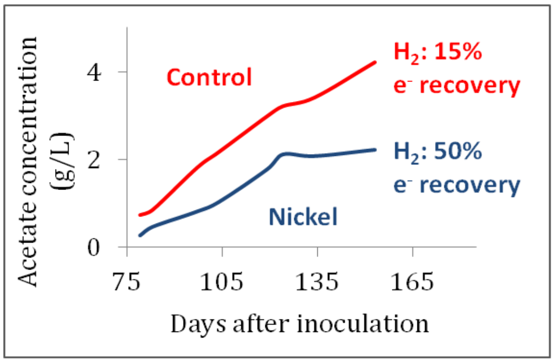


Figure 2: Acetate production during MES without (control) and with added Nickel at -1.06 V Vs. Ag/AgCl.

Acetate production: $2CO_2 + 8H^+ + 8e^- \rightarrow CH_3COOH + 2H_2O$

Hydrogen production: $2H^+ + 2e^- \rightarrow H_2$

Type of student projects envisioned

The individual and combined catalytic processes can be investigated using both modeling and laboratory methodology. Different catalysts and support materials can be compared, using chemical, electro-chemical, spectroscopic, and surface characterization techniques, in the presence and absence of bacteria.

[1] Nie, H., Zhang, T., Cui, M., Lu, H., Lovley, D.R. and Russell T.P., Phys. Chem. Chem. Phys. 15 (2013) 14290.

[2] Zhang, T., Nie, H., Bain, T.S., Lu, H., Cui, M., Snoeyenbos-West, O.L., Franks, A.E., Nevin, K.P., Russell, T.P. and Lovley D.R., Energy Environ. Sci. 6 (2013) 217.

Processing of feathers to proteins – from fundamental insight to application

Name PhD: Xinhua Goerner-Hu
Involved staff members: Strik, J; Scott, E; Haasterecht, T; Bitter ,H
Project sponsor: SARIA A/S GmbH Co. & KG
Start(expected) end date of project: 2015/2019

Background and goal of project

Feathers contain high amounts of protein (>85%) and and thus amino acids (Figure 1). When partly hydrolyzed these feathers become suitable as protein supplement for animal feed.

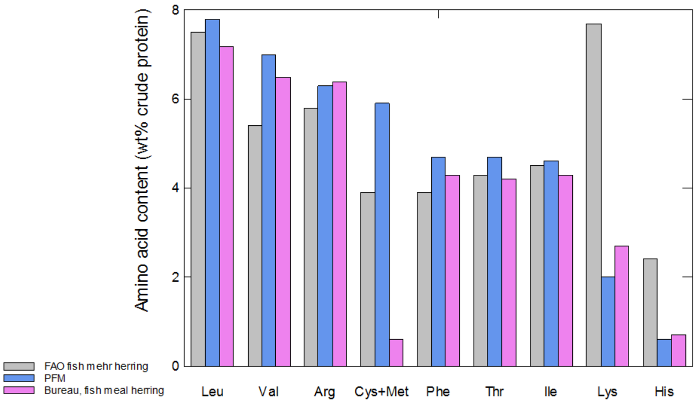


Figure 1: Essential amino acid content, adapted from FAO, fish meal,2001; Bureau, 2013; and from our research, *: without value for Cys.

Goal of my project is to understand the factors that determine the protein yield and quality during feather hydrolysis. This understanding will be used to develop a model which can describe industrial feather protein hydrolysis processes.

Highlight of the past year

Two most important reactions were involved in feather processing, e.g. hydrolysis and oxidation and reshuffling of sulphur bonds. Process conditions like temperature and time influence both reactions but the effects are reverse (Figure 2 and Figure 3). So it is essential to balance process conditions in order to get optimal digestibility and Cys content.

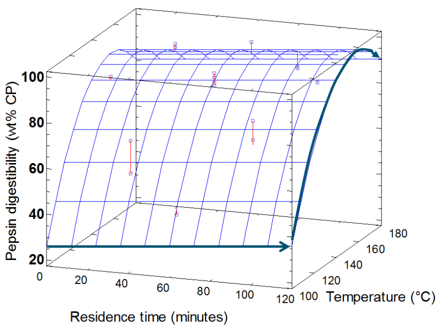


Figure 2: Pepsin digestibility affected by temperature and time

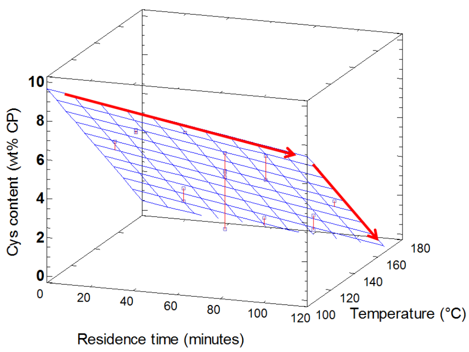


Figure 3: Cys content affected by temperature and time

Type of student projects envisioned

MSc student: lab work, e.g. experiment performance and analysis

Selective polysaccharide oxidation – new catalysts and new chains

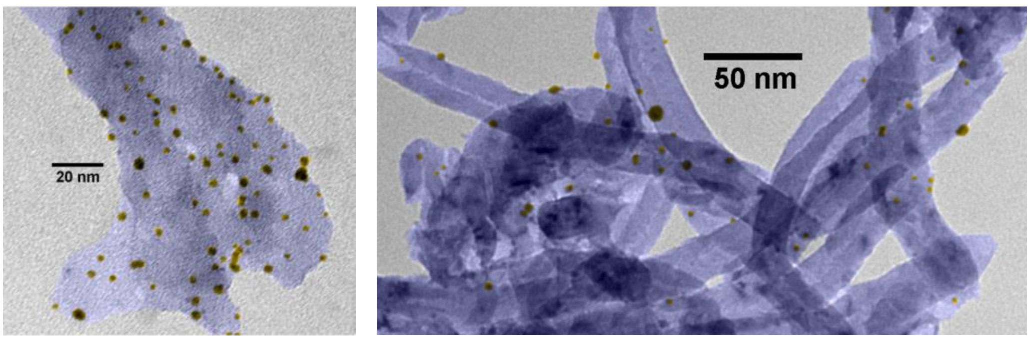
Name PhD: Evie van der Wijst
Involved staff members: Prof. Harry Bitter, Dr. Piet Buwalda
Project sponsor: NWO, Avebe
Start/(expected) end date of project: 01.01.2016 – 31-12-2019

Background and goal of project

Polyacrylates and polyacrylamides are currently produced petrochemically but anionic (negatively-charged) polysaccharides, such as oxidised starch, could be a more sustainable alternative. Applications of oxidised starch include the use as adhesive, as superabsorbents in nappies or as coating agent in the paper- and textile industry. Currently, chemical oxidation involving bleach is often applied. However, this process is not environmentally friendly due to the consumption of large amounts of chlorinated chemicals and the resulting salt formation. In response to this, homogeneous (soluble) catalysts have been developed as alternative, potentially reducing the consumption of chemicals due to their reusability. Unfortunately, these processes are hampered by the issue of separation of the product from the catalyst. An heterogeneous (insoluble) catalyst, in turn, has not yet been developed mainly because of the challenging intrinsic properties of starch. In this project, I collaborate closely with Tim Hoogstad. In general, where he studies the implications of the heterogeneously-catalysed process via a modelling approach, I focus on the development of a suitable heterogeneous catalyst. The starting point for this is to study catalysts found to be active in the oxidation of monosaccharides, mostly involving gold (Au), platinum (Pt) or palladium (Pd) nanoparticles on a support material like carbon (C).

Highlight of the past year

Due to its high average molecular weight, starch oxidation by a heterogeneous catalyst is likely to be hampered by mass transport limitation and catalyst poisoning. The latter can occur when the substrate interacts too strongly with the catalyst surface and is expected to worsen with increasing number of functional groups of the substrate. The first step is thus to study to what extent catalyst poisoning takes place with increasing molecular weight of the substrate. Catalysts like Au/activated carbon (Au/AC) and Au/carbon nanofibres (Au/CNF) have been synthesised (see below). Furthermore, initial experiments have been done with D-glucose and starch building-block methyl α-D-glucopyranoside (MGP).



TEM pictures of 1 wt% Au/AC (left) and 1 wt% Au/CNF (right)

Type of student projects envisioned

Research projects involve mostly lab work during which many different techniques are applied: catalyst synthesis and characterisation (e.g. XRD, TEM, ICP-OES), the oxidations themselves, product analysis (HPLC, HPAEC, colorimetric assays,...).

Technology

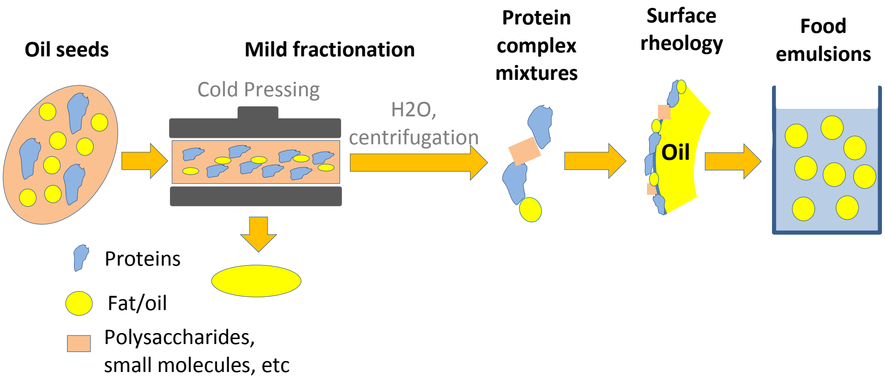
Theme leaders: A.J.B. van Boxtel, K.N. Nikiforidis

Background and goal of this theme

Creating a biobased economy needs sustainable solutions for biomass conversion and separation. For sustainable processing systems it is essential to gain fundamental knowledge on intercellular molecular interactions and behaviour in products. This knowledge is used to design, optimize and control processing systems. We combine fundamental research and Process Systems Engineering, experimental work meets modelling work to elucidate complex interactions in biomass conversion and to drive them in the aimed direction.

