# Biobased Chemistry and Technology
# Annual report 2021


WAGENINGEN
UNIVERSITY & RESEARCH

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# Introduction

It is my pleasure to present to you the annual report 2021 of the Biobased Chemistry and Technology (BCT) group.

Again this was a challenging year due to the Covid crisis. Nevertheless, by the hard work of the group members and their flexibility we were able to produce nice science, publish good papers and give good education. The year ended cheerfully with the PhD defences of Eleni Ntone and Lakshminarasimhan Sridharan just before the new lock down in December, while in June we already had the PhD defence of Jack Yang (Physical Chemistry of Foods) with Costas Nikiforidis as co-promoter.

This was also the first year we taught the organic chemistry course for biosystems engineering and we are proud of the good evaluations of that course.

In all research lines (catalysis/conversion, physical chemistry/biobased functional materials and multi-scale modelling, new projects started. Moreover, Akbar Asadi Tashvigh was promoted to tenure-track assistant professor, which further strengthens our modelling capacity and extend our capabilities with membrane expertise.

All this made 2021 an interesting and exiting year again and I'm sure you feel the same after reading this report. I sincerely hope 2022 will be a step back to a normal situation regarding do Covid crisis, but I am sure we will make it an exciting year again.

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 and based thereon suggest improvements of process technology in the biobased economy. This not only requires the incorporation of several length and time scales, but also the knowledge and expertise of multiple disciplines. Therefore, we established collaborations with other groups within and outside Wageningen. Some of our collaborations are summarized in the table below.

| Collaborating group in Wageningen | Topic |
|---|---|
| **Environmental Technology (ETE)** | Combining chemo and bio-electro-catalysis<br>Modeling of water-energy-material nexus in industrial and urban environments |
| **Organic chemistry (ORC)** | Teaching and research proposals |
| **Bionanotechnology (BioNT)** | Combining catalysis and NMR in microreactors.<br>Use of natural constructs as carriers for nanoparticles |
| **Physical Chemistry and Soft Matter (PCC)** | Education on natural materials |
| **Plant breeding (PBR)** | Synergy between plant sciences and biorefinery |
| **Food and Biobased research (FBR)** | Different research projects and acquisitions |
| **Bioprocess Engineering (BPE)** | Research collaboration |
| **Microbiology (MIB)** | Research Collaboration |
| **Food Chemistry (FCH)** | Research Collaboration |
| **Food Process Engineering (FPE)** | Research Collaboration |
| **Physics and Physical Chemistry of Foods (FPH)** | Research Collaboration |

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). The group also collaborates intensively with other academic and industrial consortia both within WUR (FBR-Wageningen Research) and outside to address the multi-disciplinary character of the challenges (e.g., within EU projects, TTW, TIFN, ISPT, Center for Biobased Economy (CBBE) and advisory boards such as the advisory board of the VNCI and the bioeconomy federation).
In 2018 Harry Bitter was appointed as adjunct (guest) professor in sustainable catalysis at the department of green chemistry of Monash University in Melbourne Australia. This collaboration will strengthen the biobased activities within Wageningen both at research and education level.

## Catalysis/Conversion

**Team Leaders:** Dr. Elinor Scott/Dr. Tomas van Haasterecht/Prof.dr. Harry Bitter

**PhD students/Post doc:** Roel Bisselink, Roxani Chatzipanagiotou, Marlene Fuhrer, Xinhua Windt, Torin de Groot, Matthijs van der Ham, Tim Hoogstad, Freek Karaçoban, Frits van der Klis, Cynthia Klostermann, Ivo van Luijk, Nazila Masoud, Dmitry Pirgach, Edwin Schreuder, Xiaojie Qin, Sanne de Smit.

**Contact:** elinor.scott@wur.nl or harry.bitter@wur.nl

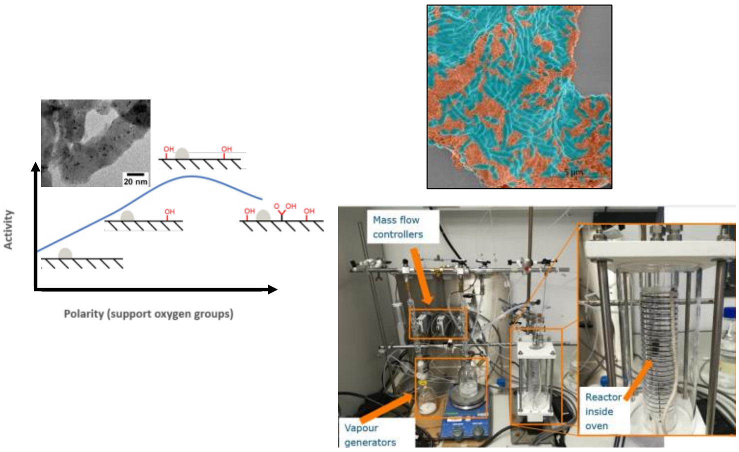
**Background and goal**

The aim in this theme is to develop sustainable conversions routes and processes utilising renewable feedstocks. To achieve this aim a multi-disciplinary approach is used i.e. catalyst development, synthesis and process development that goes hand in hand with computational methods and multi-scale modelling underpins scientific understanding at every level.

Important and emerging chemistry and technology in the area of $CO_2$ capture and conversion, as well as the use of electricity as an input to drive reactions using biobased molecules or to produce chemicals is also a major theme that has grown in the last year.

**Main (sub) topics:**

- Catalyst development for biobased feedstock conversion (heterogeneous, homogenous, bio)
- Conversion of biobased feedstocks and synthesis of biobased chemicals
- Use of non-noble metal catalyst to replace scarce noble metals in synthesis
- Electrochemical/electrocatalytic conversion of larger (biobased) molecules
- Integration of thermal catalysis with electro catalysis/chemistry
- $CO_2$ capture and conversion




Some examples: Influence of surface oxygen groups on the activity of Pt/CNF for electrochemical glucose oxidation (left). SEM visualization of starch (RS3, orange) by rod shaped bacteria (blue) (top right). Rebuild CO2 capture setup (bottom right)

**Highlights from last year**

- 3 new PhD students started (Ivo van Luijk, electrochemical $H_2O_2$ production, ECCM), Torin de Groot ($CO_2$ capture, NWO LIFT), Freek Karaçoban ($CO_2$ capture and conversion, VLAG)
- Freek Karaçoban got his own PhD project granted by the research school VLAG (graduate programme)

**Students project envisioned**

Thesis subjects are related to the research of the Ph.D. projects described on the next pages. The projects can be either lab based or modelling based. Contact Elinor Scott (Elinor.scott@wur.nl) for further information.

Electrochemical cell design for the production of valeric acid and hydrogen peroxide

**Name PhD**: Roel Bisselink
**Involved staff members:** Prof. Dr. J.H. Bitter; Dr. J. van Haveren
**Project sponsor:** NWO program, TKI BBEG-program, TKI programs
**Start/(expected) end date of project:** August 2020 – July 2026

## Background and goal of project

The availability of cheap electricity presents an opportunity to drive chemical transformations and thus enables electrification / decarbonzation of the chemical industry. Possibilities to decarbonize current processes can be found in the electrochemical conversion of 1. bio-based levulinic acid (LA) to valeric acid (VA) and 2. oxygen to hydrogen peroxide. But to come to an efficient electrochemical process design for these routes it is vital to increase understanding of various fundamental aspects of each conversion.

## Highlight of the past year

In the past year the influence of various electrode materials were assessed for the electrochemical reduction of LA to VA. Three materials, lead, cadmium and indium, were selected based on their performance (highest conversion/selectivity). Next, we investigated the influence of acidity (pH) on selectivity and conversion, i.e. activity (Figure 1). Reactions were carried out in an H-cell type electrochemical reactor using 100 mA/cm$^2$ and a charge of 4 F/mol. As a result, a clear influence of acidity is observed on the conversion of LA. Increasing the acidity shifts the selectivity of the reaction from γ-valerolactone (gVL) to VA, while simultaneously the conversion increases. At a higher acidity the conversion decreases again. We tentatively explain these observed phenomena by an increased coverage of the electrode surface by protonated levulinic acid at increasing acidity. Further increase of the acidity suppresses adsorption of protonated levulinic acid due to protons adsorption.

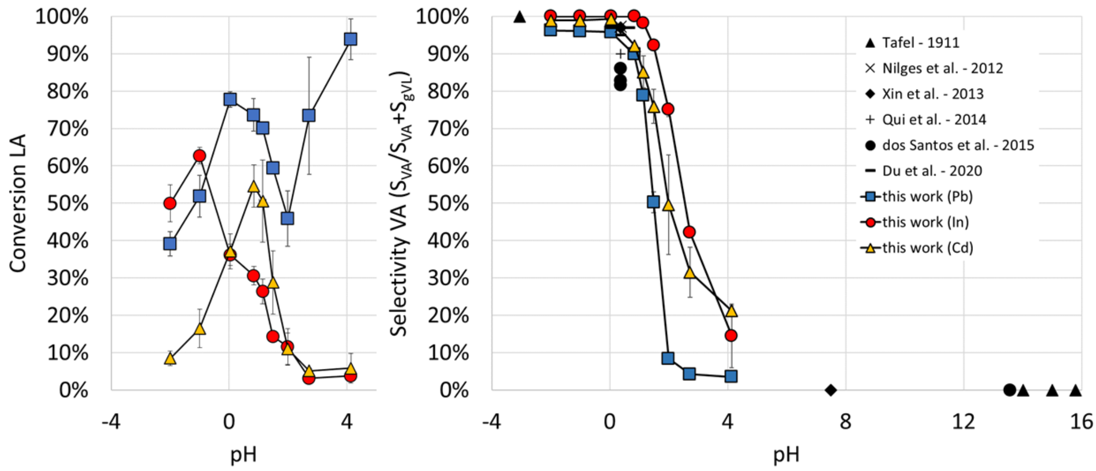



**Figure 1.** Influence of the pH on conversion and selectivity.

## Type of student projects envisioned

Experimentally oriented projects are available to improve understanding of the involved reactions, e.g. assessing the influence of reactant on the conversion, other reactants include different keto-acids, diketo-acids and alike. Work involving oxygen reduction to hydrogen peroxide is foreseen to start in 2022, here synthesis and characterisation of electrode materials are foreseen. Opportunities for modeling projects are available in electrochemical process simulation.

## References


Bisselink et al., *ChemElectroChem* **2019**, 6, 3285.
Bisselink (**2017**). Electrochemical process and reactor. (Patent No. WO2017222382)

Selective polysaccharide oxidation – new catalysts and new chains

Name PhD/PD: Konstantina-Roxani Chatzipanagiotou
Involved staff members: prof. dr. Harry Bitter
Project sponsor: Avebe
Start/(expected) end date of project: October 2019/August 2021

## Background and goal of project

With a worldwide production of over 60 million tons per year, starch is one of the most abundantly produced organic compounds on earth. Several applications have been described (e.g., for textiles, coatings, adhesives and biodegradable packaging materials) to use starch as a sustainable, alternative feedstock to petrochemicals. For such applications, pre-treatment of native starch is required, including partial oxidation, which currently relies on harmful chemicals on an industrial level. Here, a solid catalyst is proposed, consisting of platinum (Pt) nanoparticles anchored on a porous carbon support. This catalyst can oxidize starch at ambient conditions using water as solvent and oxygen gas as a sustainable oxidizing agent. The goal of this project is to investigate the role of the catalyst's properties (support polarity, surface area and porosity, Pt nanoparticle size) and substrate properties (molecular size of polymers) for starch oxidation.

## Highlight of the past year

Owing to the large molecular size of starch bio-polymers, and the variation in the sizes of native starch, several considerations have been highlighted for the design of an effective solid catalyst and confirmed in the laboratory (Figure 1). The carbon support should have high surface area (Figure 1a) and wide pore sizes, to improve diffusion of the substrate. The support should also have sufficient polarity to interact with the water solvent and the substrate (Figure 1b), but not too high, as strong substrate adsorption would block the surface of the catalyst. Smaller and highly dispersed Pt nanoparticles are expected to have optimal activity, as they have a large metallic surface area, but too small nanoparticles are prone to faster deactivation of the outer metallic surface (Figure 1c). Such design criteria may be used to optimize the synthesis of catalysts for large bio-based molecules like starch.

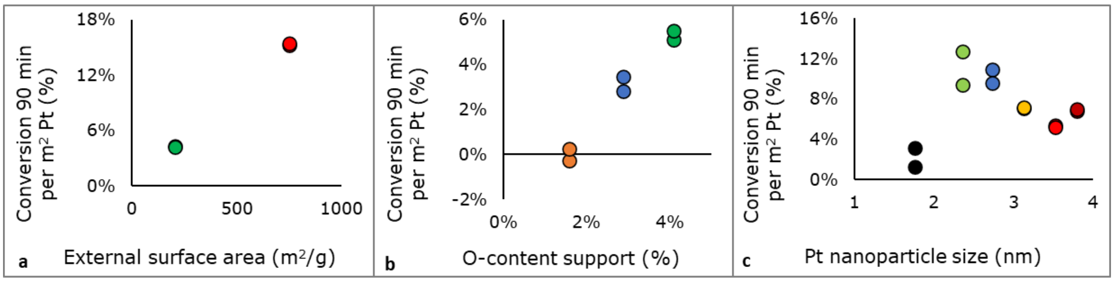



*Figure 1: Oxidation of starch (%) with duplicate experiments over different types of supported solid catalysts. Catalytic activity increases with increasing surface area (a) and polarity (i.e., amount of O-groups, b) of the carbon support. Small nanoparticle sizes of Pt exhibit low activity due to deactivation, and large nanoparticles have low activity due to the low surface area of Pt. Nanoparticles of 2-3 nm are shown to be the most active (c).*

## Type of student projects envisioned

This research project was concluded in 2021. Therefore, no student projects are available within this topic.

Novel enzymatic routes for making starch derivatives with retarded digestibility and enhanced functional properties

**Name PhD/PD**: Maurice Essers
**Involved staff members:** Harry Bitter, Ben van den Broek (WFBR), Hans Leemhuis (AVEBE)
**Project sponsor:** AVEBE
**Start/(expected) end date of project:** 1-10-2020/1-10-2024

## Background and goal of project

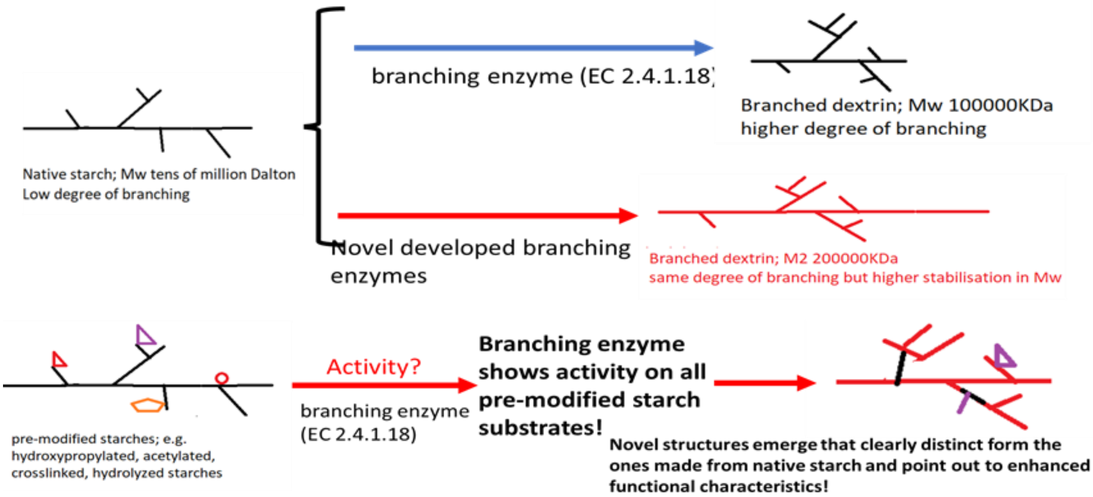
Carbohydrates that don't digest in the small intestine of the human, are referred to as dietary fibre. Dietary fibre plays an important role in the prevention of non communicable diseases such as, diabetes, obesities etc. Hence it is of importance that daily diets contain these types of carbohydrates.

