Sustainable Building Blocks for an Ambitious Chemical Sector

ARC CBBC Annual Report 2018

Advanced Research Center
Chemical Building Blocks Consortium

Table of Contents

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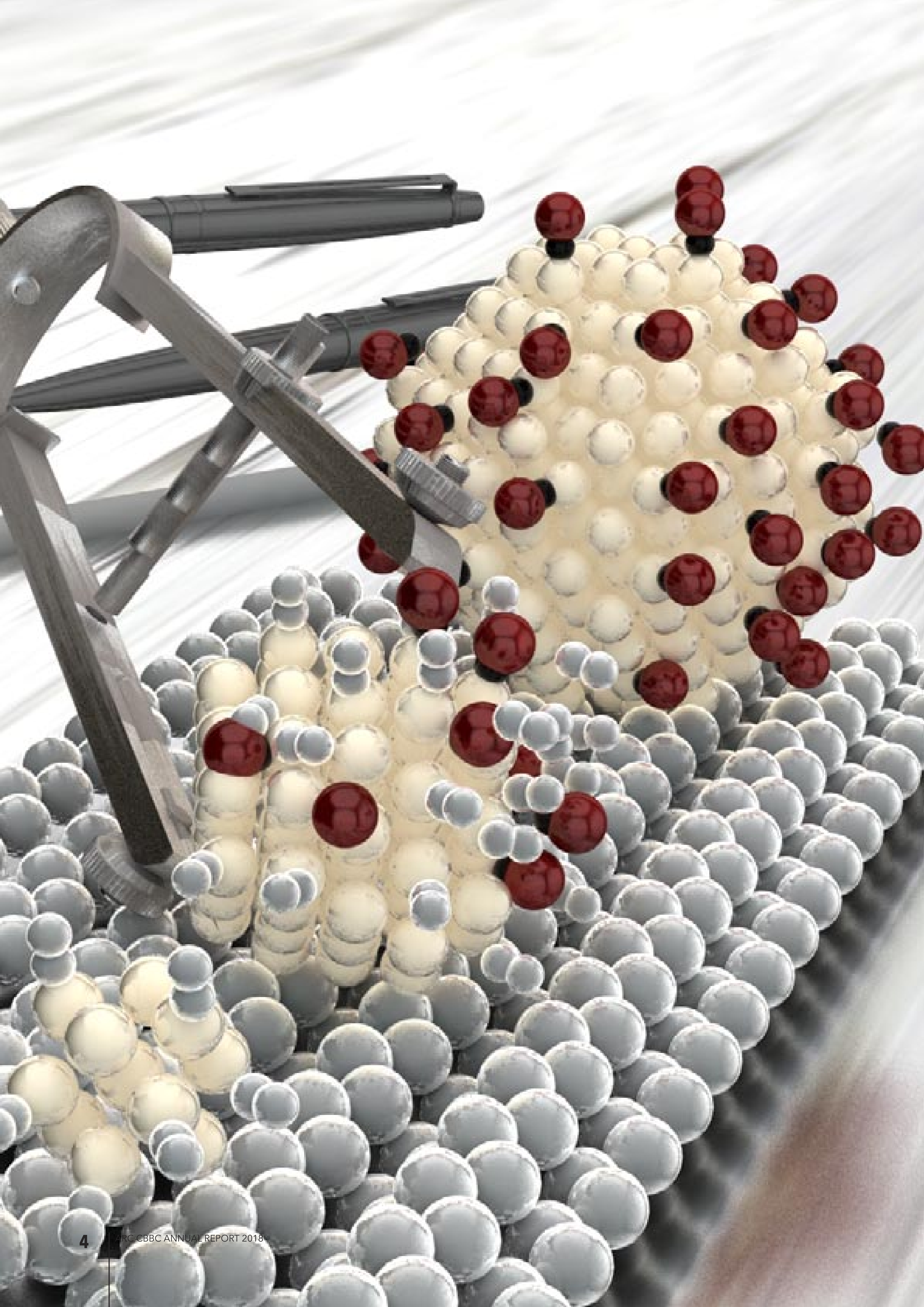
Foreword

The 2018 Dutch climate agreement speaks ambition. The Netherlands want to emit 49% less greenhouse gases in 2030 and structurally 95% less in 2050, compared to the starting year 1990. These are serious targets knowing that every citizen is responsible for the emission of about ten tons of CO_2 per year.

It is already clear that the industry is facing a tremendous challenge: the technologies required are, in part, still to be invented and for the existing ones, there is still a need to scale-up, implement and develop revenue models. The industry will have to come up with actions that actually lead to a reduction of their CO_2 footprint. Will they capture large amounts of CO_2 from the air and chemically convert it into commercially-viable carbon-based products? Will renewable electricity help to run large-scale chemical reactions? Nobody can tell us by looking into a crystal ball, but certainly our chemical manufacturing processes will look different in 30 years.

In ARC CBBC, public and private parties have found each other in the challenge to decrease the CO_2 footprint of the chemical industry. Together, we stand for decisive strategic choices: we explicitly want to pursue research that will impact science, industry and society, strengthening the knowledge position and competitiveness of the Netherlands. We are happy to have started our first three flagship projects. We are developing paint from bio-waste and catalysts that will directly lower the energy need of the chemical industry. Furthermore, we will activate small molecules, such as methane and CO_2, that can replace for example crude oil. Given the large scale of these three applications, they have the potential to contribute significantly to the climate ambitions for 2050.

Bert Weckhuysen, scientific director ARC CBBC



Vision and Ambition

Vision

To be able to safeguard human prosperity around the globe, we will need to treat the Earth's material and energy resources wisely. Chemistry is a key scientific discipline to become a more sustainable civilisation.

Ambition

The national research consortium ARC CBBC contributes to a greener chemical industry. We want to investigate and design the chemical building blocks that will make industrial production processes more sustainable and less dependent on non-renewable energy and materials use. New chemical processes should make use of electrons and photons to diminish non-renewable energy consumption and should allow renewable materials to substitute fossil feedstock. Carbon dioxide should change from a waste-product into a valuable resource to produce chemicals. Smart functional materials will replace and enhance traditional materials and devices.

Programme

ARC CBBC conducts fundamental research on sustainable energy and materials. Our scientific programme covers the three research themes Fundamentals of Catalysis, Small Molecule Activation, and Coatings & Functional Materials. We are convinced that these fields of research will help to mitigate the chemical industry's energy and materials use and carbon footprint.

Key challenges

One of our key challenges is the development of so-called carbon capture and utilization, or CCU routes, in which CO_2 is no longer considered a waste product, but can be regarded a renewable carbon source to make energy carriers and chemicals. Furthermore, the design of better performing coatings and materials will enable us to explore energy- and resource-saving opportunities. Subsequently, we want to start using photons and electrons as energy sources for the chemical industry, and to enable currently low-value renewable materials to become resources for base chemicals in future chemical manufacturing plants.

Multilateral and bilateral research projects

Each of the three research themes contains one multilateral project and a number of bilateral research projects.

The multilateral research projects address long-term joint scientific interests of several public and private partners. They give private partners the opportunity to collaborate with a multidisciplinary group of selected academic researchers, aiming to provide new knowledge and increase our fundamental understanding with long-term application perspectives. A multilateral research project typically consists of six to eight PhD or PD positions, also referred to as subprojects because of their wide range of research.

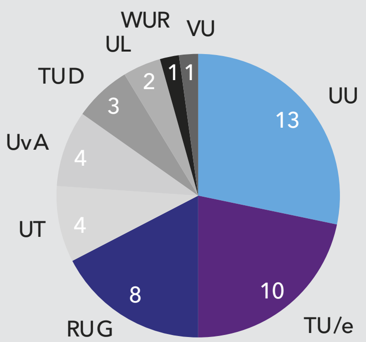
Within each bilateral research project, one of the full private partners cooperates with one or more of the selected academic researchers. Only partners who are directly involved in a particular project, have access to the results. Each bilateral research project includes one or more PhD/PD positions.

Facts and Figures

Research positions (January 2019)

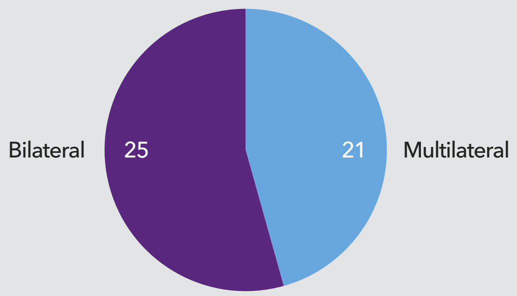
Positions allocated per university

All universities in the consortium were able to host research positions. The larger part was allocated to our hub universities in Utrecht (UU), Eindhoven (TU/e) and Groningen (RUG).



Positions in multilateral versus bilateral projects

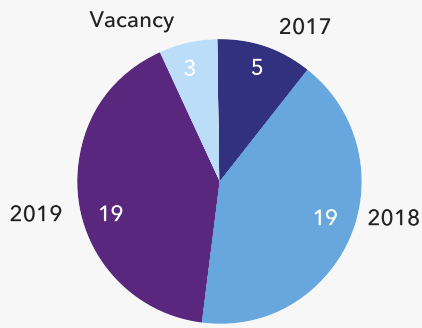
Each multilateral project is of interest to several private partners; a bilateral project is related to one private partner. The number of research positions in both types of projects are in balance.