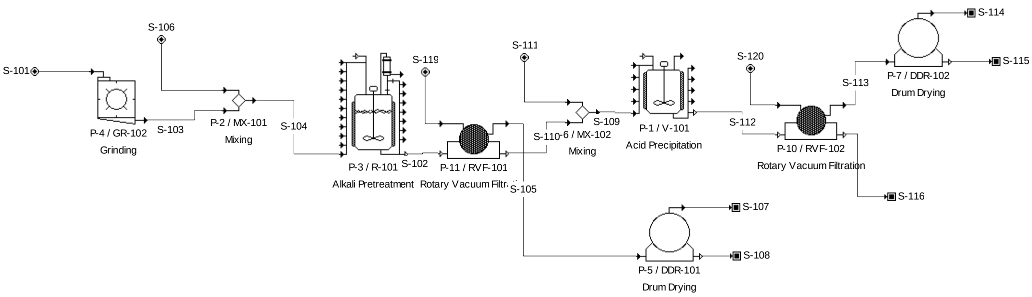
Main topics

- Mechanisms and models for pre-processing of biomass
- Reactor and production chain design for catalytic conversion of polysaccharides
- Recovery of functional protein, carbohydrate and lipid mixtures using new techniques



- Integrated sustainable biorefineries for seeds, algae, lignocellulosic biomass, milk-to-powder, duckweed.
- Life Cycle Analysis (LCA) combined with process design
- Sustainable processing in the region
- Control of individual and integrated processing steps in biorefineries
- Energy efficient processing, for example drying of biomass, vegetables

Thesis subjects are related to the research work of PhD-students and post-docs in the Technology theme and to the other two BCT main themes. Moreover, we have a strong cooperation with WUR-FPE, AlgaePARC, DLO-FBR and TNO.

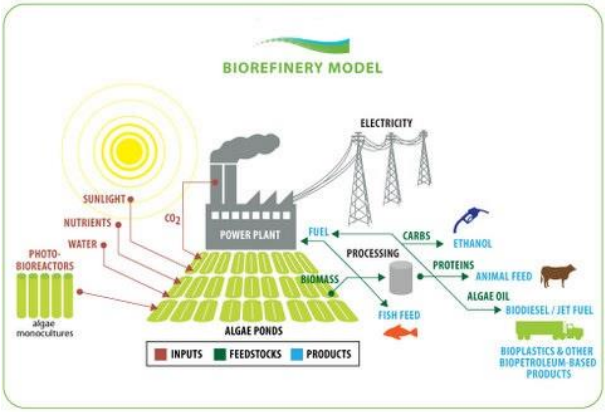


System Analysis of Algal Biorefinery

Name PhD/Postdoc: Farnoosh Fasaei
Involved staff members: Ton van Boxtel
Project sponsor: AlgaePARC
Start/(expected) end date of project: Sep2013/Sep 2017

Background and goal of project

The increasing population and increasing demands related to energy and food have resulted in the interesed in a biobased economy for the production of food, feed and materials. Microalgae feedstocks show potential to substitute fossil and animal based products. However commercial production of algal products is in its infancy. To commercialize algal biomass as a commodity, the production cost for algae based products should be decreased.
System analysis of algae borefinery offers the opportunity to find multiple solutions for processing micro algae to different range of products by scenario study of possible downstream processing. The analysis is covering different aspects such as performance and economy of potential processing chain.



Highlight of the past year

During the past year a techno-economic model for harvesting and dewatering of algae biorefinery is developed. System analysis of harvesting and dewatering shows that techno-economic feasible solutions for removing water from cultivated algal biomass exist. Further a library of models for extraction of lipids, proteins and carbohydrates has been developed. These models provide the opportunity for exploring and optimizing the potential extraction systems.

Student projects envisioned

Recovery of residual stream in algae biorefinery: model based approach
LCA analysis of algae biorefinery

Redesign and optimization of the milk powder production chain

Name PhD: Sanne Moejes
Involved staff members: Ton van Boxtel, Guus van Wonderen
Project sponsor: EU FP7 project
Start/(expected) end date of project: 12-2013 till 11-2017

Background and goal of project

Energy and water reduction are still a major topic in policy making. The food industry is responsible for high energy and water consumptions, especially when many thermal processes are involved. Milk powder production is no exception. Evaporation and spray drying consume over 90% of the energy required for the production process. Introduction of new technologies is required in order to make a next step in energy and environmental impact reduction, as current processes are already optimized to a high extend, and considerable reductions are necessary.
The goal of this project is to use a systematic way to redesign and optimize the milk powder production chain. Objective is to minimize the energy consumption, water consumption, environmental, and economic impact.

Highlight of the past year

This project is part of the EU ENTHALPY project, a three year project that finished in October 2016. The past year we integrated economics and LCA impact, in the process design. Normally process design and LCA is a two-step process. First a process (chain) is optimized in an energy and/or economic objective, while satisfying a set of product requirements. The resulting process design with its operational conditions is evaluated by an LCA, resulting in the identification of certain hotspots in the chain. After which some changes might be made to the initial design (Figure 1, conventional). Due to this two-step approach the optimal process design in terms of LCA impact might not be found. One step process design was therefore proposed, combining three objectives, the minimization of: 1) energy consumption, 2) economic impact, and 3) LCA impact.

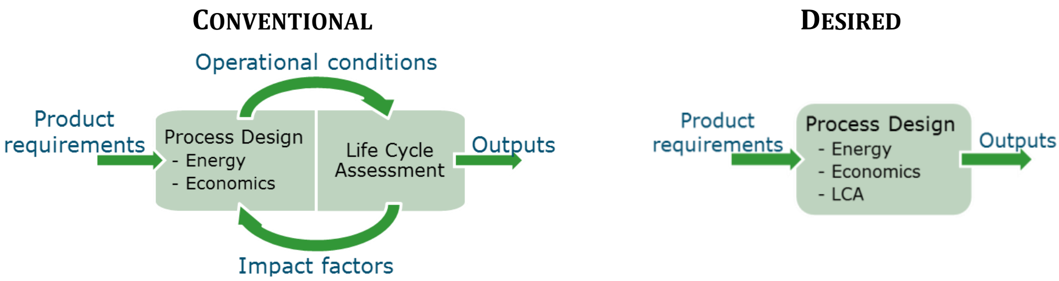


Figure 4. Conventional and desired process design with the incorporation of LCA in the optimization routine.

The developed models of the different processes in milk powder production (both conventional and new) were combined in a Graphical User interface (the ENTHALPY GUI). Users can simulate different production scenarios with different processing settings. These scenarios are evaluated on the three objectives, and can be compared to each other.

Type of student projects envisioned

Projects will involve modelling of several aspects of the (milk powder) production chain; development of in depth mechanism models of the innovative technologies, or more broth chain analysis. Main focus is on the optimization of energy and sustainability, which involves both environmental and economic aspects.

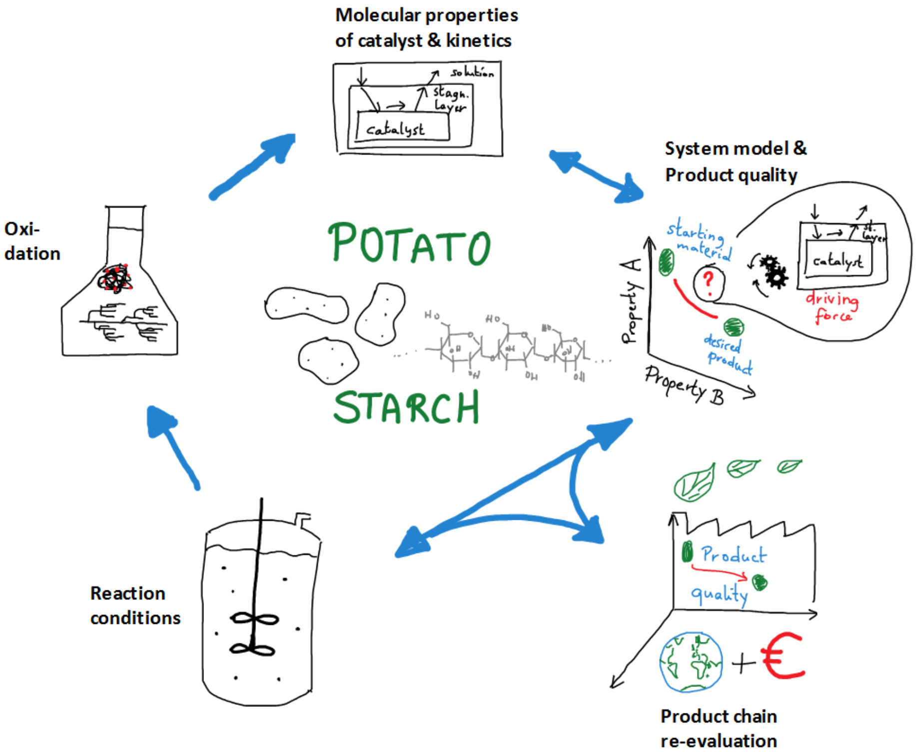
Selective polysaccharide oxidation – new catalysts and new chains

Name PhD: Tim Hoogstad
Involved staff members: Ton van Boxtel, Piet Buwalda, Harry bitter
Project sponsor: NWO, Avebe
Start/(expected) end date of project: 01-2016 till 12-2019

Background and goal of project

Nowadays more and more attention is given to biobased and biodegradable products as alternatives for oil-based materials. Negatively charged polysaccharides can be used as a sustainable replacement for polyacrylates and polyacrylamides from the petrochemical industry. These compounds are used, among other applications, as superabsorbent in diapers, coatings for paper and wastewater treatment. Currently, these anionic starches are made using homogenous catalysis with bleach as an oxidizing agent and resulting in salts as a by-product. In this project, heterogeneous catalysis is investigated as a more sustainable production method.