Remodelling or re-structuring of highly digestible and available carbohydrates, such as starch, into non-digestible carbohydrates offer potential to make dietary fibre. Remodelling can be done by means of starch modifying enzymes e.g 1,6- α-glucanotransferases such as branching enzymes (EC 2.4.1.18). By use of these enzymes one is able to increase the ratio α-1,6/1,4 glycosidic linkages in the starch chain. Nevertheless, with the current state of technology the increase of the α-1,6 glycosidic bonds are still insufficient to induce complete resistance towards digestion in the small intestine. Furthermore, due the undesired reduction in molecular weight, losses in functional properties have been observed.

In this project we will investigate the mode of action of the branching enzyme EC 2.4.1.18 on different pre-modified starch substrates in order to identify a pathway that enables to optimize the degree of branching while avoiding a too high reduction in molecular weight. The ultimate goal is to create a novel starch structure that combines both the desirable physiological as well functional properties.

## Highlight of the past year

In the first year of this project, we have investigated the mode of action of the conventional branching enzyme on different premodified starch substrates. In addition we investigated the activities of different novel branching enzymes from different families. We were surprised by the high activity of the branching enzyme on the pre-modified starches. Morever new starches emerge that clearly distinct from the branched dextrins made from native starch (see figure below).The red arrows show the progression in this project whereas the blue arrow points out to the state of art in literature.




## Type of student projects envisioned

We envision a student project which is focussed on the execution (lab work) of the next step in the program; to design a route to increase the degree of branching and to investigate its relation towards digestibility.

## Mixed metal carbides for biomass upgrading

**Name PhD/PD**: Marlene Führer
**Involved staff members:** Prof. dr. Harry Bitter, dr. ir. Tomas van Haasterecht
**Project sponsor:** NWO & FAPESP
**Start/(expected) end date of project:** September 2018- December 2022

### Background and goal of the project

Molybdenum and tungsten carbides are viable replacements for noble metals and as such suitable for the decarboxylation/decarboxylation and hydrodeoxygenation of renewable triglyceride-based feedstocks into valuable products like alkenes, oxygenates and alkanes. Interestingly, the intermediate product selectivity of W-carbides differs from that of the Mo-carbide. While supported W-carbides are more selective (>50%) towards alkenes, higher amounts of oxygenates (30%) are formed over supported Mo-carbides. In our research, we want to combine the two carbides to investigate any potential synergistic effect.

The first step is to prepare well defined mixed carbides. Therefore, we synthesised carbon-supported bimetallic Mo-W carbides either via the carbothermal reduction method (use of support carbon to make the carbide out of an impregnated oxide) or the temperature-programmed reduction method (using an external carbon source to convert the impregnated oxide to the carbide). The materials were analysed with TEM-EDX and XRD.

### Highlight of the past year

We were able to show that both methods the carbothermal reduction (CR) method and the temperature-programmed reduction (TPR) method result in well-mixed bimetallic carbide phases. The TEM-EDX images in Figure 1 display the TPR (left) and CR (right) synthesised mixed MoW-carbide with a molar ratio of 1:1 (Mo:W). The dark contrast nanoparticles can be distinguished from the carbon support. The composition of the nanoparticles itself varies; some particles contain >85 wt% Mo, and others are fully mixed (50:50 wt%).

Although both methods lead to well-mixed MoW-carbide nanoparticles, the available carbon source during the synthesis influences the crystalline phases of the nanoparticles. A cubic carbide ($MeC_{1-x}$) phase was obtained when using the TPR method while a hexagonal phase ($Me_2C$) was obtained when using the CR method irrespective of the Mo:W ratio (1:3, 1:1 and 3:1).

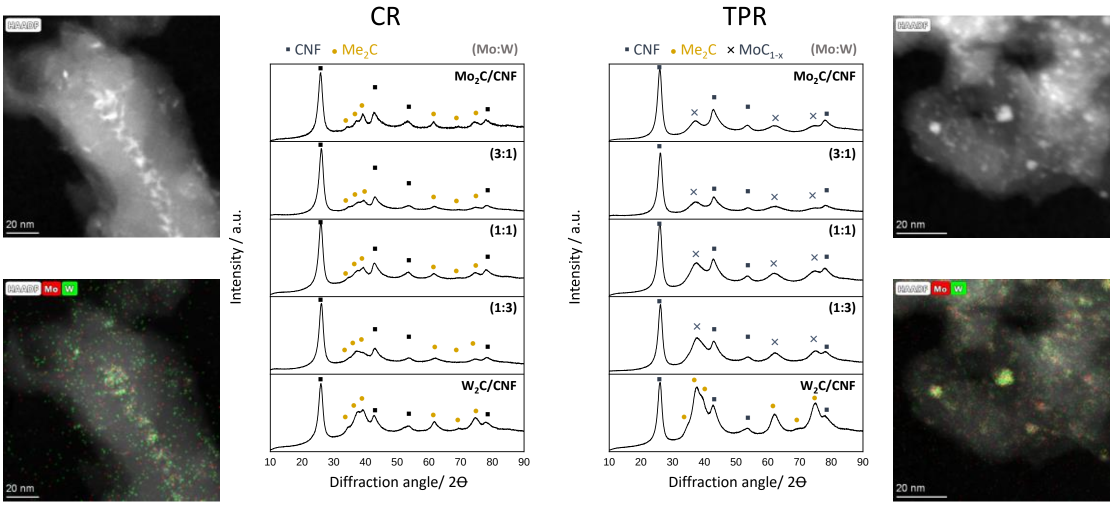



*Figure 2. TEM-EDX and XRD diffractogram of carbide catalyst synthesis via the temperature-programmed reduction under 20% $CH_4/H_2$ (TPR, left) and via a carbothermal reduction in $N_2$ (CR, right)*

### Type of student projects envisioned

A thesis within this project involves mostly lab work including catalyst synthesis, characterization with techniques like XRD, TEM, $N_2$ physisorption and chemisorption. Sofar the deoxygenation reactions are evaluated in a batch system. However, we are currently testing a plug flow system.

Enabling Direct Air Capture of CO2 through efficient and stable sorbent materials

**Name PhD**: Torin de Groot
**Involved staff members:** Prof. dr. Harry Bitter, Dr.ir. Tomas van Haasterecht, Dr. Akbar Asadi Tashvigh
**Project sponsor:** Shell LIFT
**Start/(expected) end date of project:** September 2021-September 2025

## Background and goal of project

Anthropogenic carbon dioxide is a major contributor to climate change. One way to reduce the effects of rising $CO_2$ levels is to remove the $CO_2$ by direct air capture (DAC). Improving carbon capture technology is an essential step in moving towards a carbon neutral society. This project explores ways to improve and better understand sorbent materials.

Our sorbent, potassium carbonate on a carbon support, adsorbs $CO_2$ in the presence of water to give potassium bicarbonate. We can then heat this to release the $CO_2$ so it can be stored or utilised and our sorbent is regenerated. The project aims to :

1. Elucidate the role of water in the adsorption mechanism
2. Investigate the effects of support polarity on adsorption
3. Find a way to characterise supported $K_2CO_3$ particle size

## Highlight of the past year

Preliminary adsorption and desorption curves of reference sorbent were measured using our setup shown on the right and the adsorption capacity calculated.

Initial steps towards developing polar supports and measuring particle suface areas have been made

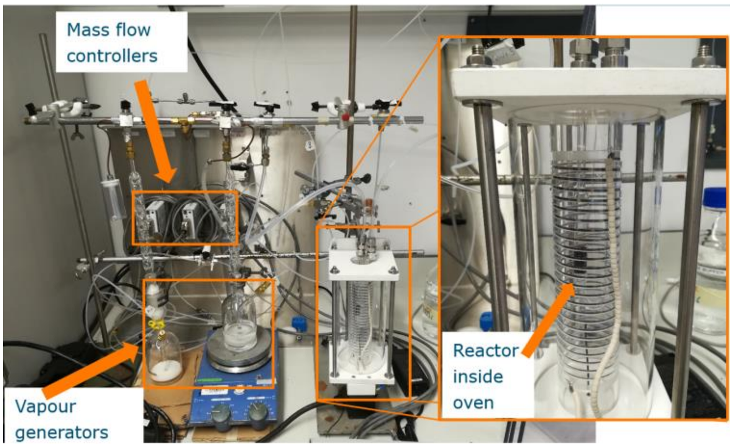



Fig 1: Picture of $CO_2$ capture setup

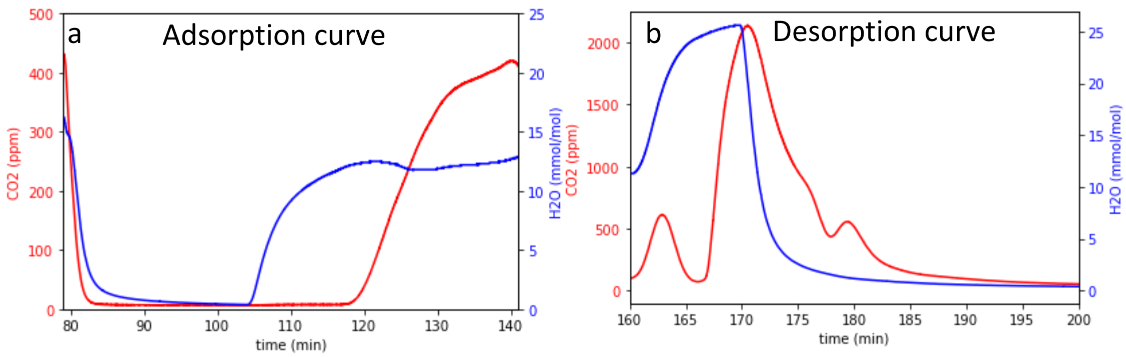



Fig 2: Adsorption and desorption curves (gas concentrations at reactor outlet). CO2 concentration in red H2O concetration in blue. (a) concentration remains 0 while sorbent removes CO2 from air, increases again when sorbent has reached capacity. (b) Sorbent heated to 200C with 10C/min under nitrogen higher concentrations mean more gas is desorbed from the sorbent, until it reaches 0 and everything is desorbed

## Type of student projects envisioned

Student projects could include developing and testing supports with different polarity, investigating particle size using physisorption and chemisorption.There is also room for some modelling.

Electrocatalytic conversion of (poly)saccharides over 3D electrodes

Name PhD: Matthijs van der Ham
Involved staff members: Prof. Dr. Harry Bitter, Dr. Akbar Asadi
Project sponsor: NWO, Avebe, TNO, Brightlands
Start/(expected) end date of project: 08-2019/08-2023

## Background and goal of project

Electrocatalysis can aid in the sustainable conversion of large biomass-based feedstocks to value-added platform chemicals, such as glucose and starch to glucaric acid and anionic starch. Electrocatalysis makes use of a potential to surpass the activation energy barrier. The potential can easily be tuned, giving a good control over the electrocatalyst selectivity. Moreover, electrocatalysts do not require elevated temperatures or harsh oxidizing agents to catalyse reactions, making it a sustainable method to produce chemicals. For this project we use 3D electrocatalysts, which have a high surface area and porous structure, consisting of a metal or carbon support decorated with nano-sized platinum (Pt). The Pt forms the active phase of the catalyst. The aim of this project is to synthesize 3D electrocatalysts that are active, stable and selective for the electrocatalytic conversion of glucose and starch.

## Highlight of the past year

Last year we have synthesized nano-sized Pt particles on carbon nanofibers (Pt/CNF) (Fig. 1A) with different amounts of oxygen groups on the CNF support. It was found that there is an optimum in the amount of oxygen groups on the support, which results in the highest catalytic activity (see Fig. 1B). Why this effect prevails is currently under research. In parallel, we have studied the selectivity and reaction kinetics for the electrocatalytic oxidation of glucose, after quantitatively analyzing the 19 different glucose oxidation products with HPLC and HPAEC. The catalyst was found to be able to oxidize anomeric carbon ($C_1$) and the primary alcohol group ($C_6$) (Fig. 1B).

The next step is to use Pt/CNF catalysts for glucose oxidation in electrocatalytic flow cells. This will be performed to study the diffusion of these large molecules through the pores of the CNF to the active phase of the catalyst (Pt). These results will be modelled to gain more insight on the design of the reactor and the catalyst for glucose and starch oxidation. Moreover, a switch will be made from the electrocatalytic oxidation of glucose to starch (Fig. 1D), where we aim to oxidize the primary alcohol group ($C_6$), to produce anionic starch. To the best of our knowledge the electrocatalytic oxidation of starch has not been performed before.

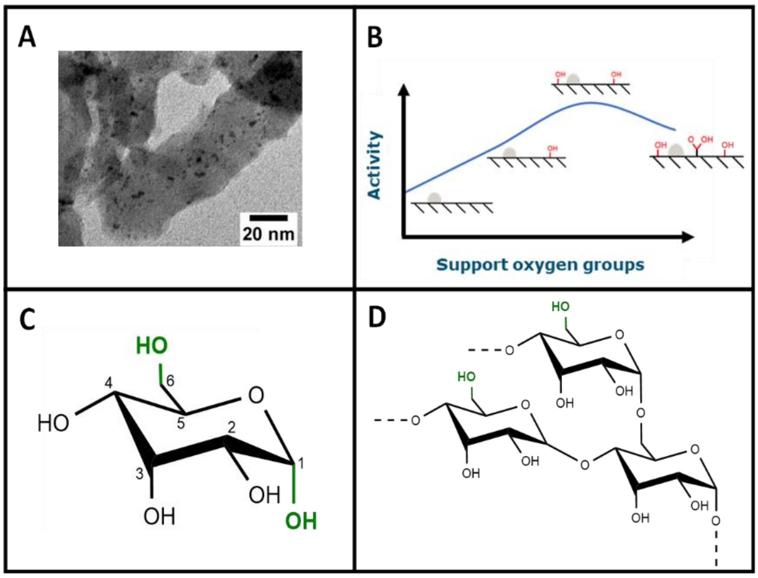
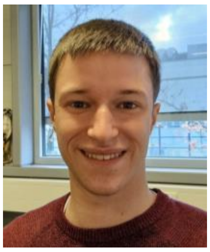



*Figure 3. A) Self-synthesized nano-sized Pt particles decorated on carbon nanofibers. B) The relation between support oxygen groups on CNF on the electrocatalytic activity of Pt towards glucose oxidation. C) Where it was found that Pt can be used for the oxidation of the $C_1$ and $C_6$ groups of glucose. D) shows the aim for next year, where we aim to oxidize starch at the $C_6$ group.*

## Type of student projects envisioned

A thesis in this project involves either lab work or lab work combined with modelling. For only lab work the project is aimed at synthesizing Pt on high surface area carbon or metal supports, the characterization of the catalysts and testing the performance in electrochemical cells for glucose and/or starch oxidation. For combined lab work with modelling the project is aimed at te develop an electrochemical flow cell, testing and modelling the flow cell.