Young researchers recruited

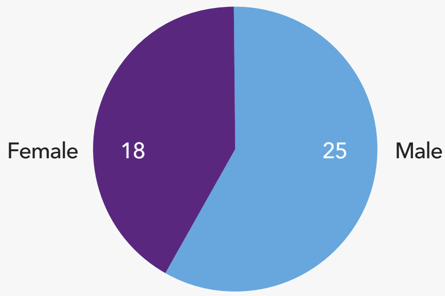
Fulfilled positions

We have been able to fulfill many of our PhD and postdoc positions. Only 6.5% is still vacant.



Male and female researchers

The share of women in our group of young researchers grew to just over 40%.



Fundamentals of Catalysis

Aims

ARC CBBC wants to contribute to the rejuvenation of the chemical industry, mitigation of its energy use as well as the sustainable improvement of feedstock use in the chemical industry by exploring novel chemical conversion pathways for the production of basic and fine chemicals and fuels.

Heterogeneous catalysts are among the most important industrial catalysts. The research groups and the chemical industry in the Netherlands have a particularly advanced position in the development such heterogeneous catalysts. Modeling and process technology are key to the development and use of new chemical building blocks and to innovations in catalytic conversions. These include monitoring the related process-dedicated advanced characterization and reaction.

Impact

The development of catalysts can be regarded as a strategic and high added-value market in itself. More importantly the development of novel catalyst materials is enabling for impact on the feedstock-, energy- and conversion-related improvement of the chemical industry.

In this way, the multidisciplinary approach of ARC CBBC is expected to be at the forefront of world-wide innovation of the chemical industry. Furthermore, many of the proposed synthesis and characterization methods may impact other fields, including functional materials, such as responsive coatings. The generic knowledge and expertise created within this ARC CBBC research theme will lead to scientific and technological developments.

Research

Within a total of thirteen projects on Fundamentals of Catalysis, fourteen PhD candidates and postdoctoral research positions have currently been funded.

Multilateral project

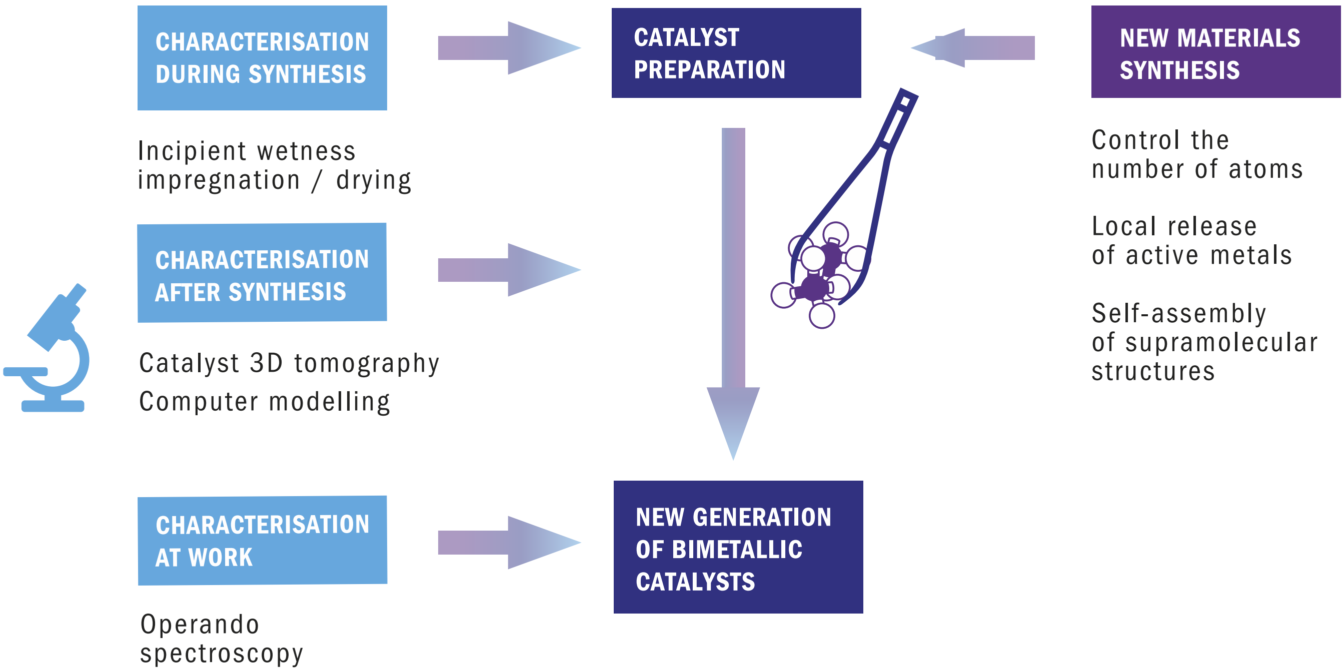
Ultimate control over nanoparticle structure, composition, size, and location in supported bimetallic catalysts

Multilateral project 2018.016.C

Project leader: **Bert Weckhuysen** (Utrecht University)
Project manager: **Robert Terörde** (BASF)

Current and future energy and chemical industries will rely on a portfolio of highly active, selective and stable catalyst materials. Bimetallic catalysts are interesting because the presence of a second metal can add a wide range of additional functionalities to the catalytic surface, usually bringing about synergies in catalysis, which can lead to fundamentally different catalytic performance, in turn leading to a higher yield and less by-products. Such extraordinary performance also allows to partially replace expensive noble metals by base metals. In addition, the concept of bimetallic catalysis allows small amounts of expensive metal to be dispersed at atomic scale in a metallic environment, leading to a more efficient use of that metal.

The aim is to dominate the chemical composition, structure and performance of bimetallic supported catalysts stronger than ever before. With our multidisciplinary approach, we are bringing together distinctly different fields of expertise. Furthermore, we are providing catalyst materials as well as catalyst-reactor combinations which will be of interest in e.g. small



molecule activation programs within ARC CBBC. In particularly, the catalytic CO_2 conversion is of high interest.

Catalyst synthesis studied in real-time with spatially-resolved TEM and EDX

Multilateral subproject 2018.016.C.UU.1

The contribution of this project is to provide fundamental understanding of impregnation, drying and reduction of various metal solutions on porous supports, such as mesoporous silica. Detailed insights will be obtained about where and what is located within the catalyst grain and how redistribution effects are influenced by various synthesis parameters. We will do this with the use of of advanced STEM-EDX, preferably in 3D. The catalyst materials will be tested in two reaction pathways: the selective hydrogenation of cinnamaldehyde and the catalytic conversion of CO_2.

Principal investigator: Krijn de Jong (Utrecht University)
PhD candidate: *Vacancy* (Utrecht University)

Active phase genesis in supported bimetallic nanoparticle catalysts: following drying, calcination and reduction in real-time with surface-sensitive spectroscopy

Multilateral subproject 2018.016.C.TU/e.2

This project is generating a detailed understanding of the preparation, activation and, specifically, the bulk and surface composition of bimetallic catalysts for the hydrogenation of CO_2. The catalysts consist of palladium, supported by cobalt, nickel or copper. Our main goal is to correlate the surface composition of the activated (*i.e.* reduced) bimetallic catalysts to catalytic performance. Complementary studies focus on high-pressure CO_2 hydrogenation and the selective hydrogenation of substituted aromatics.

Principal investigator: Emiel Hensen (Eindhoven University of Technology)
PhD candidate: Rim van de Poll (Eindhoven University of Technology)

Catalyst preparation modeling: flow, diffusion and adsorption

Multilateral subproject 2018.016.C.TU/e.3

An advanced 3D model of the catalyst preparation process will be built. With the use of computational fluid dynamics, the fluid flow of the imbibition process as well as the transport and adsorption of metal species will be modelled. We will use realistic porous structures obtained from X-ray micro-tomography scans to generate the computational meshes. For the drying stage, transport of heat, evaporation and species transport will also be considered. The final model will be validated using the experimental data generated by the other sub-projects.

Principal investigator: **Hans Kuipers** (Eindhoven University of Technology)
PhD candidate: **David Rieder** (Eindhoven University of Technology)

Characterization of bimetallic catalysts: size, structure and composition during synthesis and at work

Multilateral subproject 2018.016.C.UU.4

We aim to develop and exploit (novel) characterization tools to determine the size, structure and composition of bimetallic clusters on inorganic oxides, such as SiO_2, Al_2O_3 and TiO_2, during their impregnation, drying, calcination and reduction as well as their catalytic action. For the latter aspect, two catalytic reactions will be employed. On the one hand, we will explore the liquid-phase hydrogenation/hydrodeoxygenation of guaiacol with H2 and related substituted phenolics. On the other hand, we will investigate the gas-phase and liquid-phase hydrogenation of CO_2 with H_2.

Principal investigator: **Bert Weckhuysen** (Utrecht University)
PhD candidate: **Florian Zand** (Utrecht University)

Nanosphere complex-mediated synthesis of bimetallic particles

Multilateral subproject 2018.016.C.UvA.5

We are focusing on unconventional routes for the synthesis of supported bimetallic catalysts. The proposed research involves the use of (supra)molecular organometallic complexes as precursors to heterogeneous catalysts. The idea is to use large catalyst precursors in the form of self-assembled molecular spheres that bring together a distinct number of metal ions in a confined space. Subsequent controlled reduction then leads to the formation of ultra-small metal nanoparticles with exactly equal atomic size, extreme size homogeneity and a metal composition that can be controlled by the choice of ligands. The final goal is to explore these methods for the controlled synthesis of supported bimetallic nanoparticles using Pd and Ni.