My work within this project includes modelling of reaction kinetics, finding ideal catalyst properties based on optimizing these models and re-evaluating the current production chain based on this new production step. These tasks will be tackled using backward reasoning from product functionality and product quality. The production chain is re-evaluated with regards to mass/energy balances, Life Cycle Assessment (LCA) and economics in the hopes of finding an ideal balance between efficient technology, environmental impact and economic feasibility.



Highlight of the past year

A conceptual model has been developed to describe the simultaneous degradation and oxidation of starch. The model was made with close integration of chemical knowledge and modelling expertise.

Type of student projects envisioned

Student projects can include modelling, experimental work or a combination thereof. Modelling work will involve evaluating of production chains based on mass/energy balances, sustainability and economics. Lab work will include kinetic experiments with catalysts, product characterization and data fitting to models.

Sustainable biorefinery design

Name Postdoc: Ellen Slegers
Involved staff members: Ton van Boxtel
Project sponsor: EU FP7 MIRACLES, AlgaePARC Biorefinery
Start/(expected) end date of project: 2013 - 2017

Background and goal of project
In my research I develop simulation models to study biobased processes and biorefinery chains. Typical quantitative performance indicators considered are: mass yields, energy balances, cost (techno-economics), and environmental sustainability (LCA). The main research challenges are:
How to include and assess sustainability during process design?
How do biomass properties and processing technology affect the overall sustainability?

Highlight of the past year
In one of the projects the goal was to establish an integrated sustainability assessment during early phases of process design. For this aim a multiobjective optimisation has been applied to a micro-algae biorefinery chain. The biorefinery aims at the recovery of protein and lipids. In the optimisation the LCA and profit margin were simultaneously optimized by changing the operating conditions of the biorefinery chain. This approach generated many different process scenarios, each with a different optimum balance between LCA performance and profit margin (Figure 1A).

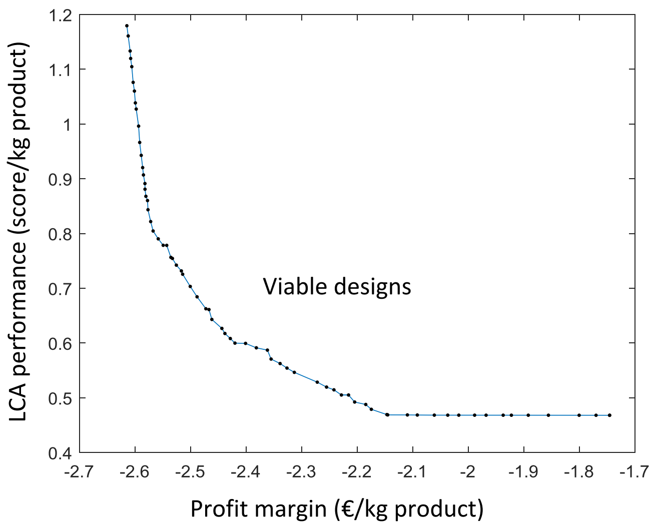


Figure 1A. Pareto plot with the multiobjective optimization results: LCA performance (X-axis) and profit margin (Y-Axis). The profit margin is expressed as negative cost. The ideal point lies in the left bottom corner (non-viable).

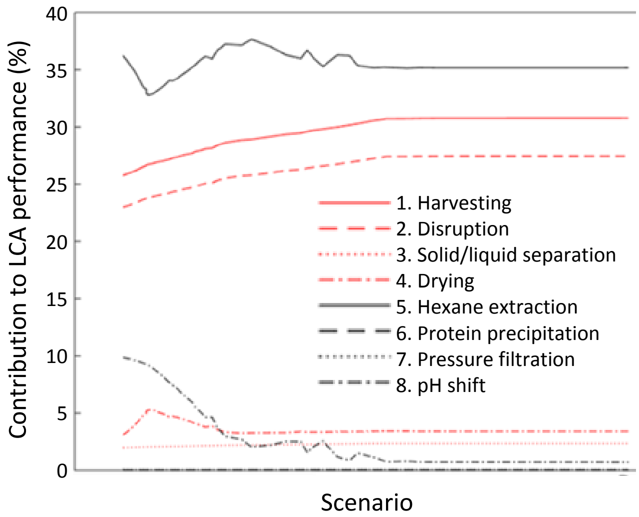


Figure 1B. Sensitivity analysis on the LCA performance for each process scenario. The figure shows the relative contribution to the LCA performance for each of the 8 process steps.

In a second step a sensitivity analysis was used to identify the influence of process steps and their parameters on the sustainability performance. This was done for each process scenario, i.e. every point in Figure 1A. The results are shown in Figure 1B. Three process steps, processes 1, 2 and 5, contributed to the majority of the LCA performance (85%). Therefore, these processes are hot-spots to consider in the process design.

Type of student projects envisioned
- Modelling: biorefinery, sustainability
- Lab work: storage experiments micro-algal paste

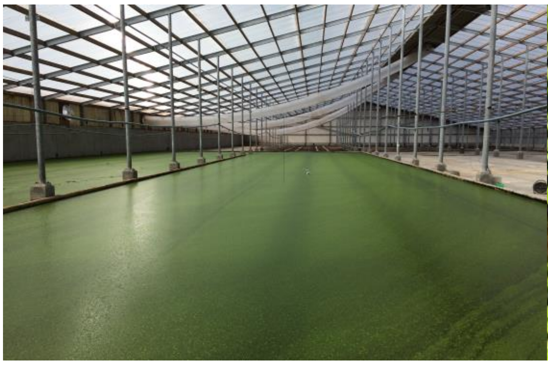
Modelling for Biorefinery and Closed Cycles

Name staff member: dr. R.J.C. (Rachel) van Ooteghem MSc.

Background and goal of project
In our group we see students from many different studies and backgrounds. What they have in common, is that they have learned to think outside the box. They are redefining production systems, redesigning the farm, thinking of new and better ways to produce food. Keeping waste streams to a minimum, or thinking of new processes to reuse waste streams and make new valuable materials from them.
One way to make valuable materials from waste streams is biorefinery: converting biomass to produce biobased products (food, feed, chemicals, and materials) and bioenergy (biofuels, power and/or heat).
Sometimes it is not necessary to convert the biomass. It could be possible to use the waste stream of one part of the production directly as nutrients for a new production process; e.g. using manure from calves to grow duck weed. It becomes even more interesting if we can then feed this duck weed to the calves again, thus closing the cycle.
Ideally we want to close the cycle on all levels: feed, nutrients, power and heat), to make the production process as sustainable as possible.
To compute if the cycle can be closed, and if all mass and energy balances are well balanced year round, we make models of the underlying processes. These models can be derived on all levels: from the energy balance on a whole farm, to the mass balance of one specific nutrient.

In previous years, thesis students have worked on various projects, ranging from local hydrogen production on a farm to be used by a tank station, to producing duckweed on calf manure.

Highlight of the past year
A Dutch company has picked up on the duckweed production research, and will go to the United States to start up a company there to grow duckweed on a large scale.




Type of student projects envisioned
Student project include the modelling based on mass and energy balances, and computing the results in Matlab. If possible, the models are validated with data which is measured on location, or in our own lab.

Tailoring the interactions of oil bodies and co-extracted proteins for development of novel food systems

Name PhD: Juliana Romero Guzmán (employed at FPE)
Involved staff members: Costas Nikiforidis (BCT) and Remko Boom (FPE)
Project sponsor: CONACyT
Start/(expected) end date of project: November 2015 - October 2019

Background and goal of project

In food industry, highly refined, pure, ingredients are being used that are produced through harsh conditions. In addition, the pure ingredients are often mixed again to formulate the final product. The harsh conditions are detrimental for the quality of the side streams and the purification and mixing makes the overall process inefficient. For example, during the plant oil extraction, the protein rich fraction is highly damaged due to the use of organic solvents, high temperatures and high pressure.