Integrating CO2 capture and utilization: towards a more efficient use of CO2 from the air



**Name PhD/PD**: Freek Karaçoban
**Involved staff members:** Prof. dr. Harry Bitter, dr.ir. Tomas van Haasterecht
**Project sponsor:** VLAG Graduate School
**Start/(expected) end date of project:** December 2021-December 2025

## Background and goal of project

To decrease $CO_2$ levels in the atmosphere and simultaneously produce useful chemicals, $CO_2$ Capture & Utilization (CCU) technologies are necessary. Currently, most considered CCU processes consist of four steps: (1) $CO_2$ capture from air by a sorbent; (2) $CO_2$ desorption by applying steam (steam stripping); (3) $CO_2$ purification, storage and transport; and (4) $CO_2$ conversion using a reducing agent (e.g. $H_2$) into a products such as methanol, a precursor for many chemicals. $CO_2$ capture from ambient air is an essential process since this tackles emissions from distributed sources such as cars. However, ***CCU from ambient air is currently unfeasible due to high energy demands of steam stripping, for which large amounts of steam must be generated and condensed.***

***In this project, we will develop new materials that are capable of both capturing $CO_2$ and converting it to interesting products such as methanol. We will thus attempt to integrate $CO_2$ capture and conversion, allowing to skip the energy intensive steam stripping. This will contribute towards feasible CCU, and thus a solution for the increasing average temperature of the planet.***

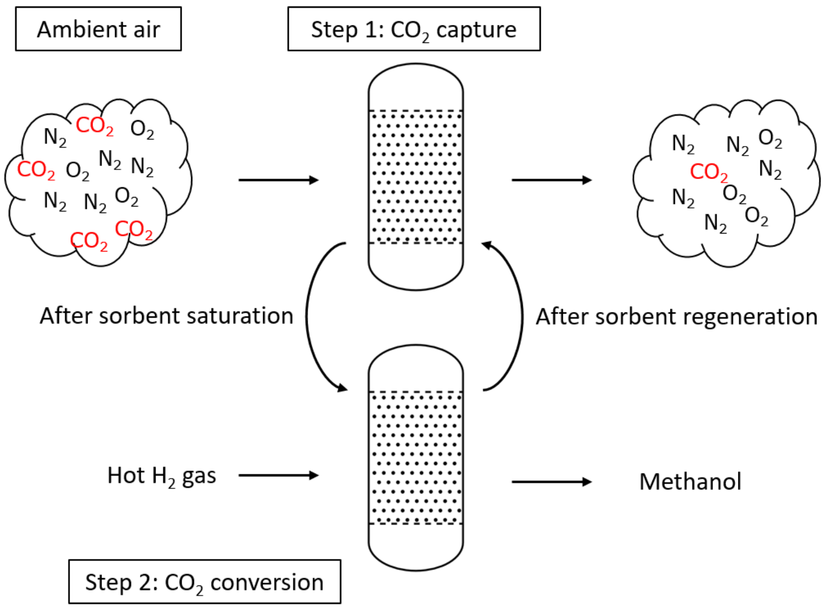



*Figure 1: Envisioned integrated $CO_2$ capture & conversion process which we aim to explore during this PhD project.*

## Highlight of the past year

Project started in December, so no noteworthy results (yet).

## Type of student projects envisioned

Students can work on either material development or process modelling. We will study the structure and performance of various $CO_2$ capture agents (sorbents), and catalysts that can convert the captured $CO_2$. The aim will be to find effective sorbents and catalysts that can work in synergy to achieve integrated $CO_2$ capture and conversion. Additionally, mathematical models of the complete CCU processes must be developed to assess how the developed materials perform in a large-scale process. This will be used to compare the materials and find targets for improvements.

## Selective catalytic transformations of non-edible carbohydrates

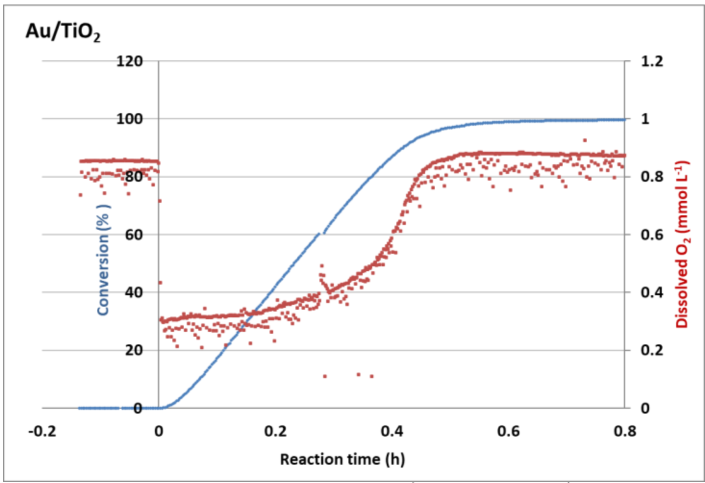
**Name PhD/PD**: Frits van der Klis
**Involved staff members:** Prof. dr. J.H. Bitter; Dr. D. S. van Es; Dr. J. van Haveren
**Project sponsor:** TKI-programs, CatchBio, EU SPLASH, EU Pulp2Value
**Start/(expected) end date of project:** 2013-2022

### Background and goal of project

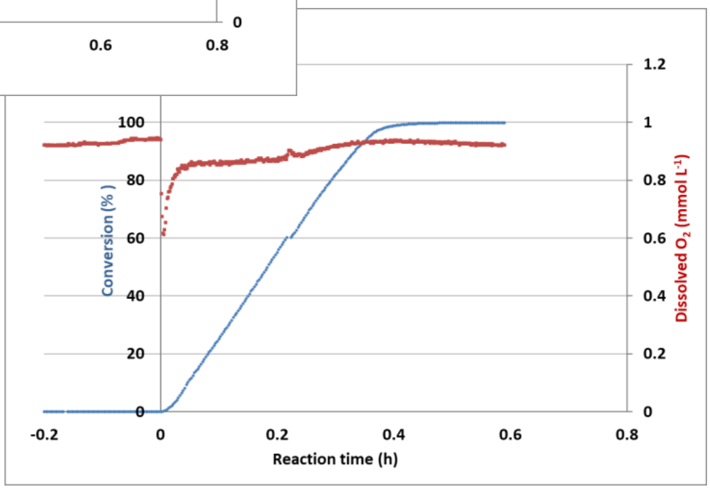
The general goal is to selectively convert carbohydrates from residual agricultural waste streams, such as sugar beet pulp, into valuable products by means of catalysis. Both the catalyst and the carbohydrate structure are influencing the conversion and selectivity, and form the core of my research.

### Highlight of the past year

Supported gold-catalysts are able to selectively oxidize carbohydrates into useful products. Molecular oxygen (air) is the sole green oxidant needed. Moreover, these environmentally friendly reactions can be easily performed in water. The solubility of oxygen in water is however low, and therefore often the rate limiting factor during reaction.




The top picture shows the conversion of a carbohydrate over time (blue line, left axis), and the dissolved oxygen concentration during reaction (red line, right axis). In this case the oxidation is performed using a low surface area catalyst support (Au/TiO$_2$). As can be seen from the red line, the oxygen concentration stays low during reaction, thereby limiting the conversion rate.
In the bottom picture, all conditions are kept identical, but additional (high surface area) activated carbon is added to the reaction mixture. In this case the oxygen concentration remains higher during reaction, resulting in an overall faster conversion.




It was found that catalyst supports with large surface areas, such as activated carbon, play an important role in the active transport of oxygen from the gas-phase to the liquid-phase, and are therefore a useful tool to optimize the catalyst performance.[1]

### 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.


[1] *React. Chem. Eng.* 2018, *3*, 540– 549.

Specific dietary fiber combinations for decreasing antibiotics use and faster recovery of gut microbiota

Name PhD: Cynthia Klostermann
Involved staff members: prof. dr. Harry Bitter
Involved members: prof. dr. Henk Schols (FCH), prof. Dr. Paul de Vos (UMCG)
Project sponsor: NWO, CCC (Carbobiotics)
Start/(expected) end date of project: 15-11-2018 / 15-02-2023

## Background and goal of project

Resistant starch type 3 (RS-3) is known to have great potential as a prebiotic by supporting beneficial gut microbiota after intestinal digestion. In contrast, antibiotics have a negative effect on beneficial microbiota and barrier function. This research investigates the opportunity of RS-3 to be used as a prebiotic after antibiotics use. RS-3 is considered a dietary fiber since it escapes digestion in the small intestine and arrives in the colon. Previously, the factors influencing resistance to digestion of specific RS-3 have been studied [1]. It has been concluded that especially a specific crystal type and chain length are of interest, since this causes are fully resistant to digestion in the small intestine and thus arrive in the colon.

## Highlight of the past year

The different RS-3 preparations were fermented using pooled adult fecal inoculum during *in vitro* batch fermentations. The speed of RS-3 degradation by microbial enzymes was found to be highly dependent on RS-3 fine structure. Furthermore, fermentation of RS-3 to short-chain fatty acids was also found to be dependent on RS-3 fine structure, i.e. some RS-3 samples stimulated production of acetate and butyrate, whereas other RS-3 samples stimulated production of acetate and lactate. After 16s rRNA sequencing of the fermentation samples, it was found that RS-3 stimulated different bacterial genera, depending on its fine structure. This could also be visualized using Scanning Electron Microscopy (SEM).

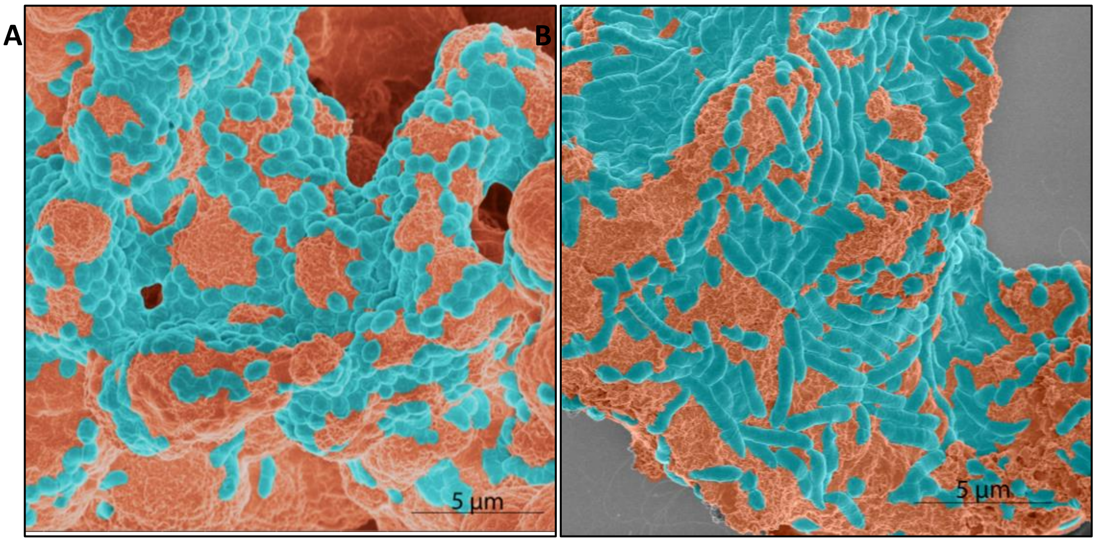



Figure A represents an RS-3 structure (orange) which seems to be degraded by mostly cocci-shaped bacteria (blue), whereas figure B represents a different RS-3 structure (orange) which seems to be degraded by mostly rod-shaped bacteria (blue). SEM images taken during *in vitro* fermentation of RS-3 by pooled adult fecal inoculum.

## Type of student projects envisioned

This project is close to its end and therefore there are no new student projects.

[1] Klostermann et al. 2021. *Carbohydrate Polymers*

Intensified electrocatalytic production of hydrogen peroxide (HYPER)

Name PhD/PD: Ivo van Luijk
Involved staff members: prof. Harry Bitter, Akbar Asadi Tashvigh
Project sponsor: NWO, Solvay
Start/(expected) end date of project: 1-11-2021/1-11-2025

## Background and goal of project

Hydrogen peroxide ($H_2O_2$) is a widely used chemical that is currently produced by the anthraquinone process. This process does unfortunately lead to 1.1 million tons of $CO_2$ emitted every year in Europe for the total 2 million tons of $H_2O_2$ produced. Producing the hydrogen peroxide with electrochemistry instead could largely eliminate these $CO_2$ emissions. The hydrogen peroxide could be created with via reduction of oxygen, as is shown in Figure 1. In this project catalyst development, membrane development and sytem design go hand in hand. My project specifically entails the development of novel cathode materials and greater understanding to help achieve the overall goal of viable industrial production. Cathodes consisting of non-noble transition metals are utilized because of their low cost and high potential, which can only fully be utilized with proper understanding.

This project will first focus on nickel nanoparticles supported on carbon nanofibers, in later stages other transition metals could be explored. Nickel is a viable cathode material that is low in cost, but to optimize its performance, the roles of particle size and support polarity will need to be investigated. For this reason carbon nanofibers are used as a support, as the polarity can be tuned by incorporation of various heteroatoms and it can be used to support Nickel nanoparticles of various sizes.

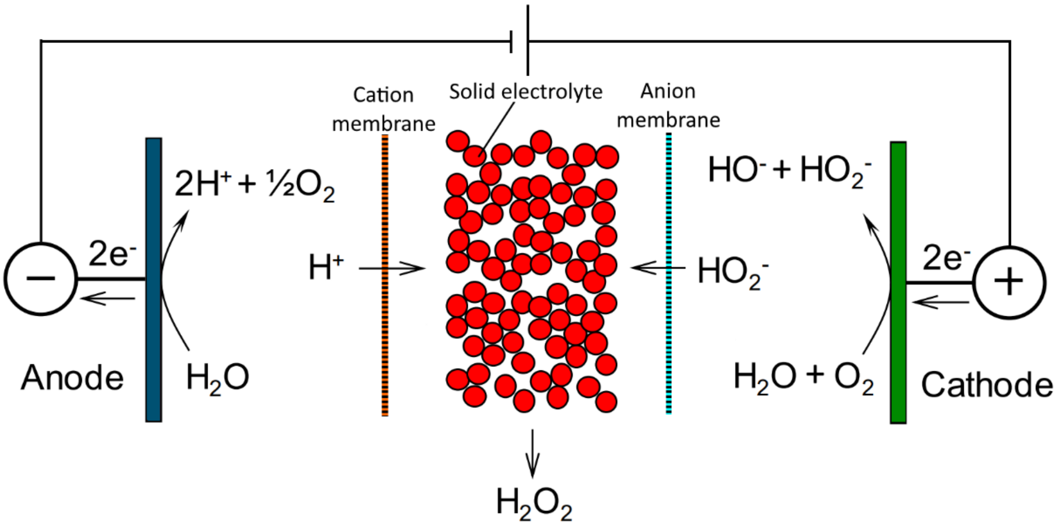



*Figure 4: Cell design for electrochemical hydrogen peroxide production in HYPER project*

## Highlight of the past year

This project only started last month, therefore there is not much to highlight.