Principal investigator: **Joost Reek** (University of Amsterdam)
PhD candidate: **Lotte Metz** (University of Amsterdam)

Light-responsive ligands controlling bimetallic catalyst formation

Multilateral subproject 2018.016.C.UT.6

Ultimately, we will aim for the light-controlled precision synthesis of catalytic particles. In this approach, light will be used as a manipulation tool for the release of metal ions to achieve control in space and time. We want to synthesize bimetallic catalysts by using smart photo-responsive ligands. The core strategy is based on using photo-responsive switches (spiropyrans) that will be tethered to either Pd nanoparticles, or to Pd-Ni nanoparticles. First, we will explore this method to control the composition of bimetallic particles. Next, we will build in anti-sintering features by photo-controlled formation of a silica shell with adjustable porosity. Irradiation with light will allow us to capture metal ions in a controlled fashion.

Principal investigator: **Nathalie Katsonis** (University of Twente)
PhD candidate: **Hasnaa El Said El Sayed** (University of Twente)

Binary supraparticles: using self-assembly to control the supramolecular structure in bimetallic catalysts

Multilateral subproject 2018.016.UU.7

This project focuses on the ability of two types of metal nanoparticles of a particular size ratio to self-assemble into binary supraparticles (SP) that are suitable catalysts for e.g. the catalytic reduction of CO_2. The intended SP are expected to require morphological modifications, such as the controlled introduction of enhanced porosity as well as reduction of the metal oxides to the active metals. The proposed synthesis approaches will focus on new nanoparticle (NP) systems composed of palladium and nickel in combination with silica.

Principal investigator: **Alfons van Blaaderen** (Utrecht University)
PhD candidate: **Kelly Brouwer** (Utrecht University)

Methanol as feedstock for sustainable polymers

Sophie van Vreeswijk
(Utrecht University)

"Currently, plastics are primarily made from crude oil. The cracking process required to prepare the base chemicals ethylene and propylene from crude oil takes up a lot of energy. Instead, we want to use small molecules of methanol as a base feedstock.

The catalyst for the reaction in which methanol is converted into ethylene and propylene is a zeolite. The reactions take place within the tiny zeolite pores. The type of product that appear, depends on the size and shape of the pores. In my PhD research, I am focusing on the optimisation of the process with the least possible amount of side products."

Bilateral projects

Apart from the multilateral projects, there are six bilateral projects and seven PhD/PD positions within the research theme of Fundamentals of Catalysis.

Fundamentals of reduction of Ni-based catalysts

Bilateral project 2016.005.UU

During catalyst preparation, is it aimed to develop stable and highly dispersed grains of the active metal.The reduction of these catalysts is a vital step in the catalyst preparation as it determines the dispersion and thereby activity. This project focuses on insights into the reduction mechanisms of nickel catalysts. In that respect, it is vital to study the evolution of the active phases of typical catalysts with a combination of complementary techniques. Along with the understanding thus generated, the project aims at improving the synthesis of current catalysts by influencing the reduction processes and beyond that leading to new and improved catalyst properties.

Principal investigator: **Krijn de Jong** (Utrecht University)
Project manager: **Bennie Reesink** (BASF)
PhD candidate: **Savannah Turner** (Utrecht University)

Unravelling structure sensitivity in CO_2 hydrogenation over nickel

Bilateral project 2016.006.UU

Controlling mechanisms, activity and selectivity of hydrogenation catalysis over supported nickel catalysts can be a means for CO_2 emission abatement. We want to study catalytic properties that vary with the structure sensitivity - the phenomenon in which not all surface atoms in a supported metal catalyst have the same activity as it can assist in the rational design of heterogeneous catalysts. By making use of advanced characterization methods and well-defined silica-supported nickel clusters ranging from one atom to about ten nm nanoparticles, we wish to investigate how structure sensitivity influences hydrogenation catalysis. With reduction as a showcase, these findings may also bring new understanding in the adsorption of selective reactants like H_2 and olefins.

Principal investigator: **Bert Weckhuysen** (Utrecht University)
Project manager: **Peter Berben** (BASF)
Postdoctoral researcher: **Matteo Monai** (Utrecht University)

Exploration of non-commodity zeolite frameworks for small molecule activation: acidity, reactivity and coke formation

Bilateral project 2016.007.TUD and 2016.007.UU

Zeolites are widely used solid catalysts. Although more than 235 zeolite frameworks are known, almost all zeolite-based catalytic processes are performed by a few of these frameworks. In this research project, several non-commodity zeolite framework structures are investigated as examples of small molecule activation processes. To gather detailed physicochemical insights of these materials, a wide variety of bulk and local characterization methods will be used, while their performance is studied in the methanol-to-olefins (MTO) process as a showcase. The latter allows making comparisons with current MTO catalysts.

Principal investigator: **Freek Kapteijn** (Delft University of Technology)
Bert Weckhuysen (Utrecht University)
Project manager: **Lukasz Karwacki** (BASF)
PhD candidates: **Chuncheng Liu** (Delft University of Technology)
Sophie van Vreeswijk (Utrecht University)

Development of new catalytic technologies for industrial waste water treatment

Bilateral project 2018.009.B.TU/e.1

With growing environmental awareness and water becoming a scarce resource in certain parts of the world, the demand for water treatment will grow considerably in the future. The treatment of waste water effluents containing biological treatment resistant chemicals (*e.g.* aromatic compounds, pharmaceuticals) is a very important topic for the chemical industry. The researchers in this project are developing new catalytic approaches to treat waste water, thus reducing the environmental burden of chemical processes.

Principal investigator: **Emiel Hensen** (Eindhoven University of Technology)
Project manager: **Karin Walter** (Nouryon)
Postdoctoral researcher: **Alexander Parastaev** (Eindhoven University of Technology)

Reactor technology for reduction of metal oxide catalysts

Bilateral project 2018.011.B.TU/e.1

The final step in the manufacturing process of industrial catalysts involves the reduction of the metal oxides of cobalt, nickel or copper, using hydrogen. This is a complex process that involves transient particle-scale and reactor-scale transportation and chemical reactions. In this project, multi-scale reactor models will be developed and experimentally validated using data from pilot scale reduction reactors. The validated model will be used to assess the optimal reaction conditions for the reduction of metal (nickel) oxides with hydrogen in fixed bed catalytic reactors.

Principal investigator:	**Hans Kuipers** (Eindhoven University of Technology)
Project manager:	**Robert Terörde** (BASF)
Postdoctoral researcher:	**Jiangtao Lu** (Eindhoven University of Technology)

In silico design of chemicals and their properties

Bilateral project 2018.019.B.VU.1

We aim at developing a computational toolbox for quickly developing efficient chemicals. The toolbox consists of a large set of consistent thermochemical and structural data as well as physical models that allow for rational design.

Principal investigator:	**Matthias Bickelhaupt** (VU Amsterdam)
Project manager:	**Martijn van der Schuur** (Nouryon)
PhD candidate:	**Eva Blokker** (VU Amsterdam)

Small Molecule Activation

Aims

Ultimately, we want to enable a transition from crude oil-based chemicals to a complete circular economy by moving to CO_2 as feedstock. To make this happen our fundamental knowledge on small molecule activation has to be increased. Using methane as chemical feedstock can be regarded as an important intermediate step in the transition from oil-based chemicals to (ultimately) a complete circular economy where CO_2 is regarded as a resource instead of a waste.

Impact

Chemicals will remain a crucial part of an affluent society. Using methane instead of crude oil as feedstock may have tremendous potential. The fact that methane is more hydrogen rich than crude oil would potentially reduce CO_2 emissions and penalties. Apart from that, as an energy source, methane will be slowly replaced by renewable energy and will thus become cheaper.

Industrially relevant direct methane conversion can have tremendous impact. It is also a credible business proposition for private investments, as the transition could possibly build on the desire to find alternative substantially-sized outlets for natural gas outside of energy production. Future crude oil-less manufacturing of important bulk chemicals (*e.g.* lower olefins) is in agreement with the roadmap of the chemical industry and, on top of that, the market for catalysts enabling such a transition could proof an interesting proposition in itself.

Research

Within a total of six projects on Small Molecule Activation, seventeen research positions have currently been allocated.

Multilateral project

Pyrolytic upgrading of methane to ethylene, aromatics and carbon materials 2018.017.C

Multilateral project 2018.017.C

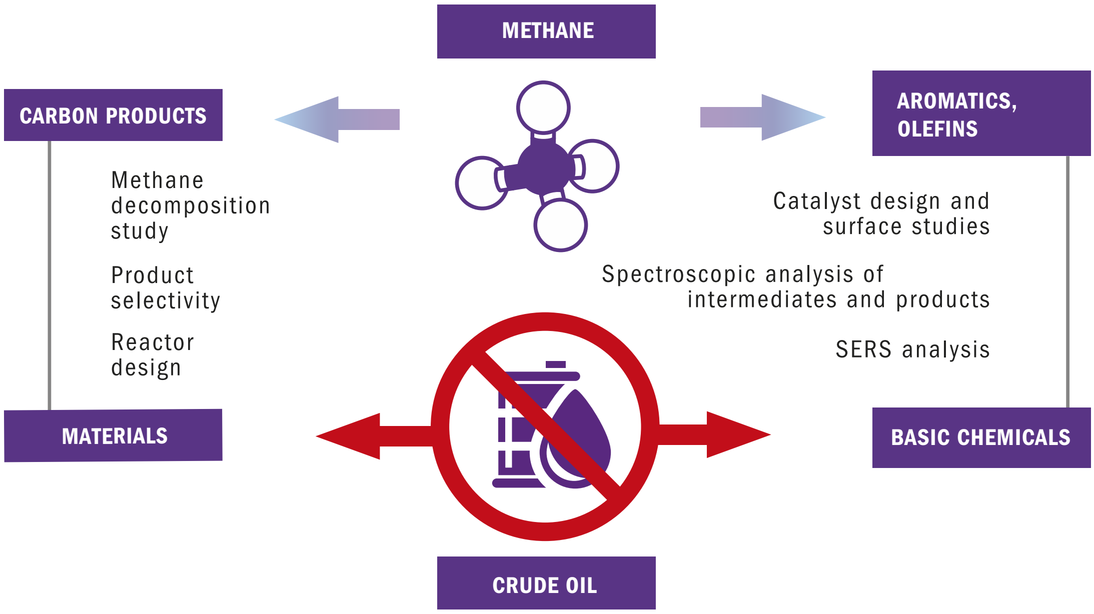
Project leader:	**Hans Kuipers** (Eindhoven University of Technology)
Project manager:	**Sander van Bavel** (Shell)

Methane has tremendous potential as chemical feedstock as it is an abundant and relatively cheap carbon source with a lower negative environmental footprint than other fossil resources, such as crude oil and coal. The multilateral project aims to use methane as a chemical feedstock. We are targeting two main approaches: production of CO_2 free hydrogen as fuel alongside value-added carbon, and direct conversion of methane into bulk chemicals, such as aromatics and ethylene.
This has ample scientific challenges from heterogeneous catalyst design, colloid chemistry, materials science and chemical reactor concepts all the way up to reactor engineering. This multi-disciplinary approach is necessary for this effort becoming a successful endeavor on the topic of pyrolytic methane conversions. The industrial participants share the long-term ambitions and scientific interest, and have the industrial background to take up and bring further results from the project.