Mild aqueous extractions are promising alternatives to fractionate biobased feedstocks. These milder process conditions allow all fractions in all streams to keep their native quality. For example, after aqueous extraction of plant oils, in the form of oil bodies (spherical oil droplets surrounded by a phospholipid/protein layer), the remaining proteins and polysaccharides are more flexible, easy to separate and are highly techno-functional comparing to the cases where organic solvents are being used.

My aim in this project is to understand the way that oil bodies interact with the other co-extracted components during aqueous extraction, in order to:

1. Optimize the extraction process: Use milder processing conditions, and decrease the water and energy usage during the extraction.
2. Find novel applications of the natural oil-in-water emulsion: Use oil bodies in conventional products that required synthetic engineered emulsions and monitor their performance.

Highlight of the past year

It was shown that aqueous extraction at neutral pH resulted in stable oil body. Unfortunately the extraction yield was lower compared to that at alkaline pH. Thus though mild i.e. at neutral pH extraction is possible the yield has to be increased for example by applying a pre-extraction cell disruption technique.

Type of student projects envisioned

The next projects on oil body extraction will focus on investigating the molecular interactions and optimizing the extraction process at neutral pH. If you are interested in sustainable production of hydrocolloids and intermolecular interactions, please contact us.

Contact: Juliana Romero Guzmán, E-mail: juliana.romeroguzman@wur.nl, Phone: +31(0) 317 480 851

Valorizing a by-product, sunflower press-cake, through mild processing

Name PhD: Dimitri Karefyllakis (FPE)
Involved staff members: Costas Nikiforidis (BCT) and
Atze Jan van der Goot (FPE)
Project sponsor: ISPT
Start/(expected) end date of project: 29/01/15-29/01/19

Background and goal of project

Plant based proteins are gaining significant interest since there is a potential to replace less sustainable animal based protein. However, the extraction of the plant protein has to be performed in a sustainable way i.e. with low impact on the environment, without creating waste during extraction and using limited energy in the processing.

Until this point, the primary aim was to extract and obtain pure compounds however it is questionable whether that is really necessary. As a case, we investigate the exploitation of sunflower press cake, which is an oil extraction by-product, to obtain valuable ingredients, such as proteins, polyphenols and phospholipids. We investigate low impact extraction methods which might result in less pure but highly functional products. The more specific aim of this project is to investigate and understand the interaction between individual components in press cakes and in the final products. This research will lead to an efficient of the press-cake and transform it from a by-product to a side product.

Highlight of the past year

Protein-phenol interactions have proven to be beneficial for the stability of emulsion based products. This means that the use of complex mixtures of these ingredients results in satisfactory functionality. Thus, using these ingredients together should be prioritized over their separation, leading to less waste and less use of energy.

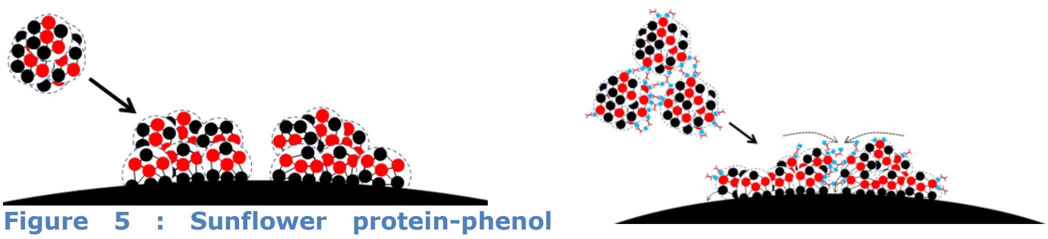


Figure 5 : Sunflower protein-phenol complexes (right) cover more effectively the emulsion interface than proteins alone (left).

Type of student projects envisioned

The projects that will be available for students will include lab work and in general terms will follow the concept of mild processing. Mixtures of ingredients from sunflower press cake will be extracted and studied and the effect of their consistency on ingredient functionality will be investigated by creating emulsions and gels.

Sustainable process design; other subjects

Theme leader: A.J.B. van Boxtel, R.J.C. van Ooteghem
Involved PhD's and post-docs: E.A.Y Amankwah, C. Gomez, student projects.
Project sponsors: WUR-sandwich PhD-fund, KNUST Ghana, Universidad Nacional de Colombia, University of Santiago de Compostela, AlgaePARC.

Background and goal of project

The theme sustainable process design includes a project on solar adsorption drying, control systems for algae cultivation and harvesting, processing systems at farm level, and some other developing projects. In these projects we develop new ideas that enhance sustainability in processing. The project are performed in cooperation with third parties like universities and non-profit organizations.

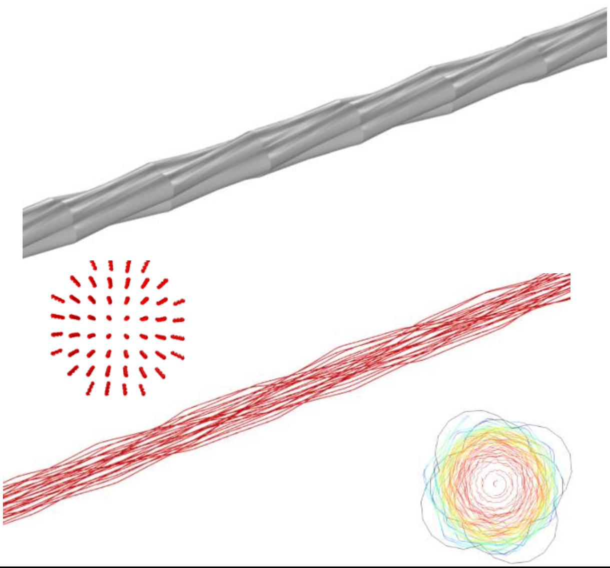
Highlights of the past year

- Analysis of the drying behavior of starch rich yam which is a major element in African and South-American diets.
- Flow pattern simulation in twisted algae tubes to enhance algae growth.
- Optimal control gives the best harvesting moments for algae cultivation
- Animal feed by grass biorefinery competes with imported soy protein.

Type of student projects envisioned

We invite students interested in:

- control methods to improve control of algae cultivation systems.
- processing systems at or nearby farms to give added value in farming are also welcome.
- the effectivity and organisation of local and circular economies (together with the logistic group ORL) .
- the design of effective gas adsorption systems.



Flow patterns in a twisted and formed tube. The use of this tube results in effective mixing, good light-dark cycles at low pressure drop over the tubes

Systems Group

Staff: Dr. Karel Keesman, Prof. Harry Bitter
PhD students and post-docs: Nurul Khairudin, Rungnapha Khiewwijit, Elvira Bozileva, Nik Grubben, Daniel Reyes Lastiri, Yu Jiang, Simon Goddek, Delaram Azari, Hakan Kandemir, Hans Cappon
Contact: karel.keesman@wur.nl

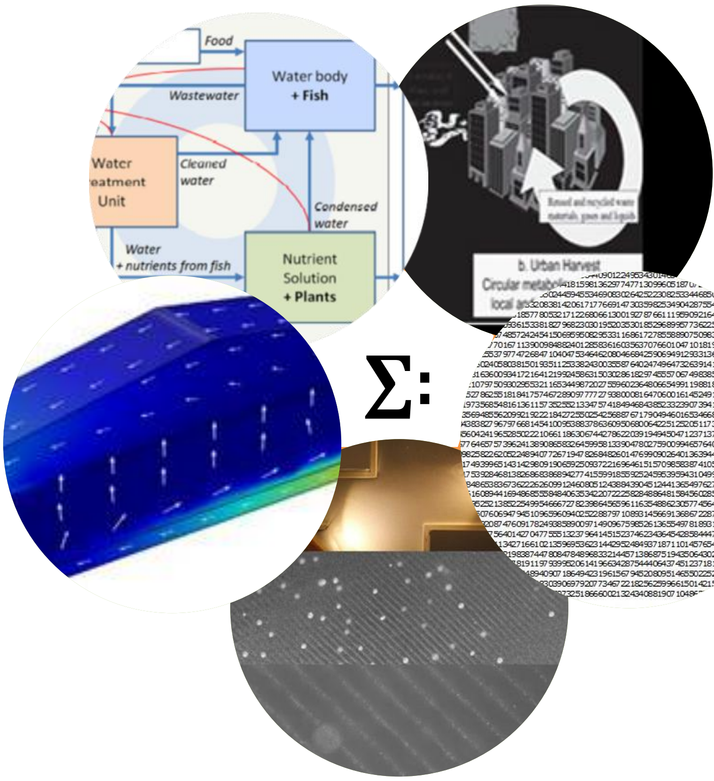
Background and goal

In the past decade, there have been strong developments in communication (internet, e-mail, smart phones, wireless), computation (Moore's exponential law - processors, memory, storage capacity), sensor networks (data warehouses) and cyber science (integration of knowledge). These developments allow the implementation of smart, high-tech, cost-effective solutions to water/energy/material related problems in a bio-based/circular economy.

The objective of the systems group is to support new and innovative technological solutions to complex, dynamic, and possible constrained, systems (∑:) in a bio-based/circular economy, such as water-energy-material cycles in urban systems, S/N/P cycles in natural and industrial environments, food storage and aquaponic systems, through **network modelling** and **data-model integration**.