## Type of student projects envisioned

For students I have projects in catalyst prepration, characterization and testing. Different materials consisting of supported nanoparticles need to be prepared, tested for their performance in electrochemical hydrogen peroxide production. In addition the catalysts need to be characterized via spectroscopic and electrochemical methods to establish property-performance relationships.

Electrochemical transformations of biobased compounds

**Name PhD/PD**: Dmitry Pirgach
**Involved staff members:** Prof. Dr. Harry Bitter, Prof. Dr. Pieter Bruijnincx (UU), Dr. Daan van Es (WFBR)
**Project sponsor:** WUR 1st stream
**Start/(expected) end date of project:** 01.12.2020 – 01.12.2024

## Background and goal of project

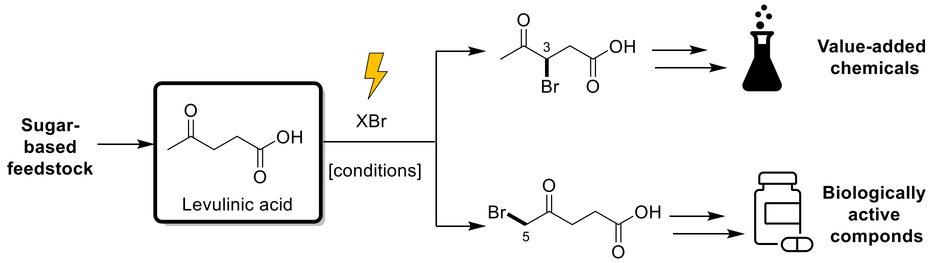
Over the past decades, chemists are more and more focusing on developing green and sustainable synthetic methods for the production of chemical building-blocks. On one hand, this involves the use of renewable feedstocks as starting materials, on the other - renewable energy, for instance electricity, to drive the reaction. Among different synthetic approaches, electrosynthesis is becoming of a particular interest. It is a highly promising and sustainable method which can also help to avoid the use of toxic or dangerous oxidizing or reducing reagents, protecting and activating groups.

The goal of the project is to develop new electrochemical methods for utilizing the products of renewable sourses (biobased feedstocks) as building blocks in the synthesis of various molecules. Natural sources of chemicals exhibit variety of different chemical structures and may require less transformation steps. On the other hand, they lead to less waste generation and sustainable economy, especially when the transformations are performed electrochemically.

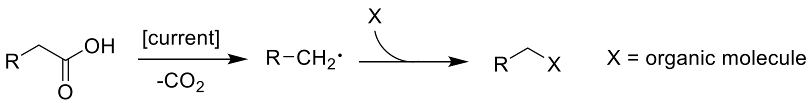
## Highlight of the past year

During the past year, new approaches for valorization of biobased molecules were discovered and studied.

For example, electrochemical bromination of levulinic acid (product of sugar-based feedstocks) can lead to valuable 3- or 5-bromolevulinic acid. The latter one is precursor of anti-cancer agents, herbicides, insecticides or antibiotics, while 3-bromolevulinic acid is a convenient starting material for the synthesis of heterocyclic compounds (aminothiazoles, pyridazines, butyrolactones) which can be further utilized in the preparation of biologically active compounds. While the traditional bromination methods require using molecular bromine or another brominating agents, electrochemical approach could offer beneficial solution by using bromide salts as bromine source. In this case bromine will be formed in-situ during the anode process in that way the concentration will remain low and bromine will be consumed immediately.




Another project developed is electrochemical decarboxylative coupling. Carboxylic acids are stable, inexpensive, and widely available in nature compounds. Transformations of carboxylic acids can give access to various valuable product classes, given the variety of readily available acids, they find wide application in organic synthesis as ready or half-ready building blocks. Radical, the active intermediate of these reactions, is generated while breaking C-COOH bond. The sole by-product of carbon dioxide is innocuous, non-flammable and can be easily removed from the reaction system.




## Type of student projects envisioned

The projects available for students mostly include lab work (planning and performing the experiments, isolating and purifying the desired product), reading the related literature and performing the analysis of reaction mixtures (TLC for reaction control, NMR/HPLC for qualitative and quantitative analysis).

## Recovery and valorization of residual keratin materials from chicken feather into biobased nanocarriers

**Name PhD**: Xiaojie Qin
**Involved staff members:** Dr. Elinor Scott (BCT), Prof. dr. Harry Bitter (BCT) and Prof. dr. Chunhui Zhang (CAAS)
**Project sponsor:** China Scholarship Council (CSC)
**Start/(expected) end date of project:** 01-01-2020/01-01-2024

### Background and goal of project

The global consumption of chicken meat has reached 114 million tons annually producing a large amount of feathers as a rest product. Feathers contain about 90% of keratin, making them a potential alternative protein resource. However, traditionally chicken feathers are discarded as solid waste without any further treatment causing protein resource waste as well as environmental pollution. Therefore, it is desirable and important to develop a novel and effective process for reusing and valorizing residual keratin materials. As a kind of amphiphilic structural protein, keratin possesses good stability, biocompatibility, biodegradability, and non-toxicity, showing a promising prospect in drug delivery system.

The project aims to develop a nano-carrier drug delivery system with high bioavailability using keratin-based materials derived from chicken feather. In this study, an efficient and green strategy for keratin processing and recycling is explored, and then the potential of keratin hydrolysate in drug delivery system will be investigated. Finally, a high-performance keratin-based oral route for drug delivery will be hopefully established.

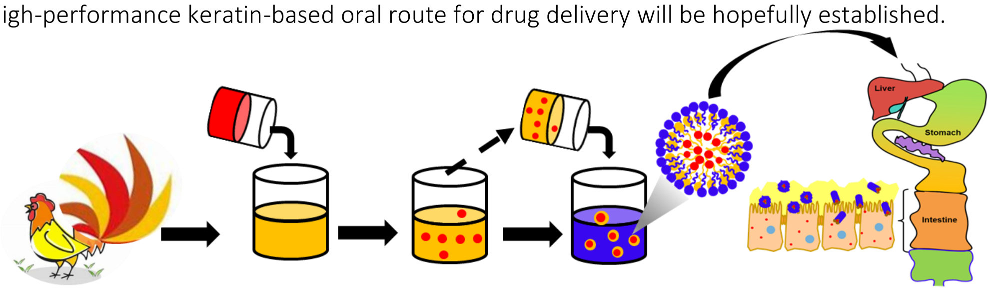
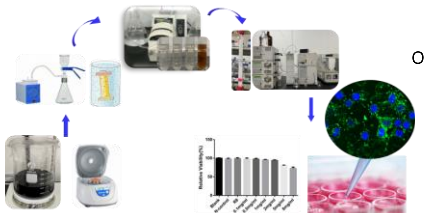



Figure 1. Scheme of keratin valorisation for drug delivery system

### Highlight of the past year



- An efficient process for keratin regeneration has been optimized based on cysteine-reduction method;
- Keratin hydrolysate exhibited potential ability in promoting insulin penetration into intestinal epithelial cells.

### Type of student projects envisioned

The lab work of this project will mainly include physical and chemical characterization of nano particles involving FT-IR, XRD, TEM, CLSM, and DLS. Additionally, the work regarding to in-vitro digestion will be explored at a later stage.

Bioelectrochemical chain elongation of CO2:
*Electrification of biotechnology*

**Name PhD**: ir. Sanne de Smit
**Involved staff members:** prof. dr. Harry Bitter (BCT), prof. dr. ir. Cees Buisman (ETE), dr. ir. David Strik (ETE)
**Project sponsor:** WIMEK, ChainCraft
**Start/(expected) end date of project:** Sep 2018 – Nov 2022

## Background and goal of project

We are facing the challenge to reduce carbon dioxide emissions to reach climate goals. Electrochemical $CO_2$ reduction is a technology that uses electrochemical systems to convert $CO_2$ into higher value compounds, using electrical energy for the conversions. By integrating microorganisms in this process, higher value products can be produced. A biofilm of bacteria grows on the electrode and uses the available energy to convert $CO_2$ to fatty acids, which can be used as animal feed additive or platform chemical for e.g. fuel production.

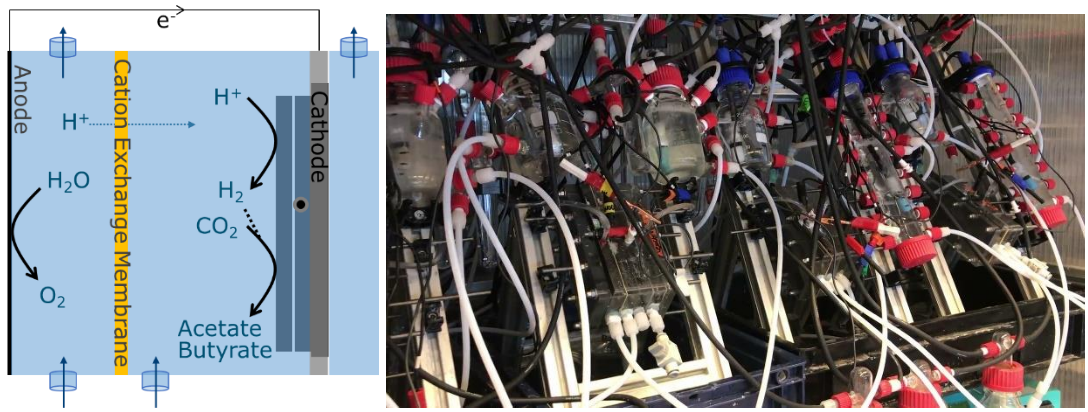



***Figure 5.*** *Schematic (left) and actual (right) setup of bioelectrochemical chain elongation systems.*

The goal of the PhD project is gain a better understanding of the working mechanisms at the cathode to obtain steering tools to optimize the system in the lab and work towards practical application.

## Highlight of the past year

We showed that the current increased significantly after performing "cyclic voltammetry", a scan during which the cathode potential is changed. This current increased was simultaneous with a deposition of trace metals on the cathode (figure 2). This suggests that the trace metals can have a catalytic effect on the reactor current. The higher current gives improved electron availability for the microorganisms. We are further exploring the mechanisms to use them as a system boost.

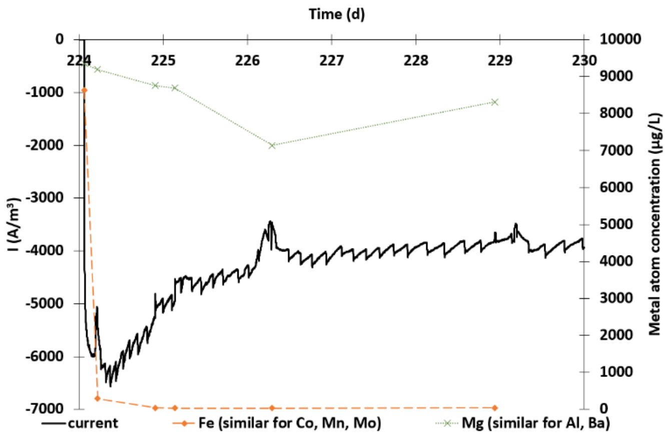



***Figure 2.*** *Current increase simultaneous with decrease of iron, cobalt, manganese and molybdenum from the liquid. The decrease from the liquid indicates they were deposited on the cathode.*[1]

## Type of student projects envisioned

No student projects available due to finalization of the project in 2022.


[1] S. M. de Smit, C. J. Buisman, J. H. Bitter, D. P. Strik, *ChemElectroChem* **2021**, *8*, 3384-3396.

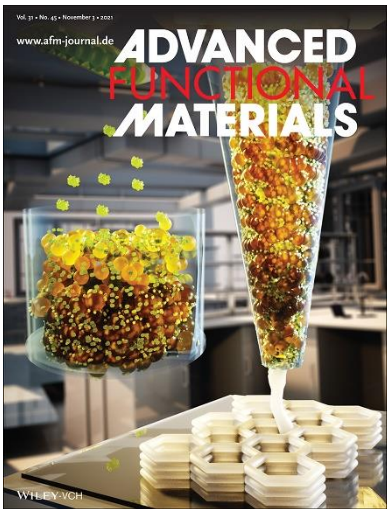
**Biobased Soft Materials**

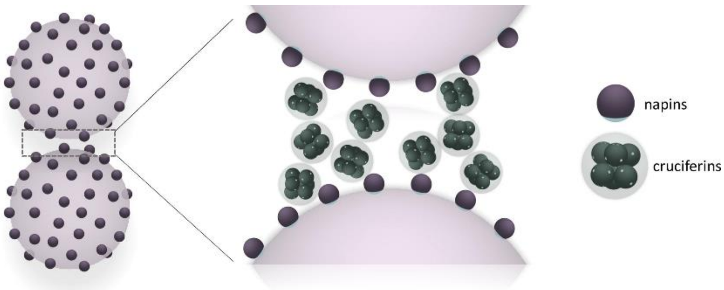
**Team Leader:** Dr. Costas Nikiforidis

**PhD students:** Kübra Ayan, Mingzhao Han, Zhaoxiang Ma, Eleni Ntone, Lorenz Plankensteiner, Laura Schijven, Simha Sridharan, Umay Sevgi Vardar.
**Postdoc:** Dr. Jack Yang

**Contact:** costas.nikiforidis@wur.nl

**Background and goal**
The Biobased Soft Materials team aims to understand the property-function relationship of biosourced molecules and complexes, and use them in soft materials for foods and medical applications. The self-assembly and equilibrium properties of the soft materials are investigated from a soft matter physics, chemistry, and biology perspective at multiple length scales, from molecular to macroscopic.
The typical analytical tools we are using in our research are atomic force, confocal, scanning and transmission electron microscopy, dynamic light scattering, interfacial, and bulk rheology.




**Main topics**
- Protein cages to carry therapeutics and diagnostics
- Trafficking molecules with Lipid Droplets (Oleosomes)
- Behavior of Lipid Droplets (oleosomes) on interfaces
- Plant protein mixtures as emulsifiers
- Jammed emulsions for 3-D printing
- Design bio-inspired oil droplets resistant to lipid oxidation
- Extraction of proteins and Lipid Droplets using their mobility under an electric field

**Highlights from last year**
-The team published 11 peer reviewed articles in highly ranked journal
-Cover at Advanced Functional Materials (https://doi.org/10.1002/adfm.202101749)
-3 articles in the Most Downloaded of Food Hydrocolloids
-Research on 3D printed emulsion feature in Resource #7

**Student project envisioned**
Thesis subjects are related to the research of the Ph.D. projects of the team including mainly experimental and in some cases computational work

Electrophoretic Oleosome and Protein Extraction from Oilseeds

**Name PhD/PD**: Kübra Ayan
**Involved staff members:** Dr. Costas Nikiforidis (BCT) & Prof. Remko Boom (FPE)
**Project sponsor:** National Education Ministry of Turkey
**Start/(expected) end date of project:** September 2020 / September 2024

## Background and goal of the project

Oilseeds such as rapeseeds are an excellent source of oils, in the form of oleosomes and proteins. Oleosomes are oil storing droplets, which form highly stable and edible oil-in-water emulsions[1][2]. Both oleosomes and proteins can be extracted simultaneously through aqueous extraction, however, it is not an efficient process as it requires a large amount of water. To minimize the use of resources during the oleosome and protein extraction, we are developing a continuous electrophoretic extraction process.