Catalyst design and testing for tailoring the reaction selectivity and intermediate formation, including in situ characterization of the solid-phase

Multilateral subproject 2018.17.C.TU/e.1

In this project, the researchers aim to convert methane into ethylene by fine-tuning the properties of metal-modified zeolites.They will investigate the role of the zeolite pore size to drive the selectivity to the light olefins and take inspiration from the methane-to-aromatics reaction. Emphasis will be put on inserting different metal



cations in the framework and/or the pores of these zeolites for proper methane activation, part of the further conversion of methane into olefinic and aromatic molecules and improved stability of the zeolite catalysts needed for high-temperature operation.

Principal investigator: **Emiel Hensen** (Eindhoven University of Technology)
PhD candidate: **Hao Zhang** (Eindhoven University of Technology)

Catalyst design and testing for tailoring the selectivity of reactions, including in situ characterisation of the solid- and gas-phase

Multilateral subproject 2018.017.C.UU.2

In this PhD project we will develop characterization techniques that work at high reaction temperatures, to monitor the chemical processes that take place within current and future (more selective) methane dehydro-dimerization (MDD) catalysts (see also 2018.17.C.TU/e.1 and 2018.017.C.UU.3). The goal is to understand the principles of olefins/aromatics production and the undesired formation of carbon deposits. Furthermore, the question arises if the active site that is responsible for the formation of these different reaction can be determined.

Principal investigator: **Bert Weckhuysen** Utrecht University)
PhD candidate: **Sebastian Haben** (Utrecht University)

Development of surface enhanced Raman spectroscopy for product analysis

Multilateral subproject 2018.017.C.UU.3

We want to provide sensor particles for surface enhanced Raman spectroscopy (SERS) that can be operated at high temperatures (well above 500 degrees Celsius) without losing their shape and thus allowing catalyst characterization under real conditions (17 1 and 2). The focus of the PhD will be the realization of SERS sensor particles that operate by overlapping multiple 'hotspots' of individual noble metals like gold, silver, palladium nano-rod particles (NPs) with a mesoporous silica coating. The syntheses of these structures will be realized by self-assembly of the individual NPs into so-called supraparticles (SPs) with a size from a few hundred nm to one hundred micrometer.

Principal investigator: **Alfons van Blaaderen** (Utrecht University)
PhD candidate: **Harith Gurunarayanan** (Utrecht University)

Nanoscale study of methane decomposition at the metal surface using in situ TEM

Multilateral subproject 2018.017.C.UU.4

Methane pyrolysis producing solid carbon and hydrogen can be catalyzed by many transition metals. Well-known examples are oxide-supported iron, cobalt, nickel and copper catalysts, which require high reaction temperatures of about 1000 degrees Celsius. Bimetallic catalysts, however, are active at much lower temperatures. At the moment, there is little understanding on the rational design of bimetallic

Use carbon dioxide to store energy

Akansha Goyal
(Leiden University)

"The amount of carbon dioxide in the air is rising due to human activity, and it is causing global warming. Until now, we have only seen CO_2 as a waste product. But what if we turn this around, and use CO_2 to store energy. Within an electrolyzer, atmospheric CO_2 can be converted into another molecule, a new fuel.

The energy that is involved in this process, would preferably come from a clean source, like the sun or the wind. In my PhD research, I am trying to find the optimal conditions for the conversion of CO_2 into a new value added product. It will bring us a step forward to closing the carbon cycle."

catalysts, and how metal composition, particle size and initial spatial distribution influence the catalyst surface composition and hence the solid carbon product structures. Studies on the growth of carbon filaments have been done before using *in situ* Transmission Electron Microscopy (TEM) at low gas pressures. Exciting new technology in TEM now enables detailed studies of what happens at the catalyst surface on the nanoscale.

Principal investigator: **Krijn de Jong** (Utrecht University)
PhD candidate: **Vacancy** (Utrecht University)

Design of nickel-based bimetallic catalysts and insight into the influence of catalyst composition and morphology on carbon yield and structure

Multilateral subproject 2018.017.UU.5

The aim of this project is to make rational designs of catalysts for the decomposition of methane into hydrogen and solid carbon products with desired structural properties. These rational designs will be based on understanding the influence of metal catalysts composition, particle size, surface properties, as well as on the morphology of the catalyst support and initial metal spatial distribution. We will use nickel with defined amounts of copper, to increase the carbon yield and to gain understanding on how the structure of the carbon product can be tuned. Not only will we study the resulting morphology, but also the electronic properties (*e.g.* via Raman spectroscopy), as well as the carbon density and crushing strength.

Principal investigator: **Petra de Jongh** (Utrecht University)
PhD candidate: **Liselotte Olthof** (Utrecht University)

Proof of concept and modelling of a gas-fluidized bed reactor

Multilateral subproject 2018.017.C.TU/e.6

Catalytic conversion of methane into carbon requires the use of multiphase chemical reactors that make solids mobile enough to add and remove particulates of desired size, and excellent fluid-particle mass and heat transfer characteristics as encountered in (dense) gas-fluidized beds. Within this project, we aim to deliver a proof of principle of a novel reactor concept that can be used to control the reaction of solid carbon production. It will be based on a structured gas-fluidized bed with temperature uniformity, optimized heat and mass transfer conditions, significant solid mobility, and short gas phase residence time. Furthermore, we will make a multi-scale model of the interplay between heterogeneous chemical reactions and the transport of mass and heat at several time and length scales.

Principal investigator: **Hans Kuipers** (Eindhoven University of Technology)
PhD candidate: **Morteza Hadian** (Eindhoven University of Technology)

Bilateral projects

Apart from the multilateral projects, there are 6 bilateral projects and 11 positions within the research theme Small Molecule Activation.

Perovskite crystallization for stable and large-scale printable solar cells

Bilateral project 2016.003.TU/e

Perovskite solar cells are a promising new energy technology. Through this project we hope to obtain fundamental insights in the processes that govern perovskite thin film formation and crystallization for photovoltaic applications. This will provide guidelines to develop large scale and fast roll-to-roll printing processes, necessary to impact global energy systems. For that, knowledge on the crystallization processes and their dependence on process conditions is required. Parameters like crystallite size, orientation and stability, surface coverage and roughness, and the interaction with the receiving surface together determine the solar cell performance. We are investigating the mechanisms and kinetics of organometal perovskite layers in real time during film formation with the use of *in situ* spectroscopic and X-ray diffraction techniques.

Principal investigator: **René Janssen** (Eindhoven University of Technology)
Project manager: **Sipke Wadman** (Shell)
PhD candidate: **Bas van Gorkom** (Eindhoven University of Technology)

The re-use of the by-product hydrochloric acid to generate valuable compounds

Bilateral project 2016.004.UU

For Nouryon, the project concerns the re-use of the by-product hydrochloric acid to generate valuable compounds, thereby aiming to close the raw material loop, to reduce the carbon footprint and to support the circular economy approach. To be able to do this in an economically viable process, new chemistry and catalysts are developed.

Principal investigator: **Bert Weckhuysen** (Utrecht University)
Project manager: **Coert van Lare** (Nouryon)
PhD candidate: **Bas Terlingen** (Utrecht University)

Electrochemical CO_2 conversion: elucidating the role of catalyst, support and electrolyte

Bilateral projects 2016.008.TUD.A, 2016.008.TUD.B, 2016.008.UL.A, 2016.008.UL.B, 2016.008.UT and 2016.008.UU

Producing a solar fuel, by reaction of water and CO_2 captured from the environment is an attractive option to store cheap intermittent renewable electricity in a fuel that can be directly introduced to the market, with net zero CO_2 emissions.

This project aims to develop electrochemical technology for this application by fundamental investigation (both computationally and experimentally) of catalysts, including metal alloys and innovative supports, and organic electrolytes. In order to screen materials and to rationalize the effect of each interplaying factor, a new testing unit will be developed wherein materials and operating conditions can be varied, mass transfer can be controlled, and in-situ analysis (both quantitatively and qualitatively) of the products of electrochemical CO_2 reduction is possible.