Main topics

- Efficient use and recovery of water, energy and nutrients in urban, industrial and agricultural environments
- Aquaponics as a novel/renewed fish-plant production system
- Smart food storage strategies for preserving quality of agricultural produce
- Ultrasound standing/travelling waves for fluid-particle or particle-particle separation
- Big data and water/energy/materials networks



Bioenergy policies for achieving liveable and sustainable cities of the future: An integrated game-model-data approach (E-game)

Name PhD: Yu Jiang
Involved staff members: Karel Keesman
Project sponsor: Climate-KIC (EU)
Start/(expected) end date of project:
01-09-2014/01-09-2018

Background and goal of project

Cities are leading the transition to a low-carbon energy system. To become sustainable, climate-resilient and self-sufficient, a higher penetration of intermittent renewable energy, such as wind and solar energy, is expected in the system. This brings challenges to balance the electricity grid and meet the greenhouse gas emission reduction goals at the same time.

The objective of this project is to investigate the potential role of bioenergy in the transition to a sustainable and smart urban energy system. Methodologies including energy system modelling, agent based simulation, inventory modelling and game theory are used to provide scientific insights and offer robust policy strategies to support the decision-making of city policy-makers.

Highlight of the past year

We evaluated the potential of bioenergy from the urban waste stream from a demand-driven perspective, showing that the potential role of bioenergy is highly dependent on the policy interventions.

Figure on the right gives the results of one of the scenarios (RES-Policy scenario), which is driven by the political motivated energy policy. A bioenergy storage capacity of 0.04 PJ is required as a buffer to meet the whole year's demand due to the monthly variation of supply and demand.

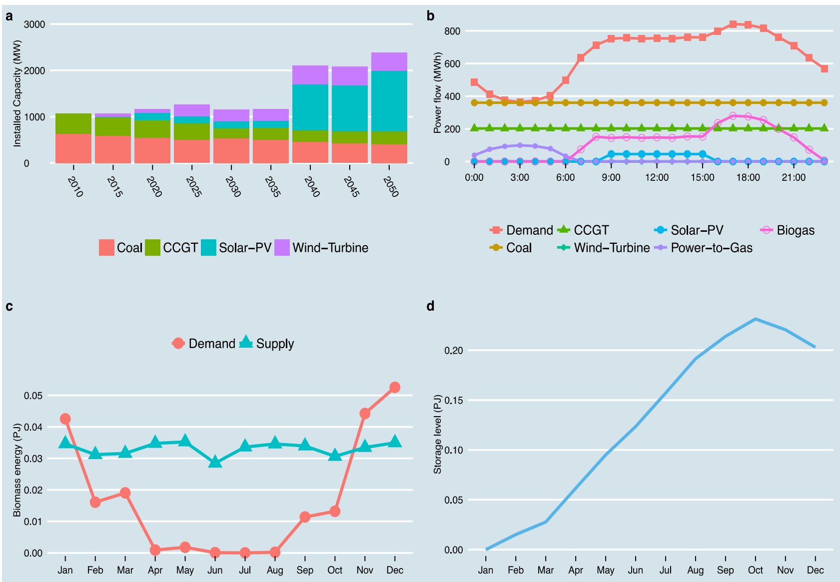


Figure 6 (a) RES-Policy scenario generation portfolio; (b) High demand and low RES supply scenario with the RES-Policy generation configuration in 2050; (c) Bioenergy supply and demand in the RES-Policy scenario; (d) Storage level of bioenergy in the RES-Policy scenario in a year.

Type of student projects envisioned

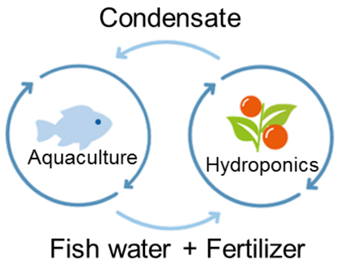
Possible topics for students' thesis: (1) Application of Energy-Returned-on–Energy-Invested indicator for urban energy system evaluation; (2) Sustainability analysis of the urban bioenergy supply chain; (3) Multi-criteria analysis for the selection of bioenergy technologies in urban energy systems.

Modelling aquaponic systems

Name PhD: Daniel Reyes Lastiri
Involved staff members: Hans J. Cappon, Karel J. Keesman
Project sponsor: INAPRO (EU)
Start/(expected) end date of project: 15/06/2014-15/06/2018

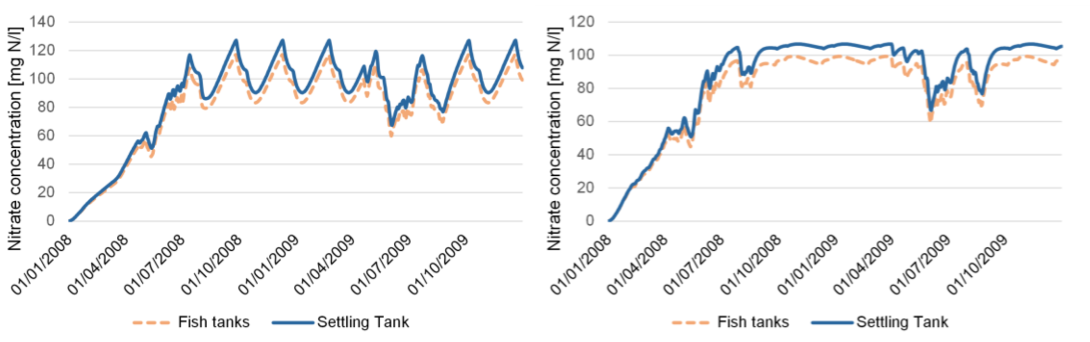
Background and goal of project

Aquaponics is a technique that combines the production of aquatic species (aquaculture) with soilless horticulture (hydroponics), reusing the waste from the aquatic animals to fertilize the plants in a single water cycle. Aquaponics has been successfully implemented for self-consumption in small scale systems. Scaling up the technique to a commercial level can help reducing the demand for water linked to our food production.



Our research is part of the EU project INAPRO, which aims at improving our understanding of aquaponic systems towards commercialization, by means of a modelling and a demonstration approach. Our main target is to aid in the design of a system that minimises water, nutrients and energy consumption using mathematical modelling and simulation.

Highlight of the past year



In aquaculture systems, the concentration of substances changes with the fish growth and harvest, forming a saw-tooth pattern (left). Our initial model proved that it is possible to stabilize the concentration of nutrients in the aquaculture unit, by sending water to the plants in amounts proportional to the fish feed (right).

Type of student projects envisioned

Student projects are focused on mathematical modeling and simulation. The data gathered by project partners can be provided to validate the models.

Real-time accounting and simulation of dynamic energy-water-material balances for achieving liveable and sustainable cities of the future

Name PhD/Postdoc: Elvira Bozileva
Involved staff members: Karel J. Keesman
Project sponsor: Climate KIC
Start/(expected) end date of project: 09-2013/09-2017

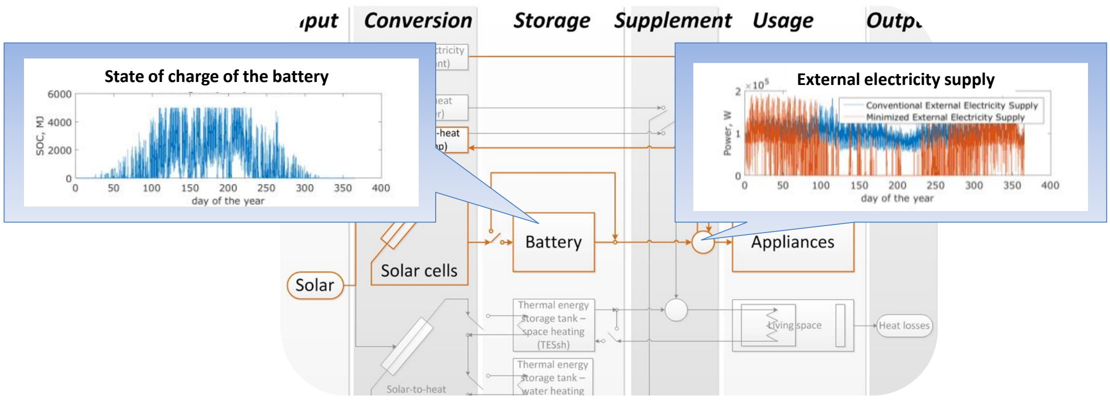
Background and goal of project

How much water is consumed to power your computer with the energy from the grid? What will change if you fully power your house with solar energy available at your location? How much area and storage capacity would you need for that? These and similar questions need to be answered if we want to live in sustainable cities where problems of the energy sector are not solved at the expense of creating problems in water sector or vice versa.

In this project we use a dynamic modelling approach to simulate interconnected energy, water and (in the final phase) nutrient conversions in buildings - the elementary units of cities. Model-based analysis allows us not only to acknowledge, but also to quantify the effects that certain technological options have on energy, water and nutrient cycles. Obtained information would allow us to answer the questions stated above and facilitate decision-making regarding technology selections within a specific context.

Highlight of the past year

A dynamic model was used to study sensitivities of the selected energy and water indicators with respect to technological factors (such as PV efficiency, roof area, water and electrical energy storage capacity, etc) for a single residential building and Wageningen University Campus (only energy cycle was concerned for the latter). Some of the highlights are:
Covering the total energy demand of a single building or a system of buildings solely by the energy generated by the photovoltaic cells will require an unrealistic large area and storage capacity, as long as the residents' habits regarding energy use remain unchanged.
Using the roof area of a building to harvest solar energy in some cases can result is saving more water than using the same area to harvest rainwater for Dutch conditions.