Electrophoretic separation systems are based on different migration rates of particles under an electric field (electrophoretic mobility)[3]. In the case of oleosome and protein separation, an electrophoretic technique is promising because it has already been confirmed that oleosomes and proteins have significantly different electrophoretic mobility at pH > 5 ($p < 0.05$). This difference allows developing a continuous process by incorporating pressure driven flow and electrophoresis (Fig.1). In this way, protein movement will be dominated by pressure driven flow while oleosome movement is governed by electrophoresis.

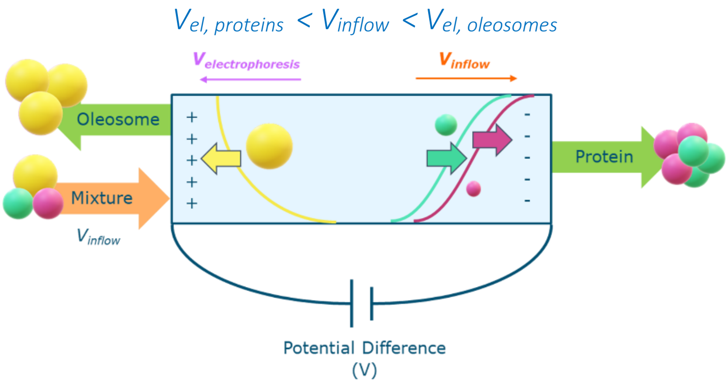



Figure 1: Schematic representation of the continuous electrophoretic extraction process.

## Highlights for last year

- Rapeseed proteins (napin and cruciferin) and oleosomes have different electrophoretic mobility at pH > 5 ($p < 0.05$).
- Napin and cruciferin has also different electrophoretic mobility at pH 5 – 7 ($p < 0.05$)
- A modelling study showed the separation between proteins and oleosomes and even between different kind of proteins are possible.
- A microscale separation system is being developed to figure out the separation mechanism.

## Type of student projects envisioned:

Lab-based MSc and BSc projects can be offered.


1. Nikiforidis, C. V. (2019). Structure and functions of oleosomes (oil bodies). Advances in Colloid and Interface Science, 274, 102039. https://doi.org/10.1016/j.cis.2019.102039
2. Ismail, B. P., Senaratne-Lenagala, L., Stube, A., & Brackenridge, A. (2020). Protein demand: review of plant and animal proteins used in alternative protein product development and production. Animal Frontiers, 10(4), 53-63.
3. Manouchehri, H. R., Rao, K. H., & Forssberg, K. S. E. (2000). Review of electrical separation methods. Mining, Metallurgy & Exploration, 17(1), 23-36.

Exploring sustainable transformation of plant extract industry

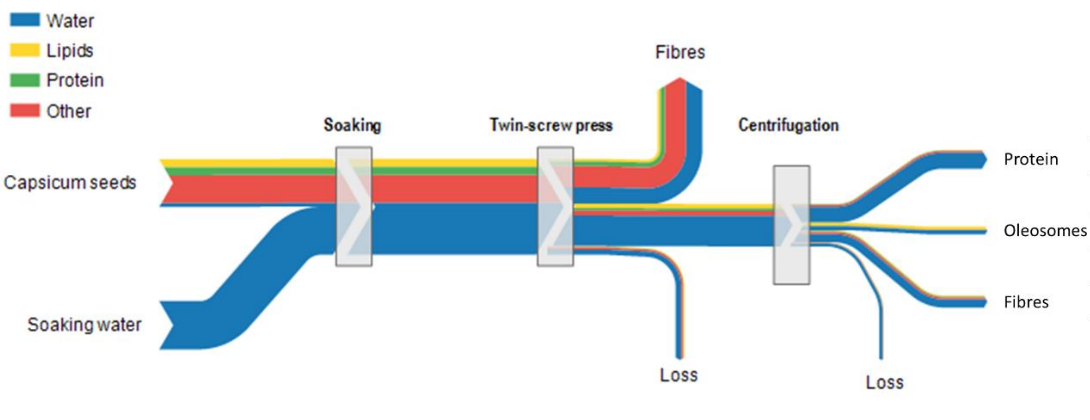
**Name PhD/PD**: Mingzhao Han
**Involved staff members:** dr. Costas Nikiforidis (BCT), Prof. dr. Remko Boom (FPE)
**Project sponsor:** Chenguang Biotech Group and CRC
**Start/(expected) end date of project:** September 2019-September 2023

## Background and goal of project

Capsicum seeds is a main side stream from the production of pigments from capsicum peppers. Chenguang Biotech Group Co., Ltd. (CCGB) is the largest capsicum pigments producer in the world, and produces significant side streams that are currently under-utilised. Capsicum peppers contain around 23% oil and 21% protein. Therefore, research in the recent years focused on explore the properties of oleosomes from capsicum seeds.

## Highlight of the past year

- Mass balance of oleosomes extraction from capsicum seeds.
- Investigation of the basic properties of oleosomes from capsicum seeds.
- Formulation of food products based on oleosome emulsions




Sankey diagram of oleosomes extraction from capsicum seeds

## Type of student projects envisioned

Student projects include lab work (characterization of oleosome-rich and protein-rich mixtures from capsicum seeds), explore the economic impact of the oleosomes production process in pilot plant.

McClements, David Julian. 2020. "Development of Next-Generation Nutritionally Fortified Plant-Based Milk Substitutes: Structural Design Principles." *Foods* 9(4):421.

Nikos Alexandratos and Jelle Bruinsma. 2012. *World Agriculture towards 2030/2050: The 2012 Revision Global Perspective Studies Team FAO Agricultural Development Economics Division*

## Increasing bioactivity of CBD by incorporating it in oleosomes

**Name PhD/PD**: Zhaoxiang Ma
**Involved staff members:** Prof. dr. Costas Nikiforidis (BCT), Prof. dr. Harry Bitter (BCT), Prof. dr. Remko boom (FPE)
**Project sponsor:** Industrial Partner
**Start/(expected) end date of project:** March 2020-February 2024

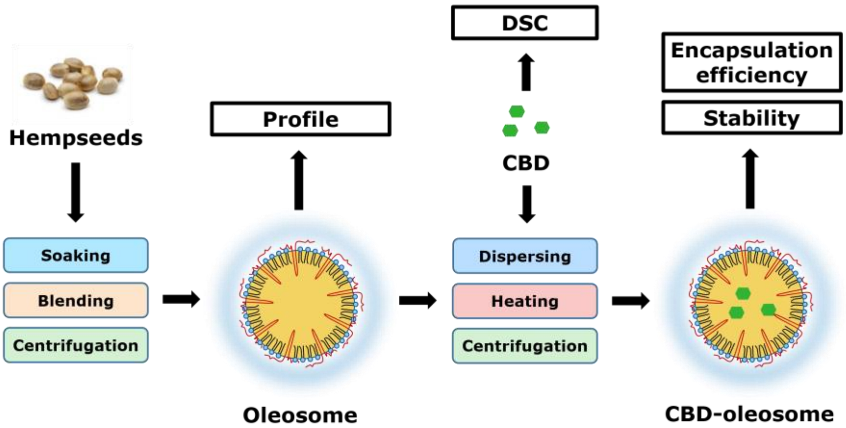
### Background and goal of project

Oleosomes are natural vesicles filled with oil, present in all eukaryotic organisms, which have a triacylglycerol (TAG) core surrounded by a monolayer of phospholipids and proteins. Oleosomes are sustainable and environmental-friendly compared with synthetic lipid droplets which have toxicity and low biodegradability. Due to the unique natural characteristics of the oleosome, it has great potential as a new type of natural delivery agent that can transport hydrophobic active molecules (like CBD) and meet the demands for healthy food from consumers.

The loading of hydrophobic active molecules depends on encapsulation conditions such as applying thermal processing and co-solvent. To gain higher encapsulation efficiency, physicochemical properties of oleosomes and hydrophobic active molecules need to be well understood. This project focuses on understanding the encapsulation mechanism of CBD into oleosomes.

### Highlight of the past year

- CBD was successfully encapsulated into hempseed oleosomes.
- Thermal processing had a great influence on the CBD form and the encapsulation efficiency of CBD into oleosomes.
- CBD-loaded oleosomes had excellent physicochemical stabilities against long-term storage.




### Type of student projects envisioned

Student projects include lab work, focusing on investigating the bioactivity of CBD during *in vitro* gastrointestinal digestion model and human skin model. For this research advanced analytical tools will be used, HPLC, dynamic laser scattering and confocal microscopy.

Versatile ingredients from rapeseeds for structuring plant-based soft materials

**Name PhD: Eleni Ntone**
**Involved staff members: BCT: Costas Nikiforidis, Harry Bitter**
**FPH: Leonard Sagis**
**Project sponsor: NWO-TIFN**
**Start/(expected) end date of project: September 2017/September 2021**

**Background and goal of the project**
Oilseeds, containing high amounts of proteins and lipids -essential structuring and nutritional ingredients in foods- are one of the most promising ingredient sources for food applications. An application of oilseed lipids is to serve as raw materials for oil-in-water emulsion-type food products, while proteins can be used in the same type of products to stabilize the free oil in water. Therefore, in this project we aim to enhance the potential use of less purified oilseed ingredients for food applications by providing an alternative extraction process and a mechanistic understanding on the relation between extraction and functionality of less purified oilseed proteins and lipids.

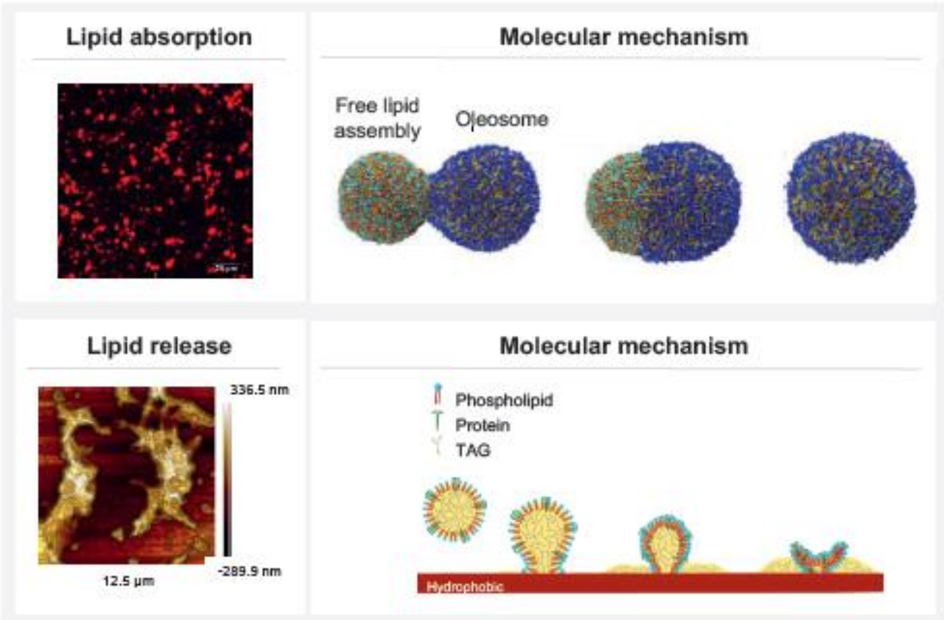
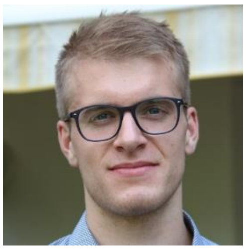



**Figure.** Summary of the mechanism on lipid absorption and release from oleosomes.

**Highlights of the past year**
- Rapeseed proteins present in mildly purified mixtures can stabilize interfaces and can be used in soft materials like emulsions and emulsion filled gels. The stabilization mechanism is pH dependent.
- Lipid droplets have an elastic dilatable monolayer that allows them to adsorb and release lipids, realizing lipid trafficking

**Type of student projects envisioned**
The project has been finalised

Nature knows best – Lessons from plants on how to design stable emulsions resistant to lipid oxidation



**Name PhD/PD**: Lorenz Plankensteiner
**Involved staff members:** Dr. Costas Nikiforidis
**Project sponsor:** Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO), Industrial Partner
**Start/(expected) end date of project:**
01.07.2020 / 01.07.2024

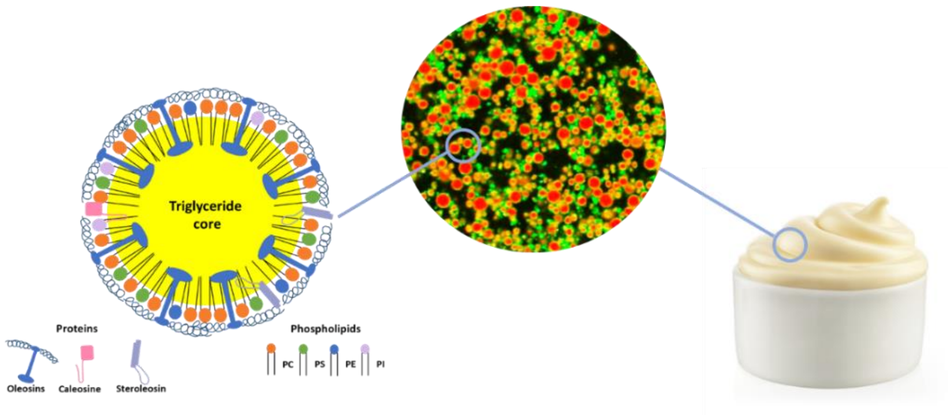
## Background and goal of project

Lipid oxidation is one of the major causes of the degradation of lipid-based products. Particularly, oil-in-water emulsions are very sensitive to lipid oxidation. Currently, the industry uses synthetic antioxidants, cold chain storage and/or special packaging conditions to prevent lipid oxidation. The increasing demand for clean label and sustainable food products makes us rethink these strategies.
What if nature has already solved the lipid oxidation problem? Plants store their lipids in special organelles, called oleosomes. They have been wisely developed during evolution to have extraordinary stability against physical and oxidative stresses. Oleosomes can be extracted from plant seeds and used as food emulsions. First studies showed they have better oxidative stability than traditional emulsions. In our research, we want to understand the mechanisms behind the stability of oleosomes to broaden their application as natural ingredients but also to develop bio-inspired products more resistant to lipid oxidation.

## Highlight of the past year

- Isolation and characterization of rapeseed oleosomes and their constituents.
- Deactivation of coextracted enzymes without affecting oleosome integrity.

Rapeseed oleosomes were found to consist of three main components: 96 % triglycerides, 3.5 % protein and 1 % phospholipids. The difference in polarity between these building blocks helped us to develop a new extraction method to efficiently separate and isolate each oleosome constituent individually. The effectiveness of our extraction was confirmed with several analytical techniques (LC-MS, SDS PAGE, Dumas, $^{31}$PNMR). This extraction method was then upscaled to produce enough material for our future work on making bio-inspired artificial oleosomes. It is the first extraction method which allows the extraction of larger amounts (~10 g) of proteins from oleosomes.