Principal investigators: **Mark Koper** (Leiden University)
Petra de Jongh (Utrecht University)
Wilson Smith (Delft University of Technology)
Guido Mul (University of Twente)
Project manager: **Emanuela Negro** (Shell)
PhD candidate: **Akansha Goyal** (Leiden University)
Francesco Mattarozzi (Utrecht University)
Sanjana Chandrashekar (Delft University of Technology)
Sobhan Neyrizi (University of Twente)
Postdoctoral researchers: **Christoph Bondü** (Leiden University)
Vacancy (Delft University of Technology)

Exploring electrochemical promotion of catalytic oxidation of methane to alcohols

Bilateral project 2018.012.B.TU/e.1

Converting methane – the main component in natural gas, a cheap and abundant feedstock – directly into a chemical such as methanol would have a tremendous impact on the chemical industry. Methanol is a fuel itself but can also be used as a building block for a range of products such as plastics, gasoline and intermediate chemicals. In this project, the researchers will first scrutinize the potential of electrochemical promotion of catalysis (EPOC) on direct methane to methanol conversion, followed by optimizing the nanomaterials that are able to convert methane into methanol. Renewable electricity is used to accelerate the reaction and control the selectivity.

Principal investigator: **Emiel Hensen** (Eindhoven University of Technology)
Project manager: **Joost Smits** (Shell)
PhD candidate: **Aleksei Perevalov** (Eindhoven University of Technology)

Photoelectrochemical fuel production: Optimizing NiO, light absorber, and catalyst

Bilateral project 2018.013.B.UvA.1 and 2018.013.B.UT.2

An attractive approach to produce green fuel is to reduce CO_2 using sunlight and protons in a photoelectrochemical (PEC) cell. A component that generally limits solar-to-fuel performance of a PEC cell, is the photocathode where the reduction needs to take place. The aim of this project, supported by Shell, is to develop a cheap, efficient and stable photocathode for the highly selective reduction of CO_2 and protons to value added products. The conversion of CO_2 into a dense energy carrier using renewable energy (also referred to as solar fuel) is an important element of Shell's so-called 'Long Range Research' program.

Principal investigators: **Joost Reek** (University of Amsterdam)
Guido Mul (University of Twente)
Project manager: **Joost Smits** (Shell)
PhD candidates: **Marie Brands** (University of Amsterdam)
Kaijian Zhu (University of Twente)

New generation of solar panels

Bas van Gorkom
(Eindhoven University of Technology)

"In solar cells, the element silicon converts light energy into electro-energy. This, in turn, can be stored in a battery or sent to the net. Current solar cells are produced at a temperature of over a 1000˚Celsius. I am trying to realize the development of a new generation of solar cells, based on the mineral perovskite. These cells can be produced at a temperature of only 100˚Celsius.

In my PhD research, I prepare perovskite solar cells and investigate how many of the light particles from all separate colours of light are converted into an electrical current. This allows me to develop the solar cells of the future."

Coatings & Functional Materials

Aim

Within this research theme, we want to replace fossil-based feedstock with bio-based materials and further develop water-based paints including lacquers and

Impact

With our research theme on Coatings & Functional materials, we aim to contribute to a more sustainable future through the development of paints, inks, lacquers and similar coatings that can be produced on the basis of renewable bio-based building blocks. Knowledge on coatings and the required industrial relevance is brought in by our industrial partners AkzoNobel, BASF, and Nouryon.

The research is opening up possibilities to design and improve paint resins from a bottom-up approach and build a strong joined basis of expertise with direct input The industry will benefit from the insights and knowledge as well as the infrastructure and research facilities in the academia. The expanding R&D capability in coating-related industries - from SMEs to multinationals will be a job market of increasing interest to young scientists.

Research

Within a total of six projects on Coatings and Functional Materials, 15 positions have been allocated.

Multilateral project

Crosslinking in waterborne coatings with new building blocks

Multilateral project 2018.015.C

Project leader:	**Ben Feringa** (University of Groningen)
Project manager:	**Jitte Flapper** (AkzoNobel)

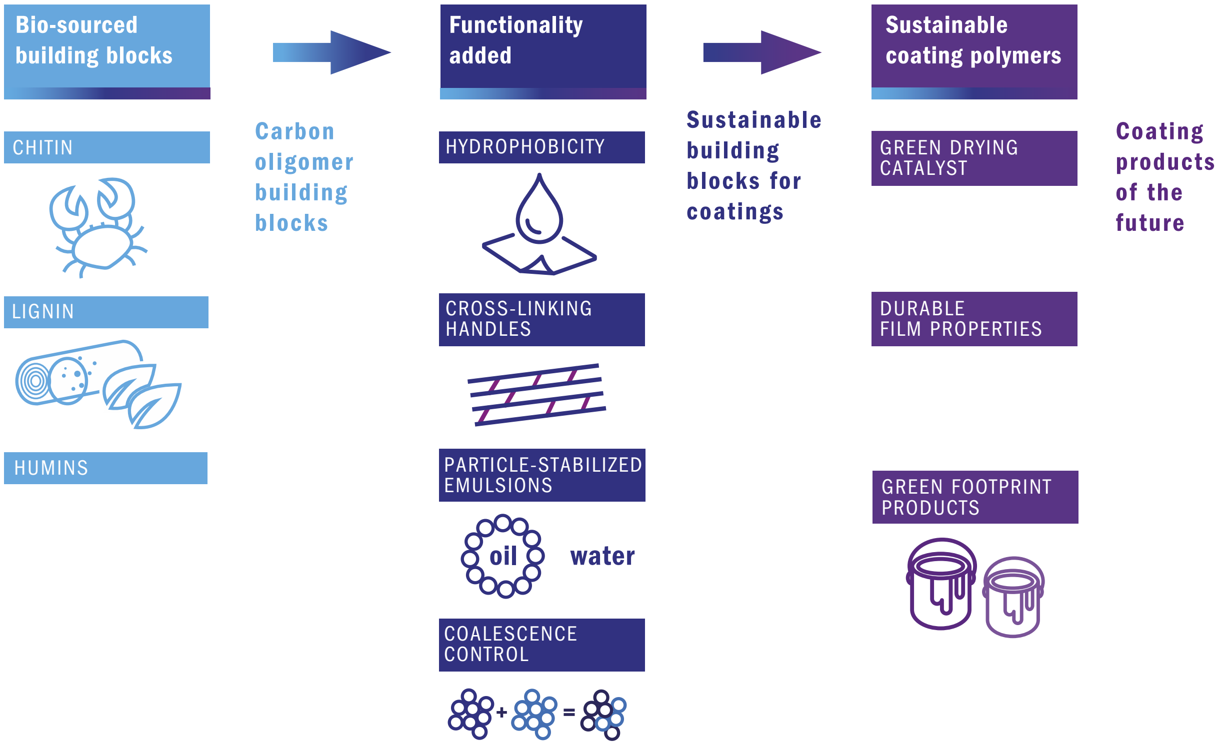
The drive towards sustainable and especially energy efficient preparation of bio-based products over the next decades compels us, in the context of coatings, to consider readily available feedstocks that can be modified on large scale in a robust manner.

The multilateral project aims to explore, develop, modify, and redesign chemical building blocks of biological origin for novel generations of coating products. Apart from substituting currently used polymer binders, this will allow for the re-designing of important coating features, including coalescence, hydrophobic properties, film formation, drying, cross-link-formation and catalytic curing of chemical bonds in coating films, thereby enhancing the mechanical properties of the resulting coating film.

Chemically switchable carbohydrate based polymers

Multilateral subproject 2018.015.C.RUG.1

The goal of this project is to develop chemically switchable carbohydrate based polymers for waterborne coating applications. Although lignin has seen considerable attention, carbohydrate polymers, especially those from animal sources such as chitin, have potential for use in coatings. This is due to their greater structural uniformity: they are less dependent on seasonal and climate-induced variations. The properties of chitin depend both on the degree of modification and extent of deacetylation of the amino groups. A key challenge is selective modification of carbohydrates or at least the



reliability of methods available to achieve batch to batch uniformity of properties.

Principal investigator: **Wesley Browne** (University of Groningen)
PhD candidate: **Hanneke Siebe** (University of Groningen)

Novel cross-linking protocols for waterborne paint curing

Multilateral subproject 2018.015.C.UvA.2

This project explores a variety of alternative metal-catalyzed crosslinking protocols for application in a variety of water borne paints. Traditional water-based paint curing happens through the automatic catalytic oxidation of C-H bonds. The process is catalyzed by cobalt, manganese or iron catalysts and involves reactions with oxygen from air. However, such crosslinks are prone to degradation by light and temperature variations, leading to a limited lifetime of alkyd paint layers. Furthermore, the same strategy cannot be applied to many other paint formulations. All newly developed crosslinking reactions will be most interesting when applicable in water at room temperature, and preferably directly applicable to existing paint formulations without pre-functionalization of the polymers involved.