Type of student projects envisioned

Student projects will involve modelling of water, energy and nutrient cycles in an urban environment using Matlab software. Especially students who wish to study different scenarios for wastewater treatment are welcome.

Smart ventilation for safe and sustainable food storage.

Name PhD: N.L.M. Grubben
Involved staff members: Karel Keesman
Project sponsor: Omnivent techniek b.v.
Start/(expected) end date of project: 01/04/2014-01/04/2018

Background and goal of project

Most agricultural products are season-dependent. To overcome seasonality of the harvested products and to guarantee a continuous flow of food products to the consumers and of biomass, in general, to bio-based industries, storage of primary food products and biomass is crucial.
This study focuses on the understanding and design of optimal ventilation strategies for safe and sustainable storage of primary food products. Computational fluid dynamics (CFD) simulation is used to provide physical insight between the product quality and the climate numerically and via visualisation. The CFD model, including product quality processes, is spatially distributed and suitable for model-based quality control.

Highlight of the past year

A complete dynamic 3-D CFD simulation model has been developed, including ventilators and moving hatches.

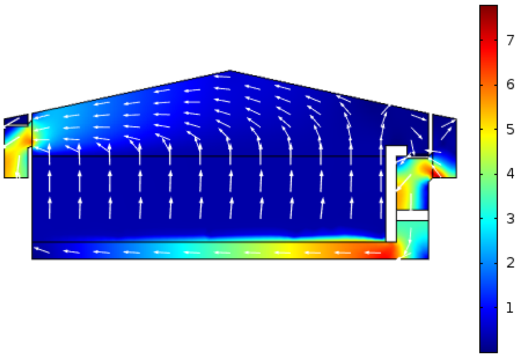


Figure 1. Air velocity profile in a food storage facility obtained by CFD simulation.

To investigate the quality development over time, between different cultivars, and of different growing conditions, experimental setups in several bulk storage facilities were realized. To calibrate and validate the spatially-distributed model of potatoes, data of these full-scale test-storage facilities were processed. One of the quality aspects of potatoes is the sugar content. For the validation of the sugar content in potatoes the sugar content is frequently measured with HPLC analyser. Also, potato proteins are more frequently used in the bio-based industry. Hence, a protein level model was set up to control the protein level in potatoes that are stored in bulk storage facilities, showing promising results.

Type of student projects envisioned

Related to the topic this project, several MSc projects can be defined. Detailed models of product specific processes are often absent, but needed for quality control. Modelling these processes can be conducted and implemented in CFD simulations. Before these models can be defined, investigation on the specific quality aspects that play a role while storing are needed, for instance, protein change, bruising, wound healing, etc.

Development of Decoupled Aquaponic Systems

Name PhD: Simon Goddek
Involved staff members: Karel Keesman
Project sponsor: Aquaponik Manufaktur GmbH and others
Start/(expected) end date of project: 03/17

Background and goal of my project

The objective of the my current sub-project is to figure out to what degree aquaculture derived sludge has the potential to be degraded and being used as a bio-fertilizer in hydroponic growing systems. For that reason, I built five reactor sets (see Fig.1) that are run in Wageningen (2x), Dortmund, Berlin, and Liege. Preliminary observations show that this concept has the potential to push open closed doors in the domain of the aquaculture waste recycling for commercial purposes.

Figure 1. An empty self-constructed anaerobic reactor set comprising an upflow anaerobic sludge blanket (UASB) reactor, and an expanded granular sludge blanket (EGSB) reactor

Highlight of the past year

We were able to show that plants (i.e. lettuce) grow much better (approx. 40%!!) in aquaculture water (complemented with salts to reach hydroponic nutrient concentrations) than in conventional hydroponic nutrient solutions (Table 1).

Table 1. Complemented Aquaponic Systems (CAP) have the potential to grow much more food than the current "non plus ultra" hydroponic production systems (Delaide et al., 2016)

Treatment [1]	(N) [2]	Shoot Fresh Weight (g/Plant) [3]	Root Fresh Weight (g/Plant)	Log_{10} (Shoot:Root)
		Trial 1		
CAP	26	136.28 [a]	4.86 [a]	1.47 [a]
HP	26	98.17 [b]	3.58 [b]	1.47 [a]
AP	25	80.55 [b]	5.80 [a]	1.14 [b]
Significance		*** [4]	*	***

Type of student projects envisioned

Hand-on experiments with anaerobic reactors in the fields of agriculture as well as system modelling with AnyLogic Software.

*Delaide, B.; Goddek, S.; Gott, J.; Soyeurt, H.; Jijakli, M.H. Lettuce (Lactuca sativa L. var. Sucrine) Growth Performance in Complemented Aquaponic Solution Outperforms Hydroponics. Water **2016**, 8, 467.*

Education

Bachelor and Master courses BCT and contribution to other courses

Code	Course title
BCT-20306	Modelling Dynamic Systems
BCT-21306	Control Engineering
BCT-22306	Sensor Technology
BCT-22803	Physical Transport Phenomena
BCT-23306	Biorefinery
BCT-30806	Physical Modelling
BCT-31306	Systems and Control Theory
BCT-31806	Parameter Estimation and Model Structure Identification
BCT-32306	Advanced Biorefinery
BCT-50306	Renewable Resources and the (Bio)Chemical Production of Industrial Chemicals
BCT-50806	Sustainability Analysis
BCT-51306	Biobased Economy

Code	Course title
BPE-10305	Process Engineering Basics
BPE-12806	Bioprocess Engineering Basics BT
BPE-60312	Bioprocess Design
FTE-12803	Introduction Biosystems Engineering part 2
FTE-13807	Engineering 2 (Electronics)
FTE-26812	Field Robot Design
FTE-32806	Automation for Bioproduction
FTE-34806	Modelling of Biobased Production Systems
ORC-13803	Bio-organic Chemistry for Life Sciences
XWT-21305	Process Dynamics (Wetsus)
YEI-60312	Research Master Cluster: Proposal Writing
YML-30303	Frontiers in Molecular Life Sciences

BCT: Biobased Chemistry and Technology
FTE: Farm Technology
BPE: Bioprocess Engineering
MAT: Mathematics
ORC: Organic Chemistry
XWT: Wetsus Academy
YEI: Educational Institute
YML: Molecular Life Sciences

PhD course

System Identification in the Life Sciences

Recent developments in biology and, more general, the Life Sciences, have led to increasingly complex models of biological systems that exhibit non-linear and complex behaviour. The modelling of these kind of systems requires advanced tools that allow model development and model selection. Calibration and validation of these models is most of the time not easy. A technique like parameter estimation is an essential tool to deal with these kind of systems. In this course an introduction to this topical field of research was given. The course included:

- Model development in Systems Biology via case studies (a.o., gene transcription modelling, network reconstruction, chemotaxis modelling, nerve conduction modelling)
- Linear and non-linear system identification techniques
- Parameter estimation techniques (including, sensitivity/uncertainty analysis, identifiability of non-linear systems)
- Experimental design

The program was offered as the DISC Winter Course 2016-2017. Lecturers were Prof. Johan Schoukens (Free University of Brussels, Belgium) and Prof. Jaap Molenaar (Biometris, Wageningen University and Research). 24 PhD students followed the course, which took place on Wednesday December 7 and Thursday December 8, 2016, at Wageningen University & Research, and was organised by Hans Stigter and Karel Keesman.

BSc Theses

- Maas, Lucas van der; The effect of dilute-acid pretreatment on cellulose crystallinity and digestibility
- Noord, Aster van; Co-production of hydrogen peroxide and nitriles by coupled enzymatic reactions
- Zeijst, Pieter van; Hydrothermal conversion of cellulose using Raney Ni catalyst under alkaline conditions
- Beugelink, Erik; Enzymatic fingerprinting of IMMPs
- Stigter, Rik; Harvesting strategies for microalgae cultivation
- Rooijakkers, Pieter; Photosynthesis model to predict duckweed growth at the Ecoferm greenhouse
- Sommeren, Marc van; Modelling and simulation of rot in potato storage facilities
- Otten, Tom; Physical Properties of IsoMalto/ MaltoPolysaccharides
- Mee, Victor du; Ethanol production from wheat straw: the influence of dilute-acid pretreatment conditions on the ethanol yield and the global warming potential

MSc Theses

- Vermeer, Niels; Towards integration of life cycle assessment in preliminary process design–An algae biorefinery case study
- Wonderen, Guus van; Membrane network configuration in milk powder production
- Antona, Alessandro; Remote fish species and size identification using broadband echosounders

- Geelen, Caspar; Dynamic model of an INAPRO demonstration Aquaponic system
- Yang, Zijang 1st MSc thesis; Optimization and simulation of hybrid renewable energy system for urban building clusters
- Alizadeh Shalchi, Linda; Valorisation of algae biorefinery through main streams and residual streams
- Verbraak, Paul; Identification of bottlenecks in the coffee chain using Life Cycle Assessment
- Yang, Zijang 2nd MSc thesis; Dynamic model for nutrient uptake by tomato plant in hydroponics
- Heeringen, Luc van; Dynamic Modelling and Control of Potato Proteins in Bulk Storage Facilities