## Type of student projects envisioned

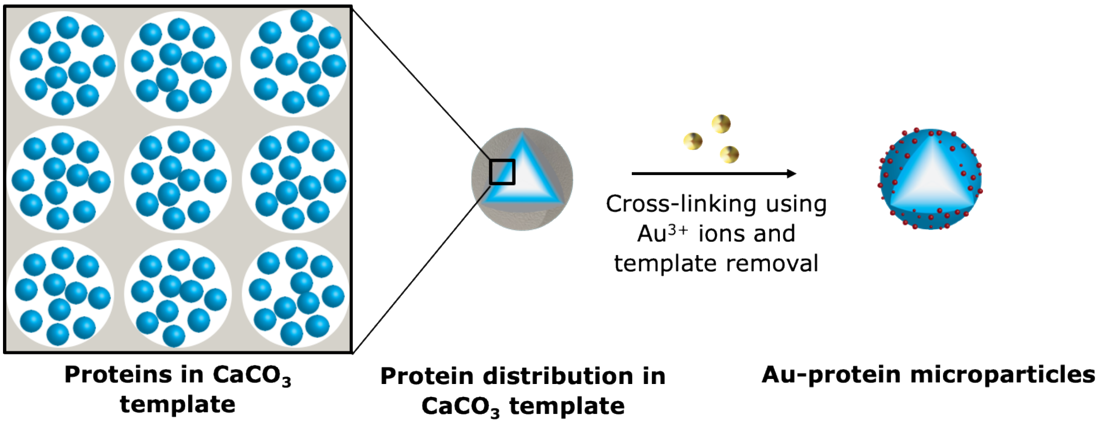
The unique approach in this project allows offering a broad spectrum of thesis topics in the fields of food/analytical chemistry and soft material science. We offer various topics with a focus on experimental lab work.

Linking Au3+ ions and proteins for the formation of protein gels and microparticles

Name PhD: Laura Schijven
Involved staff members: dr. Costas Nikiforidis (BCT), prof. dr. Harry Bitter (BCT), dr. Vittorio Saggiomo (BNT), prof. dr. Aldrik Velders (BNT)
Project sponsor: VLAG Graduate School
Start/(expected) end date of project: September 2017 – June 2022

## Background and goal of project

Understanding protein aggregation is important in biology, medical research and food products. Protein aggregation is usually induced by pH, ionic strength or temperature. In our first project, we found that $Au^{3+}$ ions and proteins can form a protein gel network through a redox reaction. Thereafter, we applied the $Au^{3+}$-induced protein gelation inside templates to fabricate protein microparticles. These protein microparticles are potential multimodal imaging agents due to their biocompatibility, but also the optical, high electron density and high attenuation coefficient properties of the embedded gold nanoparticles.




## Highlight of the past year

- $Au^{3+}$ ions can induce protein gelation through a redox reaction
- This $Au^{3+}$-induced gelation method can be applied for making protein microparticles
- Protein distribution inside the templates is conserved after cross-linking and template removal

## Type of student projects envisioned

Currently there are no student projects envisioned due to finalizing of the project

## Related publication:

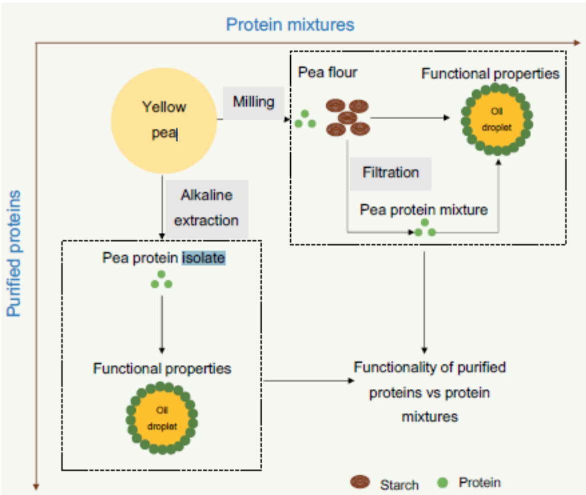

Schijven, L. M., Saggiomo, V., Velders, A. H., Bitter, J. H., & Nikiforidis, C. V. (2021). Au 3+-Induced gel network formation of proteins. *Soft Matter*, 17(42), 9682-9688.

Pea protein mixtures as structuring agent in edible soft materials

**Name PhD/PD**: Lakshminarasimhan (Simha) Sridharan
**Involved staff members:** Dr. Costas Nikiforidis, Prof. Harry Bitter, Dr. Marcel B.J. Meinders
**Project sponsor:** TiFN, Wageningen
**Start/(expected) end date of project:** 02/10/2017-02/10/2021

## Background and goal of project

Extracting proteins from plant seeds to obtain high purity proteins is resource-intensive since mechanical treatment of seeds, and large amounts of water are needed. Therefore, reducing the focus on high protein purity and using less processing steps could lead to a less resource-intensive protein extraction process. Therefore, this project aims to understand the structuring ability of pea protein mixtures in emulsion-based model soft food materials. The results show that to use pea proteins as emulsifying agents, no purification steps are necessary. The results show that by understanding and exploiting the natural interaction between proteins and proteins and starch, we can expand the structuring ability of plant protein mixtures.




## Highlights of the project

- Pea proteins at acidic pH (pH 3) form a mixture of protein particles and protein molecules
- From the mixture of protein particles and molecules, the protein molecules stabilize oil droplets, while protein particles are present in the bulk
- Pea proteins are able to stabilize high oil emulsions (jammed emulsions) without the aid of any additional emulsifiers.
- At pH 3, pea protein particles cross-link the jammed oil droplets to form elasto-plastic 3D printable material

## Type of student projects envisioned

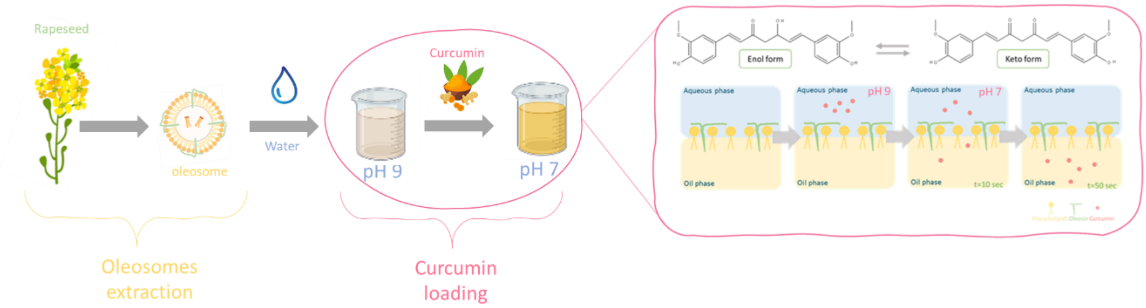
The project has been finalised

## Oleosoemes (Lipid Droplets) as Carriers of Therapeutics

**Name PhD/PD**: Umay Sevgi Vardar
**Involved staff members:** Costas Nikiforidis, Harry Bitter
**Project sponsor:** Republic of Turkey Ministry of Education
**Start/(expected) end date of project:** September 2019-September 2023

### Background and goal of project

Oleosomes (lipid droplets) are organelles aiming to store lipids and in genral hydrophobic molecules in oilseeds[1]. They can be extracted from oilseed and be used as carriers for hydrophobic therapeutics such as curcumin. Curcumin is a natural, bioactive molecule; however, its low water solubility decreases its bioavailability[2].




### Highlight of the past year

Curcumin was efficientlly loaded into oleosomes and the diffusion of curcumin into oleosomes was tracked by confocal microscopy. Effect of curcumin on oleosomes stability and digestibility was determined.

### Type of student projects envisioned

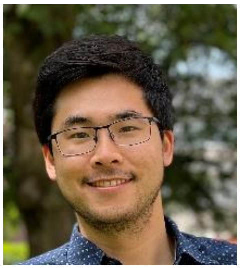
Available projects for students are included lab work, focusing on:

- Physicochemical stability of oleosome membrane
- Therapeutics release from oleosomes
- Food & Medical applications with oleosomes

For these projects, dynamic light scattering, spectroscopy, fluorescence and confocal microscopy will be extensively used.

1. Nikiforidis, C., 2019. Structure and functions of oleosomes (oil bodies), Advances in Colloid and Interface Science
2. Kharat, M., & McClements, D. J. (2019). Recent advances in colloidal delivery systems for nutraceuticals: A case study–Delivery by Design of curcumin. Journal of colloid and interface science, 557, 506-518.

Natural plant-based oil droplets as carriers of hydrophobic components



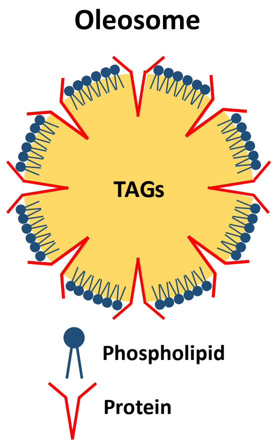
**Name**: Dr. Jack Yang
**Involved staff members:** Dr. Costas Nikiforidis
**Project sponsor:** Industry-funded
**Start/(expected) end date of project: 15-05-2021 – 14-05-2021**

## Background and goal of project

Encapsulating hydrophobic components (e.g. vitamins, flavour, or bioactive compounds) is crucial in many products, from foods to cosmetics to pharmaceuticals. We aim to encapsulate hydrophobic components using a solution provided by nature: oleosomes (also known as oil bodies or lipid droplets). Oleosomes are the oil storage organelles in plant seeds, and are abundantly present in oilseeds from sources such as sunflower seeds and soybeans. We possess the techniques to extract intact oleosomes as natural oil droplets. Many opportunities arise in the utilization of such droplets. In this study, we will explore how hydrophobic components can be encapsulated into oleosomes to produce natural plant-based carriers. In addition, we aim to understand the encapsulation mechanism and how this affects the physical and chemical stability of the oleosomes.

## Highlight of the past year

We were able to extract oleosomes from oil seeds using an easy and sustainable extraction method. Hydrophobic components could be incorporated in the oleosomes, but could lead to physical destabilization of the oleosomes depending on the encapsulation methodology. In the next steps, it is key to understand this destabilization to control the encapsulation mechanisms.



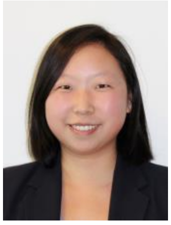

## Type of student projects envisioned

Thesis topics for this project will involve lab work. A few main research questions remain, such as:

1. How do the hydrophobic components impact the oleosome stability? Stability: resistance against rupture or droplet merging.
2. How does the oleosome membrane (outer layer) behave when in contact with a hydrophobic surface?

We aim to study these questions using machineries, such as drop tensiometry, atomic force microscopy (AFM) and confocal laser scanning microscopy (CLSM). Also, we aim to use molecular dynamics simulations to evaluate the experimental outcome.

## Modeling & Technology

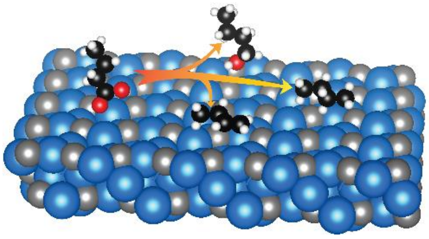
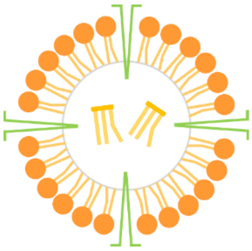
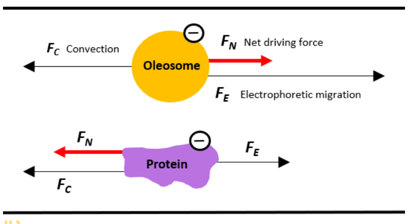
**Theme leader**: Guanna Li & Akbar Asadi Tashvigh

### Background and goal of this theme

Computational modeling has become an indispensable approach to investigate scientific questions in chemistry and related research areas. By simulation of the system at different time and space scales, It helps to get insights into the reaction processes and provide recipes for optimization or rational design of catalytic materials and reactions. With close collaboration with experimentalists, it is feasible to carry out cross-disciplinary research and realize knowledge exchange and utilization.

In the past year, we continued to apply quantum chemical modeling methodologies to investigate the reaction mechanism of heterogeneous catalytic biomass conversion and numerical simulations to study the mass and heat transfer in porous materials for electrocatalytic conversion of biomass. Meanwhile, new research lines were also opened up in the simulation of encapsulation and separation processes of biological membranes, and mechanisms of $CO_2$ adsorption and capture processes. All research topics have direct collaborations with the ongoing experimental projects of physical chemistry and catalysis/conversion themes.

For the coming period, the objectives are to further develop multiscale and operando modeling approaches to narrow the gap between models and real systems and to strengthen the reaction mechanism investigations of electrocatalytic systems.


### Main topics

- **Solid (electro)catalysts for biomass conversion**
  Development of kinetic models
  Investigation of diffusion in porous materials
- **Capture of $CO_2$ from air (Direct Air Capture, DAC)**
  Development of kinetic models
  Modeling condensation in micro- and mesopores
  Reactor/process design and heat integration
- **Mass transfer in biological membranes**
  Modeling of encapsulation process of bioactive compounds in lipid droplets
  Modeling of protein separations
- **Electro-conversion of biobased feeds into valuable platform chemicals**
  Development of model electrocatalyst for biomass conversion
- **Multiscale modeling of supported solid catalyst for biomass conversion**
  Investigation of the structure-reactivity relationships of metal carbide catalysts
  Development of operando modeling approaches

### Student projects envisioned

Thesis subjects are related to the research work of Ph.D. students and Postdocs in the Modeling & Technology theme or cooperation with the other BCT themes.

If you are interested in a thesis, please contact guanna.li@wur.nl or akbar.asaditashvigh@wur.nl to discuss specific details and possibilities.

Biocompatible and sensitive MRI sensors - Elucidating the complex contrast mechanisms of nanoparticles by synergy of experiment and modelling

**Name PhD:** M.P. (Merlin) Cotessat, MSc (BNT-BCT-ORC)
**Involved staff members:** dr. G. Li (BCT-ORC), dr. J.R. Krug (BNT);
prof.dr. A.H. Velders (BNT), prof.dr. J.T. Zuilhof (ORC)
**Project sponsor:** VLAG
**Start/(expected) end date of project:** October 2021/October 2025

## Background and goal of project

The aim of this PhD project is to adopt a dual approach to the development of next-generation contrast agents for magnetic resonance imaging (MRI) applications, by simultaneously experimenting on new promising transition metal-based nanoparticles as well as furthering a better understanding of their contrast-generating mechanisms with quantum chemistry computer modelization.

## Highlight of the past year

The project is still at its very beginning, so there are no specific highlights to showcase yet. Progress has however been done in the coordination of the experimental and computational parts of the project.

## Type of student projects envisioned

With the project being still in its first months, it is difficult to accurately forecast which kind of student projects would be adapted in the future. Nevertheless, the project is laying on three main pillars, which are chemical synthesis of the contrast agents, experimental MRI measurements, and quantum chemistry computer modelling; for this reason, student projects including any one or two of these three elements could be envisioned.