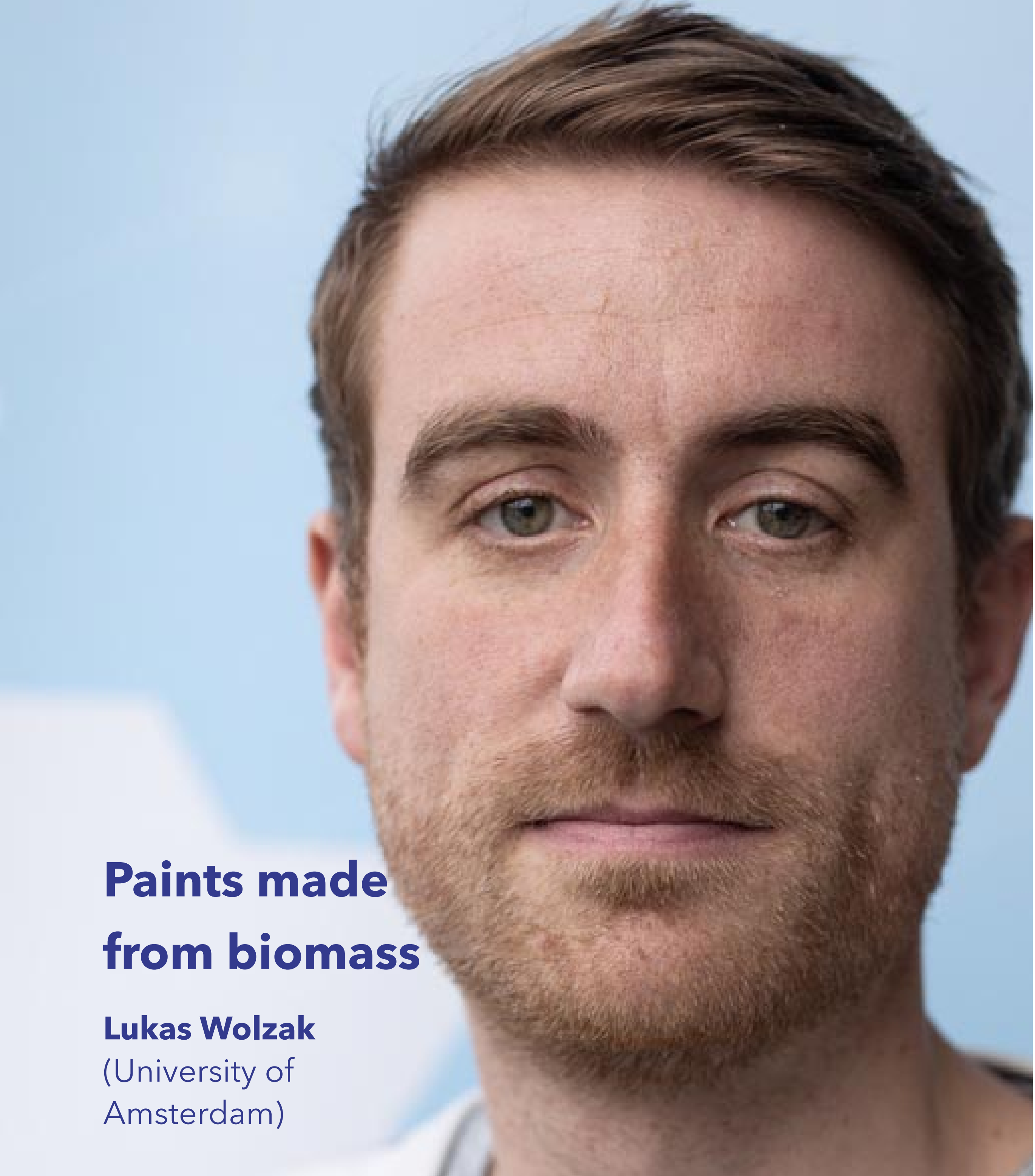
Principal investigator: **Bas de Bruin** (University of Amsterdam)
PhD candidate: **Felix de Zwart** (University of Amsterdam)

New reactions and cross-linking in water / photoactivation

Multilateral subproject 2018.015.C.RUG.3

A major goal in the introduction of waterborne coatings is to introduce latent curing that can be activated under very mild conditions. It is a wish to trigger the formation of cross links and thus, stable films in such a way. Within this project, we address three main challenges. First of all, we are exploring highly controlled, metal-free and non-invasive (using light) cross-linking and novel reactivity in water. Secondly, we want to obtain control over film formation and the organization of large molecules. As a third topic, we are trying to develop unconventional (bio-based) building blocks for waterborne coatings. To that purpose, we are introducing photochemical cross-linking and supramolecular assembly procedures as well as functionalized modified carbohydrates and furanoic-based monomers and cross-linkers.

Principal investigator: **Ben Feringa** (University of Groningen)
PhD candidate: **Bianka Sieredzińska** (University of Groningen)



Paints made from biomass

Lukas Wolzak
(University of Amsterdam)

"The binding agent of paint is currently produced at a temperature of around 250˚Celsius. Keeping in mind the large scale at which paints are applied in society, much energy can be saved if we could bring this reaction temperature down even a little bit. In my PhD project, I am trying to bring it down to around 100˚Celsius. At that temperature, sustainable base materials such as biomass could be used as binding agents.
In order to enable the lower production temperature of the binding agent, a new catalyst has to be developed. I am investigating a wide variety of molecules, in order to find out if they could would be suitable for this purpose."

Building blocks preparation through the selective catalytic oxidation of oligosaccharides

Multilateral subproject 2018.015.C.RUG.4

We aim to develop new building blocks: modified oligosaccharides that can be used for (reversible or irreversible) cross-linking, the stabilization of colloids, and components for supramolecular responsive systems. To that purpose, we want to apply selective catalytic oxidation of polysaccharides and oligosaccharides, to modify these in such a way that these can be used to prepare waterborne coatings with desired properties. We are developing the application of our catalytic oxidation, on the one hand to produce oligosaccharides and on the other hand for the modification of these oligomers. Functionalizing them with at least one ketone, will open manifold opportunities for crosslinking and other modifications.

Principal investigator: **Adri Minnaard** (University of Groningen)
PhD candidate: **Sarina Massmann** (University of Groningen)

Controlled catalytic breakdown of humin and chitin to waterborne building blocks including spatially-resolved spectroscopy of film formation and drying processes

Multilateral subproject 2018.015.C.UU.5

Limitations in thermal stability, poor reactivity and water sensitivity prohibit the widespread use of bio-based building blocks in waterborne coating applications. Biopolymers such as lignin, humin and chitin may offer new possibilities here. AFM-IR and AFM-Raman spectroscopy are now capable of studying these growth processes under controlled atmospheres and temperatures making use of an in-situ cell. In this project, we will use these two methods to elucidate the film formation and drying processes of waterborne coatings based on the humin and chitin depolymerization products. In this way, we are able to evaluate if indeed the amine and carboxyl functionalities react during the hardening process and which factors are optimal for film formation, like water vapor pressure, temperature and catalyst concentration.

Principal investigator: **Bert Weckhuysen** (Utrecht University)
PhD candidate: **Kordula Schnabl** (Utrecht University)

Inorganic nanoparticles for robust waterborne films

Multilateral subproject 2018.015.C.TU/e.6

One of the major challenges for waterborne coatings is to achieve a good balance between the extent/timing of crosslinking and the drying/coalescence processes taking place during film formation. Together, those factors will determine the final film properties, and thus the chemical/physical resistance. Several chemistries have been tried resulting in minor improvements. Hence, a solution only based on chemical reactions between the pre-formed polymer particles dispersed in water, might not be enough to address such complicated matter. This research aims to investigate a new approach in which inorganic nanoparticles, functionalized with specific chemical groups, will be used in a combined role of pickering stabilizer, cross-linking agent and filler.

Principal investigator: **Catarina Esteves** (Eindhoven University of Technology)
PhD candidate: **Siyu Li** (Eindhoven University of Technology)

Particle-enhanced coalescence and film formation

Multilateral subproject 2018.015.C.RUG.7

Strong interactions are required to achieve strong cohesion between polymer particles in a coating. Still, these interactions have to remain dynamic to allow for defect correction and thus avoid kinetic traps that cause defects in the coating. We are investigating two approaches based on the use of either silica particles or dendrimers as a multivalent glue, to yield homogeneous films with high performance characteristics, from heterogeneous waterborne formulations. As multiple interactions are involved per water-soluble dendrimer or per silica nanoparticle, the kinetic barrier to disrupt the coating will be extremely high, even if, taken separately, each individual interaction may be unstable under humidity.

Principal investigators: **Nathalie Katsonis** (University of Twente)
Wesley Browne (University of Groningen)
Postdoctoral researcher: **Alexander Ryabchun** (University of Twente)

Hydrophilic-hydrophobic transitions using complexation chemistry

Multilateral subproject 2018.015.C.UT.8

One of the most challenging aspects in creating a successful waterborne coating, is that, after drying, it will form a sufficient barrier to water. The initial components must be hydrophilic enough to dissolve or disperse in water, but after drying they must become hydrophobic and/or densely cross-linked. We propose that forming complexes of oppositely charged polyelectrolytes could be a promising approach to facilitate the required sharp transition from hydrophilic, water-soluble moieties to hydrophobic, water-resistant coatings. For many polyelectrolytes it is their charge that provides their hydrophilic nature. When bringing together a positive and negative charged polyelectrolyte, their solubility strongly reduces and this allows the formation of a new and much more hydrophobic material.

Principal investigator: **Wiebe de Vos** (University of Twente)
PhD candidate: **Jiaying Li** (University of Twente)

Bilateral projects

Apart from the multilateral project, there are now five bilateral projects and seven positions within the research theme Coatings and Functional Materials.

Cobalt-free curing of alkyds and of vinylester-styrene coatings

Bilateral project 2016.001.RUG and 2016.001.UvA

Many coatings dry via chemical crosslinking reactions, which are catalyzed by transition metal complexes. The toxicity of some of these metals is currently under review. In this project, we are searching for alternative catalysts based on transition metals that avoiding toxic compounds.

Principal investigators: **Wesley Browne** (University of Groningen)
Bas de Bruin (University of Amsterdam)
Project manager: **Jitte Flapper** (AkzoNobel)
PhD candidates: **Linda Eijsink** (University of Groningen)
Johan Bootsma (University of Amsterdam)

Polyester synthesis using novel and efficient esterification catalysts

Bilateral project 2016.002.RUG and 2016.002.UvA

Aim of this project is to develop new catalysts for polyester syntheses with an attractive environmental and economic profile. These catalysts will lead to more eco-friendly processes and will broaden the scope of raw materials (including renewable-based raw materials) that can be used in polyester syntheses.