PhD Theses

- Khiewwijit, Rungnapha; New wastewater treatment concepts towards energy saving and resource recovery
- Widyarani; Biorefinery of Proteins from Rubber Plantation Residues
- Zhang, Chen; Biorefinery of leafy biomass using green tea residue as a model material
- Spekreijse, Jurjen; Biobased Chemicals from Polyhydroxybutyrate

Scientific Publications 2016

Refereed article in a journal

- Shear-induced fibrous structure formation from a pectin/SPI blend
Dekkers, Birgit L. ; Nikiforidis, Costas ; Goot, Atze Jan van der (2016)
Innovative Food Science and Emerging Technologies 36 . - p. 193 - 200.
- Lettuce (Lactuca sativa L. var. Sucrine) growth performance in complemented aquaponic solution outperforms hydroponics
Delaide, Boris ; Goddek, Simon ; Gott, James ; Soyeurt, Hélène ; Jijakli, M.H. (2016)
Water 8 (10).
- Navigating towards Decoupled Aquaponic Systems: A System Dynamics Design Approach
Goddek, Simon ; Espinal, Carlos ; Delaide, Boris ; Jijakli, Mohamed ; Schmautz, Zala ; Wuertz, Sven ; Keesman, Karel (2016)
Water 8 (7).
- The Effect of Anaerobic and Aerobic Fish Sludge Supernatant on Hydroponic Lettuce
Goddek, Simon ; Schmautz, Zala ; Scott, Ben ; Delaide, Boris ; Keesman, Karel ; Wuertz, Sven ; Junge, Ranka (2016)
Agronomy 6 (2).
- Effect of initial nickel particle size on stability of nickel catalysts for aqueous phase reforming
Haasterecht, Tomas Van; Swart, Marten ; Jong, Krijn P. De; Bitter, J.H. (2016)
Journal of Energy Chemistry 25 (2). - p. 289 - 296.
- Joint pollution control in the Lake Tai Basin and the stabilities of the cost allocation schemes
Jiang, Yu ; Hellegers, Petra (2016)
Journal of Environmental Management 184 . - p. 504 - 516.
- Efficient and economical way of operating a recirculation aquaculture system in an aquaponics farm
Karimanzira, Divas ; Keesman, Karel ; Kloas, Werner ; Baganz, Daniela ; Rauschenbach, Thomas (2016)
Aquaculture Economics & Management . - p. 1 - 18.
- Dynamic modeling of the INAPRO aquaponic system
Karimanzira, Divas ; Keesman, Karel J. ; Kloas, Werner ; Baganz, Daniela ; Rauschenbach, Thomas (2016)
Aquacultural Engineering 75 . - p. 29 - 45.
- Quantitative modeling and analytic assessment of the transcription dynamics of the XlnR regulon in Aspergillus niger
Omony, Jimmy ; Mach-Aigner, A.R. ; Straten, Gerrit van; Boxtel, A.J.B. van (2016)
BMC Systems Biology 10 . - 10 p.
- Model of an aquaponic system for minimised water, energy and nitrogen requirements
Reyes Lastiri, D. ; Slinkert, T. ; Cappon, H.J. ; Baganz, D. ; Staaks, G. ; Keesman, K.J. (2016)
Water Science and Technology 74 (1). - p. 30 - 37.
- Inhibition of a biological sulfide oxidation under haloalkaline conditions by thiols and diorgano polysulfanes
Roman, Pawel ; Lipińska, Joanna ; Bijmans, Martijn F.M. ; Sorokin, Dimitry Y. ; Keesman, Karel J. ; Janssen, Albert J.H. (2016)
Water Research 101 . - p. 448 - 456.
- Optimal Day-to-Night Greenhouse Heat Storage : Square-Wave Weather
Seginer, Ido ; Straten, Gerrit van; Beveren, Peter van (2016)
IFAC-PapersOnLine 49 (16). - p. 375 - 380.
- The Future of Ethenolysis in Biobased Chemistry

Spekreijse, Jurjen ; Sanders, Johan P.M. ; Bitter, Johannes H. ; Scott, Elinor L. (2016)
ChemSusChem .

- Mechanochemical Immobilisation of Metathesis Catalysts in a Metal–Organic Framework
  Spekreijse, Jurjen ; Öhrström, Lars ; Sanders, Johan P.M. ; Bitter, Harry ; Scott, Elinor L. (2016)
  Chemistry-A European Journal 22 (43). - p. 15437 - 15443.
- Conversion of polyhydroxyalkanoates to methyl crotonate using whole cells
  Spekreijse, J. ; Holgueras Ortega, J. ; Sanders, J.P.M. ; Bitter, J.H. ; Scott, E.L. (2016)
  Bioresource Technology 211 . - p. 267 - 272.
- Field tests of dielectric sensors in a facility for studying salt tolerance of crops
  Straten, Gerrit Van; Vos, Arjen De; Vlaming, Rik ; Oosterbaan, Roland (2016)
  International Agricultural Engineering Journal 25 (2). - p. 102 - 113.
- Simultaneous and selective decarboxylation of l-serine and deamination of l-phenylalanine in an amino acid mixture—a means of separating amino acids for synthesizing biobased chemicals
  Teng, Y. ; Scott, E.L. ; Witte-van Dijk, S.C.M. ; Sanders, J.P.M. (2016)
  New Biotechnology 33 (1). - p. 171 - 178.
- Maize feedstocks with improved digestibility reduce the costs and environmental impacts of biomass pretreatment and saccharification
  Torres Salvador, A.F. ; Slegers, Ellen ; Noordam-Boot, C.M.M. ; Dolstra, O. ; Vlaswinkel, L. ; Boxtel, A.J.B. van; Visser, R.G.F. ; Trindade, L.M. (2016)
  Biotechnology for Biofuels 9 . - 15 p.
- Production of hydrophobic amino acids from biobased resources : wheat gluten and rubber seed proteins
  Widyarani, W. ; Sari, Yessie W. ; Ratnaningsih, Enny ; Sanders, Johan P.M. ; Bruins, Marieke E. (2016)
  Applied Microbiology and Biotechnology 100 (18). - p. 7909 - 7920.
- Fractional Precipitation of Amino Acids from Agro-industrial Residues Using Ethanol
  Widyarani, Rani ; Bowden, Nathan A. ; Kolfschoten, Ruben C. ; Sanders, Johan P.M. ; Bruins, Marieke E. (2016)
  Industrial & Engineering Chemistry Research 55 (27). - p. 7462 - 7472.
- U-D factorisation of the strengthened discrete-time optimal projection equations
  Willigenburg, L.G. van; Koning, W.L. de (2016)
  International Journal of Systems Science 47 (5). - p. 1032 - 1041.
- Improving yield and composition of protein concentrates from green tea residue in an agri-food supply chain: Effect of pre-treatment
  Zhang, Chen ; Krimpen, Marinus M. Van; Sanders, Johan P.M. ; Bruins, Marieke E. (2016)
  Food and Bioproducts Processing 100 (Part A). - p. 92 - 101.
- Integration of galacturonic acid extraction with alkaline protein extraction from green tea leaf residue
  Zhang, Chen ; Bozileva, Elvira ; Klis, Frits van der; Dong, Yiyuan ; Sanders, Johan P.M. ; Bruins, Marieke E. (2016)
  Industrial Crops and Products 89 . - p. 95 - 102.
- A new formula to calculate activity of superoxide dismutase in indirect assays
  Zhang, Chen ; Bruins, Marieke E. ; Yang, Zhi Qiang ; Liu, Shu Tao ; Rao, Ping Fan (2016)
  Analytical Biochemistry 503 . - p. 65 - 67.

PhD Theses

- Biobased chemicals from polyhydroxybutyrate
  Spekreijse, Jurjen (2016)
  University. Promotor(en): Johan Sanders, co-promotor(en): Elinor Scott; Harry Bitter. - Wageningen : Wageningen University, - 148 p.
- Biorefinery of proteins from rubber plantation residues
  Widyarani, R. (2016)
  University. Promotor(en): Johan Sanders, co-promotor(en): Marieke Bruins. - Wageningen : Wageningen University, - 236 p.
- Biorefinery of leafy biomass using green tea residue as a model material
  Zhang, C. (2016)
  University. Promotor(en): Johan Sanders, co-promotor(en): Marieke Bruins. - Wageningen : Wageningen University, - 156 p.
- New wastewater treatment concepts towards energy saving and resource recovery
  Khiewwijit, R. (2016)
  University. Promotor(en): Huub Rijnaarts, co-promotor(en): Karel Keesman; Hardy Temmink. - Wageningen : Wageningen University, - 148 p.