Spuramolecular Continueous Flow Catalysis

**Name PhD/PD**: Tunan Gao
**Involved staff members:** Guanna Li, Fedor Miloserdov, Han Zuilhof, Harry Bitter
**Project sponsor:** VLAG graduate school
**Start/(expected) end date of project:** 12/2019-12/2023

## Background and goal of project

In order to develop a catalysis system that combines the advantages of both homogeneous catalysis and heterogeneous catalysis, we propose to develop a novel flow catalytic system, that would benefit from the use of the unique structures of pillararenes as supramolecular hosts. First we are going to design a pillararene-based supramolecular host and a catalyst-linked guest that is strongly bound to host. Then the designed supramolecular host will be immobilized on a surface to capture the guest molecules with a homogeneous catalytic site on the tail. The non-covalent interaction between guest molecules (catalyst) and host molecules (pillararenes) will be used to prevent the catalyst from leaching. Because the non-covalent interaction is reversible, the deactivated catalyst can be removed and regenerated by specific stimulation treatments such as pH, salt, environment polarity, etc.

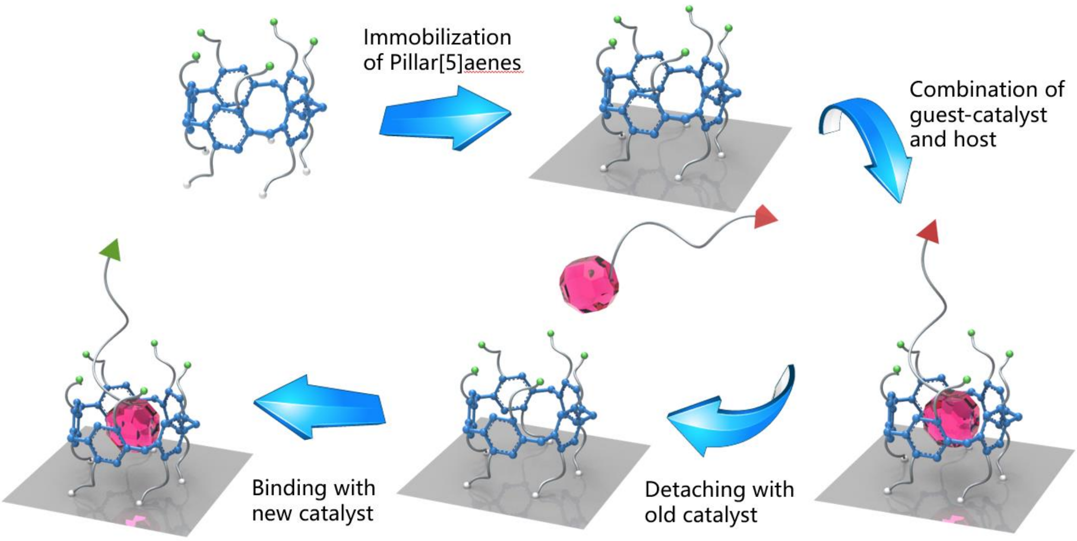



**Figure 1.** Schematic illustration of immobilization pillararenes on support and regeneration of deactivated catalysts with stimulations.

## Highlight of the past year

We successfully synthesized pillararenes with ten amino groups in the past year. At this stage we are going to test the binding between pillararenes and fluorinated pollutant--perfluorooctanesulfonic acid(PFOS) and Perfluorooctanoic acid(PFOA). Perfluorinated alkyl acid can be very useful in antifouling, but they are also becoming an emerging risks of our environment. Because the Perfluorinated pollutants accumulate over time in humans, and they are difficult to detact and remove from water body. Superisingly, this amino group-modified pillararenes show a high affinity to those perfluornatied pollutant. After the investigation of host-guest interaction, the pillararenes will be modified and immobilized on a silica plate by click reactions and surface modification for further applications.

## Type of student projects envisioned

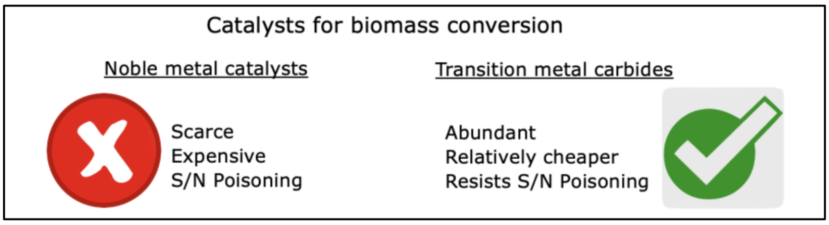
This project mainly involves lab work, specifically organic synthesis skills. Characterization like NMR, MS, UV-vis will be applied. Also some surface chemistry and supramolecular chemistry techniques like NMR titration, surface modification, will be needed in this project. Please contact tunan.gao@wur.nl or guanna.li@wur.nl if you are interested in doing a thesis related to these topics.

Multiscale modeling of the supported solid catalysts for biomass conversion

Name PhD/PD: Raghavendra Meena
Involved staff members: Prof. Harry Bitter, Prof. Han Zuilhof, Dr Guanna Li
Project sponsor: Sectorplan Chemistry and Physics
Start/(expected) end date of project: 01.10.2020/30.09.2024

**Background and goal of project**

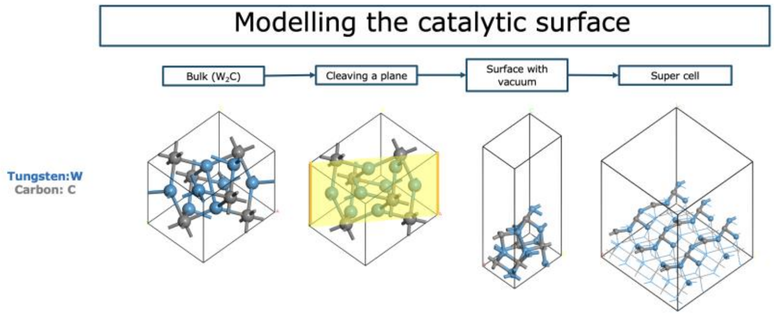
The depletion of fossil resources such as oil, coal and natural gas has initiated the search for renewable substitutes. Therefore, sustainable resources such as biomass for chemicals is emerging. To convert biomass to valuable chemicals, heterogeneous catalysts molybdenum- and tungsten-carbides are viable replacements of noble metal catalysts.




Experimentalists (in our group) found that these carbides remain active even after the interaction with S and N impurities present in the feedstock. While their catalytic activity is to some degree known, it is still not clear what the property-performance relationships are for these carbide-based catalysts. These fundamental understandings are of great importance for the optimization and rational design of metal carbide catalysts. Therefore, I am using the density functional theory (DFT) computational modeling approach to get insights into the nature of active sites and the complicated reaction mechanisms involved. By DFT calculations, we can address the originality of the activity and selectivity differences observed in the experiments.

**Highlight of the past year**

Koen Draijer (master's thesis student) and me studied HDO mechanism for the conversion of butyric acid to butane ($C_4H_8O_2 + 3{\cdot}H_2 \rightarrow C_4H_{10} + 2{\cdot}H_20$) on β-$Mo_2C$ and β-$W_2C$ catalysts. We modelled the catalytic surfaces as seen in the Figure below. One interesting outcome of the study shows the differences in the $H_2$ dissociative adsorption process. In case of β-$W_2C$ catalyst, each $H_2$ dissociates homolytically while for β-$Mo_2C$ catalyst $H_2$ dissociates heterolytically. At this stage, we are about to finish the HDO mechanism for both the catalysts. Finally, we would be able to comment on the feasibility of the reaction thermodynamically and kinetically.




**Type of student projects envisioned**

The nature of the projects is theoretical and computational. I offer short-term (3 months) projects in which a student can learn the basics of heterogeneous catalysis and DFT. I also offer a couple of long-term (6 months) projects in which students can deep dive into the research involved in the group. The two projects currently available are:

1) Studying the facet effect for HDO reaction mechanism on metal carbide catalysts.
2) Studying the HDO reaction mechanism on mixed metal carbides, e.g., MoWC.

If interested, please feel free to contact me (raghavendra.meena@wur.nl) or dr. Guanna Li (guanna.li@wur.nl) to schedule a talk.

## Education

**Bachelor and Master courses BCT and contribution to other courses**

| Code | Course title |
|---|---|
| BCT-10302 | Organic Chemistry BAT |
| BCT-10805 | Process Engineering Basics |
| BCT-20306 | Modelling Dynamic Systems |
| BCT-22803 | Physical Transport Phenomena |
| BCT-23306 | Biorefinery |
| BCT-23806 | Principles of Biobased Economy |
| BCT-24306 | Renewable Resources and the (Bio)Chemical Production of Industrial Chemicals |
| BCT-30806 | Physical Modelling |
| BCT-32306 | Advanced Biorefinery |
| BCT-33806 | Conversions in Biobased Sciences |
| BCT-34324 | Micromaster Biobased Sciences |
| BCT-34818 | Micromaster Biobased Chemistry |

| Code | Course title |
|---|---|
| BPE-12806 | Bioprocess Engineering Basics BT |
| BPE-60312 | Bioprocess Design |
| FTE-12803 | Introduction Biosystems Engineering part 2 |
| ORC-12803 | Organic Chemistry 1 |
| ORC-12903 | Organic Chemistry 2 |
| ORC-13803 | Bio-organic Chemistry for Life Sciences |
| PCC-33808 | From Molecule to Designer Material |
| PPH-31804 | Frontiers in Molecular Life Sciences |
| YWU-60312 | Research Master Cluster: Proposal Writing |

BCT: Biobased Chemistry and Technology
BPE: Bioprocess Engineering
FTE: Farm Technology
ORC: Organic Chemistry
PCC: Physical Chemistry and Soft Matter
PPH: Plant Physiology
YWU: Wageningen University

**BSc Theses**

- Reynierse, Wessel; Lipid droplets as carriers in biology and applications
- Giessen, Laurens van der; Microscopy techniques for oleosome research: A literature review
- Puiman, Jort; A kinetic model for electrocatalytic oxidation of glucose over polycrystalline platinum
- Dalen, Anne van; Depolymerization of sodium alginate - A first step towards the two-step conversion of sodium alginate to mannitol and sorbitol
- Broersen, Maurits; Economic evaluation of aqueous oleosome and protein extraction from Capsicum seeds

**MSc Theses**

- Lankveld, Mark van; The influence of surface oxygen groups on carbon nanofiber supported platinum electrocatalysts on the electrocatalytic oxidation of glucose
- Karaçoban,Freek; Insights into direct air capture of CO2 by honeycomb and RFPB reactors through multiscale modelling
- Vanderreydt, Valentine; CO2 utilisation for production of high-value chemicals
- Qu, Qiyang; The underlying mechanism of interface stabilization when using rapeseed protein mixtures as emulsifiers at pH 3.8
- Michalopoulou, Ourania; Anhydrous betaine separation from sugar beet molasses
- Kamphuis, Joris; Role of additive on physiochemical modifications of graphite
- Zuidema, Norwin; Reductive catalytic depolymerisation of wheat straw lignin with different pre-treatments
- Does, Wouter van der; Modelling and simulations of trickle-bed and honeycomb reactors for selective hydrogenation of stearic acid
- Yang, Alice; Characterization of cellulose obtained by zinc chloride hydrate pretreatment and valorization of cellulose by oxidation
- Boot, Michael; Catalytic hydrogenation of alginates for sugar alcohol synthesis
- Tjalsma, Tjalling; Two aspects towards specific starch oxidation: ozone oxidized CNF and methylation pretreatment method
- Draijer, Koen; DFT study of butyric acid hydrodeoxygenation on W2C(101) surface
- Ramachandran, Krishnakumar; Molybdenum carbides for biomass upgrading oxidative and reuse stability of catalyst during stearic acid hydrodeoxygenation
- Splunder, Hielke van; The encapsulation of cannabidiol in hemp seed- derived oleosomes. Towards biobased drug carriers
- Kuijsters, Kevin; The effect of ozone treating carbon nanofiber-supported platinum catalysts, on catalyst characteristics and glucose oxidation
- Schie, Sümeyye van; Fatty alcohols from stearic acid over Mo2C/CNF: Influence of temperature, stirring rate, and type of CNF; and the effect of upscaling on the environment
- Kleine, Gijs; Pre-treatment of substrates for selective starch oxidation
- Steller, Jos; Effect of S impurities on the catalytic performance of carbon supported molybdenum carbides during hydrodeoxygenation of stearic acid
- Zegers, Thijmen; The combined effect of anions and pH on the performance of electrocatalytic oxidation of glucose over polycrystalline platinum electrodes

- Rieffe, Melvin; Utilizing dry ball milling to develop graphitic bi-functional catalysts for carboxylation of epoxides
- Konings, Gijs; Effects of rapeseed oleosome membrane composition on curcumin encapsulation, oleosome stability, and digestibility
- Wisse, Sam; Trade-offs in a dual use of green manures between biobased industry and soil quality
- Gerritse, Jet; The *in vitro* fermentation of starch and galacto-oligosaccharides by the faecal microbiota of a 6-month-old infant
- Quadens, Mignon; Effect of amoxicillin on in vitro fermentation of resistant starch type 3 by the microbiota of 3- and 7-week-old piglets
- Ashok Kumar, Shanjana; Molecular simulations of nanoparticle dynamics for bio nanocomposits in food packaging
- Cao, Xueying; The structure of oil body emulsion with Tristearin and its effect on physicochemical properties and lipid digestibility
- Vogelaar, Thomas; Study on the formation of egg yolk HDL microparticles as a carrier for AuNPs using $Au^{3+}$ -ions as a crosslinker