Principal investigators: **Adri Minnaard** (University of Groningen)
Moniek Tromp (University of Groningen)
Project manager: **Keimpe van den Berg** (AkzoNobel)
PhD candidates: **Hung Chien Lin** (University of Groningen)
Lukas Wolzak (University of Amsterdam)

Smart waterborne coatings with tunable barrier properties

Bilateral project 2018.010.B.TU/e.1

Due to their excellent properties and low cost, waterborne acrylic emulsion polymers are widely used coating materials. Although good barrier properties for a variety of migrating compounds can be achieved, their performance is often insufficient for demanding applications due to their intrinsic non-zero permeability for both polar and non-polar small molecules. Barrier properties can be enhanced by blending in impermeable materials.
Following an entirely new strategy, in this project we are developing unprecedented polymer coatings with tunable barrier properties, which will allow the selective interception of some key migrating molecules.

Principal investigator: **Albert Schenning** (Eindhoven University of Technology)
Project manager: **Gerald Metselaar** (BASF)
PhD candidate: **Sterre Bakker** (Eindhoven University of Technology)

Sustainable coatings for containers

Linda Eijsink
(University of Groningen)

"Liquids like crude oil or some consumer products can cause containers to rust. This can be prevented with a coating: a thin, protective layer on the inner surface of the container. The currently most widely used coating material is a polyester styrene, a liquid resin that solidifies under the influence of a catalyst.

In my PhD project, I want to find sustainable alternatives for the catalysts that are currently usedin this application. With infrared spectroscopy, I aim to study the activity of the current catalyst. I am looking for fundamental insights into this process, which will hopefully enable me to find sustainable alternatives."

Development of biobased coatings

Bilateral project 2018.014.A.RUG.1

This project is exploring new sustainable building blocks for coatings based on renewable materials. The use of green building blocks for coatings and paint applications and the development of sustainable chemical transformations towards these materials is desired. Here photo- or redox-mediated chemical synthesis will be used to convert carbohydrates into building blocks that can replace current monomers in coatings formulations. In this project we aim to demonstrate the use of bio-based feedstock, low-waste sustainable transformations using light or electricity, novel monomers and cross-linkers and 'step-in solution' for some current coating formulations.

Principal investigator: **Ben Feringa** (University of Groningen)
Project manager: **Keimpe van den Berg** (AkzoNobel)
PhD candidate: **George Hermens** (University of Groningen)

Enhanced waterborne coatings through increased understanding of stratification mechanisms & control of particle distributions

Bilateral project 2018.018.B.WUR.1

Several desired properties of paints and coatings are believed to be closely linked to the distribution of the different coating components, e.g. latex particles, pigments or colloidal silica, in the coating layer. This project will build the necessary fundamental understanding of how parameters like rheology, drying and particle properties govern the movement of the coating components in the paint layer during the time from application to a dry paint film and their final distribution in the coating. Indeed, studies of the movement of components in full paint formulations are challenging. The research will therefore necessarily start with simple systems (only 2-3 components) and complexity will then gradually be added to the system.

Principal investigator: **Jasper van der Gucht** (Wageningen University & Research)
Project manager: **Daniel Persson** (Nouryon)
PhD candidate: **Ellard Hooiveld** (Wageningen University & Research)

Visibility and Output

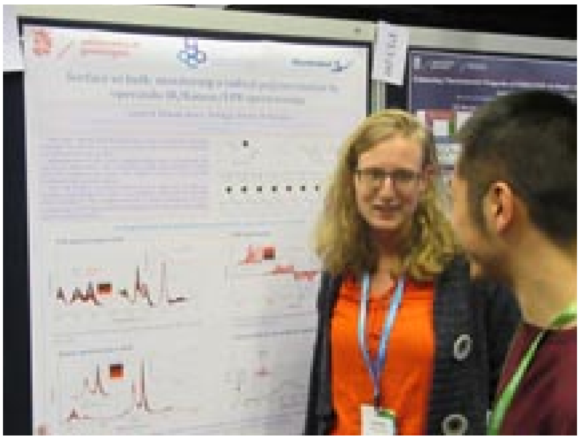
Scientific

First ARC CBBC symposium

On 12 April 2018, our community, including academics, company researchers, and board members, gathered in the beautiful historic museum Catharijneconvent in Utrecht. We discussed our research topics, shared ideas and inspire each other in our work. Three members of our Scientific Advisory Board gave inspiring presentations on their own scientific fields.

First PhD poster presentation

At the Dutch annual chemistry conference CHAINS 2018 in Veldhoven, our PhD candidate Linda Eijsink presented her scientific poster to the research community on 5 December.



Patents

Momentarily, three patents applications are being prepared. As soon as they are officially filed and approved, we will take up external communications on these highlights.

Professorships

Four of our scientific members were appointed to be a professor. At Utrecht University, Pieter Bruijnincx was appointed a professor of Sustainable chemistry & catalysis. At the University of Groningen, Moniek Tromp is now a professor of Materials chemistry, Wesley Browne became a professor of Molecular inorganic chemistry, and Syuzanna Harutyunyan was appointed professor of Synthetic organic chemistry.

Communications

New website

The development of a new ARC CBBC website provided more possibilities to share our news on the home page. The use of large images and moving page sections make the website much more attractive and dynamic.

Logo

We changed our logo into a version with two instead of four text lines, making it easier to read.

Advanced Research Center
Chemical Building Blocks Consortium

The Sustainable Future Game

During Summer, ARC CBBC has developed the exhibit The Sustainable Future Game, in which players learn about the variety of ARC CBBC's public-private research projects. Players are challenged to combine images of base materials and their envisioned sustainable applications, after which six short videos are presented as a reward for a right combination. The stand-alone interactive game was present at various event in Fall: at the BASF neighbour's day in De Meern on 6 October. The next day, it attracted a large and broad audience at the Dutch public weekend on science, the 'Weekend van de Wetenschap'. Many visitors were enthusiastic about the way in which ARC CBBC is contributing to a sustainable future. The CHAINS conference in Veldhoven, from 3-5 December, was the third opportunity to present The Sustainable Future Game, this time to people with a scientific background.

Short videos and animation

The six 90 seconds videos that served as 'rewards' in The Sustainable Future Game, were provided with an animated introduction on ARC CBBC's partnership concept. Our public and private partners shared the videos via social media like Twitter and LinkedIn.

Public lectures

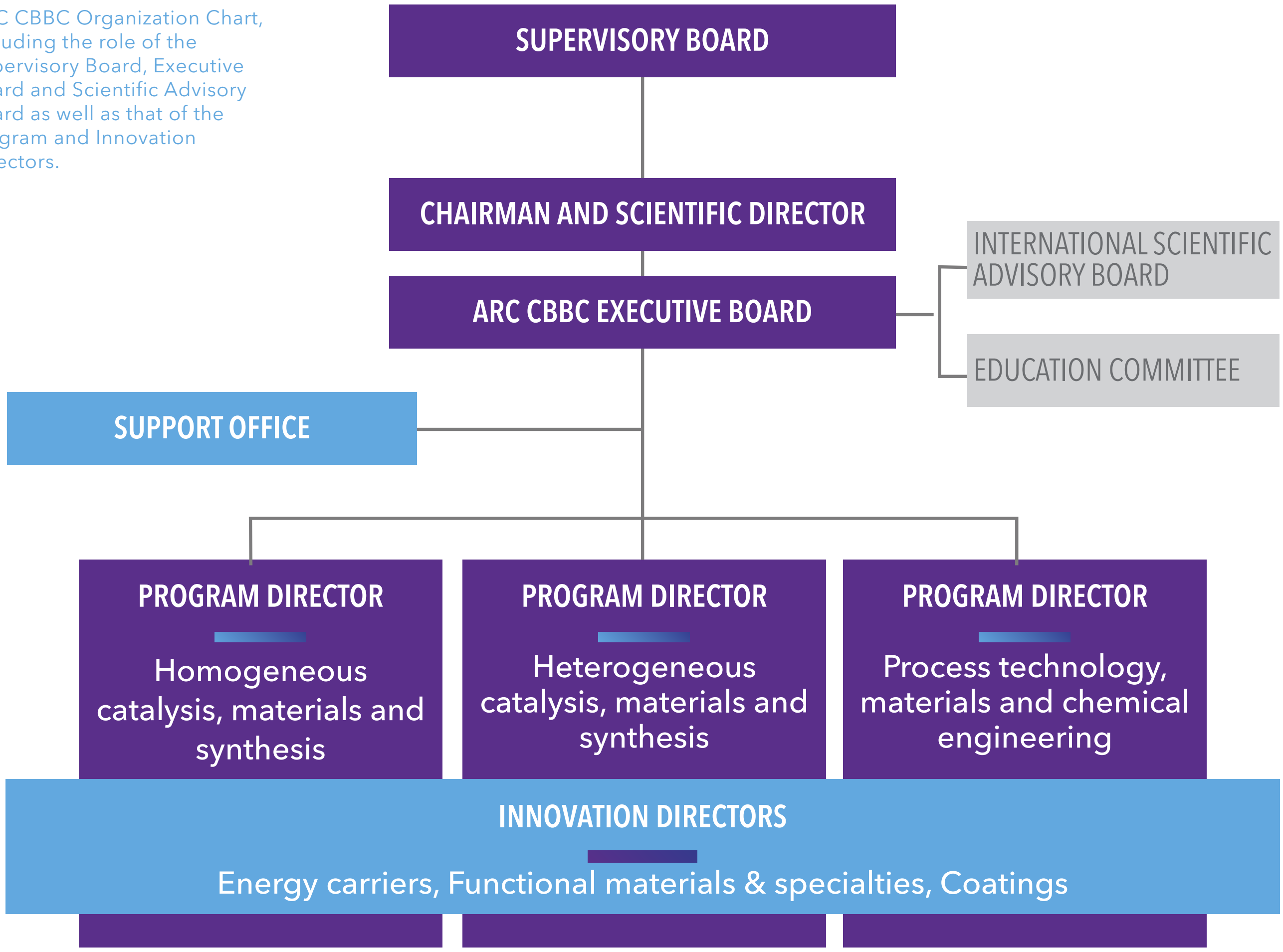
ARC CBBC was present at the first Pathways to sustainability Conference in Utrecht on 9 February. The conference was open to stakeholders from all fields of research and policy on sustainability questions. ARC CBBC scientific director Bert Weckhuysen was a keynote speaker, and we informed the visitors of the conference on the 'Sustainable Marketplace'.
On 5 November, Bert Weckhuysen gave a public lecture about the future of sustainable energy, titled Earth to Earth, dust to dust, carbon to carbon at the Royal Institution in London. The lecture was recorded and spread through social media in the UK and the Netherlands.