Refereed conference paper

- Numerical design and experimental evaluation of an acoustic separator for water treatment
  Cappon, H.J. ; Keesman, K.J. (2016)
  In: Acoustofluidics 2016, Thursday 22 - Friday 23 September 2016, Technical University of Denmark. - DTU, Acoustofluidics 2016 Conference, Lyngby, 2016-09-22/2016-09-23 - p. 63 - 64.
- Energy efficient powder production by closed-loop spray drying
  Moejes, S.N. ; Visser, Quirien ; Boxtel, A.J.B. van (2016)
  In: Proceedings IDS2016, 20th International Drying Symposium, August 7-10 2016, Gifu, Japan. -
- Recursive identification of time-variant model parameters from drying curves
  Ooteghem, R.J.C. van; Amankwah, E.Y.A. ; Boxtel, A.J.B. van (2016)
  In: Proceedings IDS2016, 20th International Drying Symposium, August 7-10 2016, Gifu, Japan. - - 6 p.
- Techno-economical evaluation of protein extraction for microalgae biorefinery
  Sari, Y.W. ; Sanders, J.P.M. ; Bruins, M. (2016)
  In: IOP Conference Series: Earth and Environmental Science. - Institute of Physics Publishing, (IOP Conference Series: Earth and Environmental Science) International Seminar on Science of Complex Natural Systems 2015, ISS-CNS 2015, Bogor, 2015-10-09/2015-10-10

Other output

Awards

- Rudy Rabbinge Award for the best poster at The annual meeting of the Carbohydrate Competence Center, Zaal, Piet van der, Groningen, Netherlands, 21 Apr 2016
  Isomalto/Malto-polysaccharide: a novel polysaccharide from starch

Outreach

- The biobased raw materials industry is growing up
  Bitter, Harry (interviewee) (2016) Online platform Rabobank Highlights, 5 July 2016
- http://www.processinnovation.nl/melkpoeder-doorgerekend
- Engels onderwijs op z'n Twents, Harry Bitter (Rob Ramaker), Resource 27 oktober 2016, 27 Oct 2016
  http://resource.wur.nl/nl/show/Engels-onderwijs-op-zn-Twents.htm
- New ways of learning for an emerging industry, Harry Bitter, Bio-based world quarterly #3 autumn 2016, 19 Sep 2016
  https://www.biobasedworldnews.com/read-your-copy-bio-based-world-quarterly-issue-3
- Sectie uitgelicht: Dutch Catalysis Society - Bestuurslid Harry Bitter aan het woord, Harry Bitter, Chemisch2Weekblad, 4 Mar 2016
- Duurzaam verdwijnen in een kist van bioplastic, Harry Bitter (Robin van Wechem), Trouw, 15 Jan 2016
- 'We weten precies hoe we het productieproces kunnen sturen', Harry Bitter
  Highlights van het Centre for Biobased Economy p. 19, 1 Oct 2016
  http://edepot.wur.nl/395259
- Nieuwe masteropleiding leidt studenten op voor biobased economy, Harry Bitter, Gerlinde van Vilsteren
  Highlights van het Centre for Biobased Economy p. 7, 1 Oct 2016
  http://edepot.wur.nl/395266
- Potential synergy between biocatalysis, fermentation and chemocatalysis, Bitter, J., Weusthuis, R., Boeriu, C., 2016, Wageningen UR- Food & Biobased Research
- Melkpoeder doorgerekend, Sanne Moejes (David Redeker), Process innovation, Netherlands Process Technology Networks, 21 Nov 2016

Oral presentations

- Novel catalytic route from agro-residues to furan-2,5-dicarboxylic acid; Frits van der Klis , NCCC XVII The Netherlands' Catalysis and Chemistry Conference, Noordwijkerhout, The Netherlands, 8 Mar 2016
- Homogeneous, heterogeneous and bio catalytic deoxygenation of biobased feedstocks, Harry Bitter, Green and Sustainable Chemistry Conference, Berlin, Germany, 5 Apr 2016
- Sesame proteins for microbubble foams, Costas Nikiforidis, Food Colloids 2016,Wageningen, The Netherlands, 11 Apr 2016
- Isomalto/Malto-polysaccharide: a novel polysaccharide from starch, Piet van der Zaal, Carbohydrate Competence Centre, Groningen, The Netherlands, 21 Apr 2016
- Three-loop aquaponic systems: Chances and challenges, Simon Goddek, Aquaponics Research Matters 2016, Ljubljana, Slovenia, 22 Apr 2016
- Non noble metals in heterogeneous catalysis, Harry Bitter, MSV Alchimica , Wageningen, The Netherlands, 1 Jun 2016
- Novel catalytic route from agro-residues to furan-2,5-dicarboxylic acid, Frits van der Klis, 24 th European Biomass Conference and Exhibition Amsterdam , Amsterdam, The Netherlands, 7 Jun 2016
- Carbon Supported Tungsten and Molybdenum Carbides for Biomass Deoxygenation , Harry Bitter, 7th International Symposium on Carbon for Catalysis, Strasbourg, France, 16 Jun 2016

- Modelling and climate control in potato storage facilities, Nik Grubben, EAPR Postharvest Section Meeting, Wageningen, The Netherlands, 29 Jun 2016
- Particle size effects in Mo-carbide and W-carbide catalysts for deoxygenation, Harry Bitter, 16th International Congress on Catalysis , Beijing, China, 5 Jul 2016
- Recursive identification of time-variant model parameters from drying curves , Ton van Boxtel, 20th International Drying Symposium, Gifu, Japan, 7 Aug 2016
- Energy efficient powder production by closed-loop spray drying, Sanne Moejes, 20th International Drying Symposium, Gifu, Japan, 10 Aug 2016
- Potential for tungsten carbide and molybdenum carbide in deoxygenation , Harry Bitter, DSM Research, Geleen, The Netherlands, 17 Aug 2016
- Towards a biobased economy, Harry Bitter, Saxion University of applied sciences: Opening of semester, Deventer, The Netherlands, 20 Aug 2016
- Numerical design and experimental evaluation of an acoustic separator for water treatment, Hans Cappon, Acoustofluidics 2016 Conference, Lyngby, Denmark, 23 Sep 2016
- Redesign of the milk powder production chain with emerging technologies, Sanne Moejes, ENTHALPY final Conference, Monells, Spain, 26 Oct 2016
- Integrated approaches in dealing with dilute heterogeneous biomass sources for the production of chemicals , Elinor Scott, Frontiers in Biorefining 2016 , St Simons Island, United States, 9 Nov 2016
- Isomalto/malto-polysaccharides from starch, Piet van der Zaal, Starch Round Table EU 2016, Villeneuve d'Ascq, France,18 Nov 2016
- Redesign of the milk powder production chain with emerging technologies , Sanne Moejes, Nederlandse Werkgroep Drogen (NWGD) symposium , Wageningen, The Netherlands, 21 Nov 2016
- Structure-property relations of biobased polyesters from 1,4-butanediol-analogues and biobased diacids, Frits van der Klis, Chemistry As INnovating Science (CHAINS), Veldhoven, The Netherlands, 6 Dec 2016

Poster presentation

- Evaluation of selected microalgae value chains – the MIRACLES project
  Breitmayer, E. ; Slegers, P.M. ; Liptow, C. ; Willems, P. ; Schatteman, K. ; Boxtel, A.J.B. van, European roadmap for an algae-based industry, Olhao, Portugal, 8 Apr 2016
- SPECIFIC: Starch – Poly Ethylene Compounds in Films with Improved barrier Characteristics
  Kappen, F.H.J. ; Alvarado Chacon, F.M. ; Schennink, G.G.J. ; Beukelaer, H.J. de; Martens, H. ; Soliman, Maria ; Buwalda, P.L, BPM Symposium 2016, Wageningen, Netherlands, 16 Jun 2016
- Process chain development of five algae-to-product value chains
  Slegers, P.M. ; Olivieri, G. ; Boxtel, A.J.B. van; Sijtsma, L., AlgaeEurope 2016, Madrid, Spain, 12-15 Dec 2016
- Assessing micro-algae productivities with scenario studies
  Slegers, P.M. ; Straten, G. van; Wijffels, R.H. ; Boxtel, A.J.B. van, Internal WUR Algae & Seaweed Symposium, Wageningen, Netherlands, 18 Feb 2016
- Logistic aspects of algae cultivation?
  Slegers, P.M. ; Leduc, S. ; Wijffels, R.H. ; Straten, G. van; Boxtel, A.J.B. van, Internal WUR Algae & Seaweed Symposium, Wageningen, Netherlands, 18 Feb 2016
- Integrating conceptual process design and LCA for micro-algae production systems
  Slegers, Ellen ; Bitter, J.H. ; Boxtel, A.J.B. van, Internal WUR Algae & Seaweed Symposium, Wageningen, Netherlands, 18 Feb 2016
- Evaluating the technical, economic and environmental performance of micro-algae biorefineries
  Slegers, Ellen ; Fasaei, F. ; Bitter, J.H. ; Boxtel, A.J.B. van, Internal WUR Algae & Seaweed Symposium, Wageningen, Netherlands, 18 Feb 2016

- Next level biotech: integrating conceptual process design and LCA, for micro-algae production systems
  Slegers, Ellen ; Bitter, J.H. ; Boxtel, A.J.B. van, Netherlands Biotechnology Conference 16, Wageningen, Netherlands, 14 Apr 2016
- Conceptual process design modelling for early evaluation of value chains
  Slegers, P.M. ; Boxtel, A.J.B. van, European roadmap for an algae-based industry, Olhao, Portugal, 6-8 Apr 2016
- Ni2P as catalyst in oleic acid HDO- Influence of different carbon based supports
  Souza Macêdo, L. ; Bitter, J.H. ; Teixeira da Silva, Victor, NCCC XVII The Netherlands' Catalysis and Chemistry Conference, Noordwijkerhout, Netherlands, 8 Mar 2016
- Isomalto/Malto-polysaccharide: a novel polysaccharide from starch
  Zaal, P.H. van der; Buwalda, P.L. ; Bitter, J.H., Carbohydrate Competence Centre, Groningen, Netherlands, 21 Apr 2016