**Scientific Publications 2021**

**Refereed article in a journal**

- Development of Thin-Film Composite Membranes for Nanofiltration at Extreme pH
Asadi Tashvigh, Akbar ; Elshof, Maria G. ; Benes, Nieck E. (2021)
*ACS Applied Polymer Materials 3 (11). - p. 5912 - 5919.*
- Catalytic Cooperation between a Copper Oxide Electrocatalyst and a Microbial Community for Microbial Electrosynthesis
Chatzipanagiotou, Konstantina Roxani ; Soekhoe, Virangni ; Jourdin, Ludovic ; Buisman, Cees J.N. ; Bitter, J.H. ; Strik, David P.B.T.B. (2021)
*ChemPlusChem 86 (5). - p. 763 - 777.*
- Gold and Silver-Catalyzed Reductive Amination of Aromatic Carboxylic Acids to Benzylic Amines
Coeck, Robin ; Meeprasert, Jittima ; Li, Guanna ; Altantzis, Thomas ; Bals, Sara ; Pidko, Evgeny A. ; Vos, Dirk E. De (2021)
*ACS Catalysis 11 (13). - p. 7672 - 7684.*
- Enhanced surface area and reduced pore collapse of methylated, imine-linked covalent organic frameworks
Dautzenberg, Ellen ; Lam, Milena ; Li, Guanna ; Smet, Louis C.P.M. de (2021)
*Nanoscale 13 (46). - p. 19446 - 19452.*
- Highly selective recovery of medium chain carboxylates from co-fermented organic wastes using anion exchange with carbon dioxide expanded methanol desorption
Fernando-Foncillas, Clara ; Cabrera-Rodríguez, Carlos I. ; Caparrós-Salvador, Francisco ; Varrone, Cristiano ; Straathof, Adrie J.J. (2021)
*Bioresource Technology 319 .*
- Alizarin Grafting onto Ultrasmall ZnO Nanoparticles : Mode of Binding, Stability, and Colorant Studies
Haan, Michel P. De; Balakrishnan, Naveen ; Kuzmyn, Andriy R. ; Li, Guanna ; Willemen, Hendra M. ; Seide, Gunnar ; Derksen, Goverdina C.H. ; Albada, Bauke ; Zuilhof, Han (2021)
*Langmuir 37 (4). - p. 1446 - 1455.*
- Unraveling the Nature of Extraframework Catalytic Ensembles in Zeolites : Flexibility and Dynamics of the Copper-Oxo Trimers in Mordenite
Khramenkova, Elena V. ; Medvedev, Michael G. ; Li, Guanna ; Pidko, Evgeny A. (2021)
*Journal of Physical Chemistry Letters 12 (44). - p. 10906 - 10913.*
- Digestibility of resistant starch type 3 is affected by crystal type, molecular weight and molecular weight distribution.
Klostermann, C.E. ; Buwalda, P.L. ; Leemhuis, H. ; Vos, P. de; Schols, H.A. ; Bitter, J.H. (2021)
*Carbohydrate Polymers 265 .*
- The influence of α-1,4-glucan substrates on 4,6-α-D-glucanotransferase reaction dynamics during isomalto/malto-polysaccharide synthesis
Klostermann, C.E. ; Zaal, P.H. van der; Schols, H.A. ; Buwalda, P.L. ; Bitter, J.H. (2021)
*International Journal of Biological Macromolecules 181 . - p. 762 - 768.*
- Distinct fermentation of human milk oligosaccharides 3-FL and LNT2 and GOS/inulin by infant gut microbiota and impact on adhesion of : Lactobacillus plantarum WCFS1 to gut epithelial cells
Kong, Chunli ; Akkerman, Renate ; Klostermann, Cynthia E. ; Beukema, Martin ; Oerlemans, Marjolein M.P. ; Schols, Henk A. ; Vos, Paul De (2021)
*Food & Function 12 (24). - p. 12513 - 12525.*
- Structure-Specific Fermentation of Galacto-Oligosaccharides, Isomalto-Oligosaccharides and Isomalto/Malto-Polysaccharides by Infant Fecal Microbiota and Impact on Dendritic Cell Cytokine Responses
Logtenberg, Madelon J. ; Akkerman, Renate ; Hobé, Rosan G. ; Donners, Kristel M.H. ; Leeuwen, Sander S. Van; Hermes, Gerben D.A. ; Haan, Bart J. de; Faas, Marijke M. ; Buwalda, Piet L. ; Zoetendal, Erwin G. ; Vos, Paul de; Schols, Henk A. (2021)
*Molecular Nutrition & Food Research 65 (16).*
- Effect of Support Surface Properties on CO2Capture from Air by Carbon-Supported Potassium Carbonate
Masoud, Nazila ; Bordanaba-Florit, Guillermo ; Haasterecht, Tomas Van; Bitter, Johannes Hendrik (2021)
*Industrial & Engineering Chemistry Research 60 (38). - p. 13749 - 13755.*

- Mechanistic investigation of benzene esterification by K2CO3/TiO2: the catalytic role of the multifunctional interface
  Meeprasert, Jittima ; Li, Guanna ; Pidko, Evgeny A. (2021)
  *Chemical Communications 57 (64). - p. 7890 - 7893.*
- Adsorption of rapeseed proteins at oil/water interfaces. Janus-like napins dominate the interface
  Ntone, Eleni ; Wesel, Tessa van; Sagis, Leonard M.C. ; Meinders, Marcel ; Bitter, Johannes H. ; Nikiforidis, Constantinos V. (2021)
  *Journal of Colloid and Interface Science 583 . - p. 459 - 469.*
- Set-membership parameter estimation based on Voronoi vertices
  Reyes Lastiri, D. ; Cappon, H.J. ; Keesman, K.J. (2021)
  *Environmental Modelling & Software 143 .*
- Au3+-Induced gel network formation of proteins
  Schijven, Laura M.I. ; Saggiomo, Vittorio ; Velders, Aldrik H. ; Bitter, Johannes H. ; Nikiforidis, Constantinos V. (2021)
  *Soft Matter 17 (42). - p. 9682 - 9688.*
- Divalent Ion Selectivity in Capacitive Deionization with Vanadium Hexacyanoferrate : Experiments and Quantum-Chemical Computations
  Singh, Kaustub ; Li, Guanna ; Lee, Juhan ; Zuilhof, Han ; Mehdi, Beata L. ; Zornitta, Rafael L. ; Smet, Louis C.P.M. de (2021)
  *Advanced Functional Materials 31 (41).*
- Structure-heat transport analysis of periodic open-cell foams to be used as catalyst carriers
  Sinn, Christoph ; Wentrup, Jonas ; Pesch, Georg R. ; Thöming, Jorg ; Kiewidt, Lars (2021)
  *Chemical Engineering Research & Design 166 . - p. 209 - 219.*
- Cyclic Voltammetry is Invasive on Microbial Electrosynthesis
  Smit, Sanne M. de; Buisman, Cees J.N. ; Bitter, Johannes H. ; Strik, David P.B.T.B. (2021)
  *ChemElectroChem 8 (17). - p. 3384 - 3396.*
- Jammed Emulsions with Adhesive Pea Protein Particles for Elastoplastic Edible 3D Printed Materials
  Sridharan, Simha ; Meinders, Marcel B.J. ; Sagis, Leonard M. ; Bitter, Johannes H. ; Nikiforidis, Constantinos V. (2021)
  *Advanced Functional Materials 31 (45).*
- Phosphorus Induced Electron Localization of Single Iron Sites for Boosted CO2 Electroreduction Reaction
  Sun, Xiaohui ; Tuo, Yongxiao ; Ye, Chenliang ; Chen, Chen ; Lu, Qing ; Li, Guanna ; Jiang, Peng ; Chen, Shenghua ; Zhu, Peng ; Ma, Ming ; Zhang, Jun ; Bitter, Johannes H. ; Wang, Dingsheng ; Li, Yadong (2021)
  *Angewandte Chemie-International Edition 60 (44). - p. 23614 - 23618.*
- Digestion, fermentation, and pathogen anti-adhesive properties of the hMO-mimic di-fucosyl-ß-cyclodextrin
  Verkhnyatskaya, Stella A. ; Kong, Chunli ; Klostermann, Cynthia E. ; Schols, Henk A. ; Vos, Paul De; Walvoort, Marthe T.C. (2021)
  *Food & Function 12 (11). - p. 5018 - 5026.*
- Interfacial behavior of plant proteins — novel sources and extraction methods
  Yang, Jack ; Sagis, Leonard M.C. (2021)
  *Current Opinion in Colloid and Interface Science 56 .*
- Air-water interfacial behaviour of whey protein and rapeseed oleosome mixtures
  Yang, Jack ; Waardenburg, Leonie C. ; Berton-Carabin, Claire C. ; Nikiforidis, Constantinos V. ; Linden, Erik van der; Sagis, Leonard M.C. (2021)
  *Journal of Colloid and Interface Science 602 . - p. 207 - 221.*
- Air-water interfacial and foaming properties of whey protein - sinapic acid mixtures
  Yang, Jack ; Lamochi Roozalipour, Sarah P. ; Berton-Carabin, Claire C. ; Nikiforidis, Constantinos V. ; Linden, Erik van der; Sagis, Leonard M.C. (2021)
  *Food Hydrocolloids 112 .*
- Foams and air-water interfaces stabilised by mildly purified rapeseed proteins after defatting
  Yang, Jack ; Faber, Iris ; Berton-Carabin, Claire C. ; Nikiforidis, Constantinos V. ; Linden, Erik van der; Sagis, Leonard M.C. (2021)
  *Food Hydrocolloids 112 .*

**Refereed book chapters**

- Metal containing nanoclusters in zeolites
  Li, G. ; Pidko, Evgeny A. (2021)
  *In: Reference Module in Chemistry, Molecular Sciences and Chemical Engineering Elsevier,*

**PhD Theses**

- Versatile ingredients from rapeseeds for structuring plant-based soft materials
  Ntone, Eleni (2021)
  *Wageningen University. Promotor(en): J.H. Bitter, co-promotor(en): K. Nikiforidis; L.M.C. Sagis. - Wageningen : Wageningen University, - 194*
- Pea protein mixtures as structuring agent in edible soft materials
  Sridharan, Lakshminarasimhan (2021)
  *Wageningen University. Promotor(en): J.H. Bitter, co-promotor(en): C.V. Nikiforidis; M.B.J. Meinders. - Wageningen : Wageningen University, - 176*
- Rethinking plant protein extraction : interfacial and foaming properties of mildly derived plant protein extracts
  Yang, Jack (2021)
  *Wageningen University. Promotor(en): L.M.C. Sagis, co-promotor(en): C.C. Berton-Carabin; K. Nikiforidis; E. van der Linden. - Wageningen : Wageningen University, - 210*

## Other output

### Orals contributed

The release of lipids from lipid droplets
Eleni Ntone, 2nd International Conference on Lipid droplets and Oleosomes, Strasbourg, France, 2/12/2021 - 3/12/2021

An interplay between oleosomes and proteins at the air-water interface
Jack Yang, 2nd internation conference on lipid droplets and oleosomes, Strasbourg, France, 2/12/2021 - 3/12/21

Wolfram schittert niet alleen in een gloeilamp maar ook als katalysator
Marlene Führer, KNCV Avond van de chemie 2021, Eindhoven, Netherlands, 14/10/2021

Resistant starch type 3: a bioactive ingredient
Cynthia Klostermann, 7th EPNOE conference, Nantes, France, 11/10/2021 - 15/10/2021

Effect of support oxygen groups on the performance of supported electrocatalysts
Matthijs van der Ham, 240th ECS Meeting, Orlando, United States, 10/10/2021 - 14/10/2021

CO2 conversion by combining a Cu electrocatalyst and microorganisms
Roxani Chatzipanagiotou, 5th European Meeting of the International Society for Microbial Electrochemistry and Technology (ISMET), Girona, Spain, 13/09/2021 - 15/09/2021

3D printing of plant based jammed emulsions
Lakshminarasimhan Sridharan, 95th ACS Colloid and Surface Science Symposium, 14/06/2021 - 16/06/2021

The potential of oleosomes in food products
Eleni Ntone, Virtual Research Conference Plant-Based Foods & Proteins Europe 2021, 20/05/2021 - 21/05/2021

Resistant starch type 3: a healthy food ingredient
Cynthia Klostermann, Starch Convention 2021, Detmold, Germany, 20/04/2021 - 22/04/2021

Lipid droplets as carriers of lipids
Eleni Ntone, 1st Young Scientist Symposium on Lipid droplet/oleosome conference, 4/03/2021

Effect of support oxygen groups on the performance of supported electrocatalysts
Matthijs van der Ham, NCCC The Netherlands' Catalysis and Chemistry Conference (2021), Noordwijkerhout, Netherlands, 1/03/2021

### Poster presentations

'Are micelles actually at the interface in micellar casein stabilized foam and emulsions?'
Zhou, X.; Yang, J.; Sagis, L.M.C.; Sala, G., 35th EFFoST International Conference 2021, Lausanne, Switzerland, 1/11/2021 – 4/11/2021

'Rethinking plant protein extraction: Plant albumins - from waste stream to excellent foaming ingredient'
Yang, J.; Kornet, C.; Diedericks, C.F.; Yang, Q.; Berton-Carabin, C.C.; Nikiforidis, K.; Venema, P.; van der Linden, E.; Sagis, L.M.C., 35th EFFoST International Conference 2021, Lausanne, Switzerland, 1/11/2021 – 4/11/2021

'Lipid droplets (oleosomes) as carriers of curcumin'
Vardar-Kule, U.; Bitter, J.H.; Nikiforidis, K., 2nd International Conference on Lipid droplets and Oleosomes, Strasbourg, France, 2/12/2021 - 3/12/2021

‘Preparation of Au-protein microparticles with a tunable core density’
Schijven, L.M.I.; Saggiomo, V.; Velders, A.H.; Bitter, J.H.; Nikiforidis, K., 2nd International Conference on Lipid droplets and Oleosomes, Strasbourg, France, 2/12/2021 - 3/12/2021

‘Effect of thermal processing on the encapsulation of cannabidiol in hempseed oleosomes’
Ma, Z.; Boom, R.M.; Bitter, J.H.; Nikiforidis, K., 2nd International Conference on Lipid droplets and Oleosomes, Strasbourg, France, 2/12/2021 - 3/12/2021

‘Specific resistant starch type 3: a bioactive ingredient’
Klostermann, C.E.; Silva Lagos, L.; de Vos, Paul; Bitter, J.H.; Schols, H.A., 7th EPNOE conference , Nantes, France, 11/10/2021 – 15/10/2021

‘Explore to produce a dairy fat globules alternatives by oleosomes from capsicum seeds’
Han, M.; Boom, R.M.; Nikiforidis, K., 2nd International Conference on Lipid droplets and Oleosomes, Strasbourg, France, 2/12/2021 - 3/12/2021

‘Electrochemical conversion of acid hydrolysis products derived from sugars’
Bisselink, R.J.M.; van Haveren, J.; Thiyagarajan, S.; Bitter, J.H., 12th European symposium on Electrochemical Engineering, Leeuwarden, 14/06/2021 – 17/06/2021

‘Electrophoreticrecovery of oleosomes and proteins from rapeseed’
Ayan, K.; Boom, R.M.; Nikiforidis, K., 2nd International Conference on Lipid droplets and Oleosomes, Strasbourg, France, 2/12/2021 - 3/12/2021

**Press/Media**

The future on a plate: A 3D printed burger?
Resource jrg. 16 nr. 7 p. 12-14
https://edepot.wur.nl/559583
Martijn Noort & Costas Nikiforidis
2/12/21

Miscanthus as the new petroleum?
Kennis Online Magazine
https://magazines.wur.nl/ko-magazine-2021-en/fossil-free/
Harry Bitter
1/09/21

Catalysis: key for sustainable production
Bioplastics Magazine
https://www.bioplasticsmagazine.de/202104/flipbook_04-2021.html
Harry Bitter
31/08/21

Mission Fossil Free
Wageningen University & Research
https://edepot.wur.nl/556197
Luisa Trindade, Harriette Bos, Harry Bitter & Siet Sijtsema
30/08/21

Innovation in education ... thanks to Covid
Resource jrg. 15 nr. 15 p. 20-21
https://edepot.wur.nl/546126
Arjen Wals, Bauke Albada, Harry Bitter & Han Zuilhof
15/04/21

Leading role for electricity in reducing petroleum use
Linkedin
https://www.linkedin.com/posts/wageningenuniversity_leading-role-for-electricity-in-reducing-activity-6767392065690112001-Utix
Harry Bitter & Jacco van Haveren
28/02/21

Makkelijker proces voor het maken van biobased materialen
Innovation Origins
https://innovationorigins.com/nl/makkelijker-proces-voor-het-maken-van-biobased-materialen/
Harry Bitter
7/02/21

Bouwstenen voor een biobased toekomst
Wageningen University & Research
https://www.wur.nl/nl/nieuws-wur/Show/Bouwstenen-voor-een-biobased-toekomst.htm
Harry Bitter
3/02/21

**Prizes**

Runner up Spotlight prize KNCV Avond van de Chemie 2021
Führer, Marlene (Recipient)
Granting Organisation: Dutch Society of Chemistry (KNCV)
KNCV Avond van de Chemie, Eindhoven, Netherlands, 14/10/2021