Visit of Utrecht University Board to ARC CBBC lab

On 20 September, lab technician Hannie van Berlo-van den Broek, postdoctoral researcher Matteo Monai and ARC CBBC PhD candidates Bas Terlingen, Savannah Turner and Sophie van Vreeswijk gave the Utrecht University Board a tour through the newly-built ARC CBBC Utrecht hub lab. Professor Pieter Bruijnincx closed the meeting with a presentation of the relevance of sustainable chemistry.

Organisation and Governance

ARC CBBC Organization Chart, including the role of the Supervisory Board, Executive Board and Scientific Advisory Board as well as that of the Program and Innovation Directors.



Laboratories

At all three hub locations, we intend to build specially equipped lab facilities.

Utrecht hub

In Utrecht, ARC CBBC was assigned a lab floor in the brand new Vening Meinesz Building on Utrecht Science Park. The lab was delivered to Utrecht University by the building company in March 2018. From that moment on, the 270 square meter space was equipped. It contains several lab-rooms, including a catalyst synthesis lab, a catalysis and characterisation lab and a furnace and catalyst preparation lab.

At the end of Summer, two Utrecht University-hub lab technicians moved into the building and commenced their activities on the design of research set-ups, which are financed from the Large Equipment Fund. Their first project was to design and build a closed box multi-purpose catalyst test set-up with operando IR and Raman spectroscopy. With this set-up, our researchers can safely carry out catalytic reactions and gain operando information on the catalyst. This will enable them to selectively develop and produce novel and stable catalytic solids, for the activation of various building blocks including CO_2, methane, light alkanes and other small molecules.

Between September and December 2018, one postdoc, eight PhD researchers and six bachelor and master students started working there office as well.

Groningen hub

In 2018, at the Groningen Hub of ARC CBBC arrangements were made for the realization of a completely equipped, ARC CBBC wing at the ninth floor of the Linnaeusborg. With this wing, the three expert centers Photo-flow Chemistry, Electrosynthesis and Building Block Synthesis, and two fully equipped synthetic laboratories will be made available to facilitate the to-be-hired Tenure Track Assistant Professors on Electrosynthesis and Functional Materials and provide the CBBC members with state-of-the-art equipment and facilities.

With the commitment of the Faculty of Science and Engineering we aim at delivering the new ARC CBBC facilities at the start of the new academic year. This allows us to expand our ARC CBBC team at the University of Groningen. With our expert centers we aim at the activation of small molecule building blocks from renewable resources applying photocatalysis, photoredox chemistry and electrosynthetic transformations using equipment made available by the Large Equipment fund.
Getting the Groningen hub fully equipped and set-up, we hope to keep strengthening our ARC CBBC team and continue our fruitful collaboration with ARC CBBC partners from academia and industry in the coming years.

Eindhoven hub

In 2018, at the TU/e hub of ARC CBBC preparations have been made for the extension of two facilities that will enable advanced non-invasive characterization/monitoring at different length scales relevant to the development of catalysts and multiphase catalytic reactors. With the combined facilities the detailed study of transport phenomena and the interplay with catalytic transformations can be performed. As such these investments connect very well with the key research elements addressed within current and future flagships under the umbrella of "Fundamentals of Catalysis" and "Small Molecule Activation".

For gas phase flow imaging, an extension to the recently established brand new MRI lab located at the ground floor of the Helix building is reserved. The lab houses a 7T MRI scanner capable of measuring both vertically and horizontally. The scanner is now fully operational enabling detailed flow and dispersion measurements in packed bed chemical reactors. The extension allows for unique imaging of flow and chemical species transport in gas-solid and gas-liquid-solid (trickle-flow) reactors.
For catalyst characterization, the capabilities of the solid-state NMR facilities will be extended with focus on the detailed characterization of catalytic solids, including catalyst-reactant complexes and operando analysis. To make full use of the advanced probe head extensions, the current electronics of the NMR setup will be upgraded with the most powerful console available.
The new instrumentation will form an integral part of the advanced ARC CBBC hub's facilities. Dedicated technicians (embedded in the two research groups) with substantial experience are available for both NMR facilities for running and maintaining the new instrumentation and training of young ARC CBBC researchers.

Education

Education Committee

The ARC CBBC Education Committee is composed as follows:

- **Hans Kuipers** (Chair), Eindhoven University of Technology
- **Jitte Flapper**, AkzoNobel

- **Keimpe van den Berg**, AkzoNobel
- **Javier Ruiz Martinez**, Nouryon
- **Peter Klusener**, Shell
- **Hannah Thuijs**, ARC CBBC
- **Maurice Mourad**, ARC CBBC

Programme

The Education Committee will implement ARC CBBC's talent programme, which has the following three main aims:

1. Educate the next generation of researchers and equip them with the knowledge, insights and skills needed to succeed both in academia and industry.

2. Provide the stimulating environment and opportunities required for the most talented young assistant/associate professors to develop into the next generation of world-class researchers.

3. Professional development of research staff of industrial partners to keep up-to-date on the newest technologies and insights.

Internships

Professional development of research staff of industrial partners to keep up-to-date on the newest technologies and insights. Most young researchers who start on a project in the Coatings area do not have a background in this field. Therefore, AkzoNobel invites all PhD candidates and postdocs with whom they collaborate, for an internship. The young academic researchers spend at least one week at the company and work side-by-side with experienced coating researchers in the industrial labs. The training provides the PhD students and postdocs with hands-on experience with paints and coatings, and they become aware of the way the industry works. It also lowers the barrier for future visits and interactions. The effort has already shown its value, as some PhD candidates have conducted part of their own research at AkzoNobel. Up to now, seven PhD candidates have visited the sites in Sassenheim in the Netherlands and/or Felling in the United Kingdom. More starting academic researchers will hopefully follow.

BASF, Nouryon and Shell also train the young academic researchers they cooperate with. However, they link one PhD candidate or postdoc to one of the companies' senior researchers for a long-term guidance trajectory.

Preview of next year

In 2019, the first ARC CBBC Education Day will take place on Wednesday 17 April. During this event, PhD candidates and postdoctoral researchers will be offered a workshop on presentation skills.

Support

Support office

The support office team has changed in 2018: Emke Molnar and Anne-Claire Hoenson left and Marga Jansen (secretary), Anita ter Haar (financial control) and Hannah Thuijs (office manager) joined Tjitske Visscher (communications) and Maurice Mourad (programme).

Knowledge experts

The Executive Board members of all private partners are supported by knowledge experts:

- **Jitte Flapper** (AkzoNobel Paints & Coatings)
- **Peter Berben** (BASF)
- **Mathieu Ahr** (Nouryon)
- **Sander van Bavel** (Shell)

Boards

Executive Board (EB)

Prof. dr. ir. Bert Weckhuysen, Scientific Director (Utrecht University)

Prof. dr. Ben Feringa, Chair (University of Groningen)

Prof. dr. ir. Hans Kuipers (Eindhoven University of Technology)

Ir. Adrie Huesman (Shell)

Ir. André van Linden (AkzoNobel Paints & Coatings)

Dr. Marcel Schreuder Goedheijt (Nouryon)

Dr. Robert Terörde (BASF)

Drs. Mark Schmets (Liaison NWO)

Supervisory Board (SB)

Mr. Marjan Oudeman, Chair

Prof. dr. Anton Pijpers (Utrecht University)

Prof. dr. Jasper Knoester (University of Groningen)

Ir. Jan Mengelers (Eindhoven University of Technology)

Prof. dr. Stan Gielen (Netherlands Organisation for Scientific Research, NWO)

Prof. dr. Emmo Meijer (Holland Chemistry)

Drs. Michiel Sweers (Ministry of Economic Affairs and Climate Policy)

Dr. Dirk Smit (Shell)

Dr. Peter Nieuwenhuizen (AkzoNobel)

Dr. Klaus Harth (BASF)

Scientific Advisory Board (SAB)

Prof. dr. Matthias Beller, Chair (Leibniz-Institut für Katalyse, Germany)

Prof. dr. Markus Antonietti (Max-Planck Institute of Colloids and Interfaces, Germany)

Prof. Ib Chorkendorff (Technical University of Denmark, Denmark)

Prof. dr. Christophe Copéret (ETH Zürich, Switzerland)

Dr. Tanja Cuk (University of California at Berkeley, CA, USA)

Prof. John Dennis (University of Cambridge, UK)

Prof. Rodney O. Fox (Iowa State University, USA)

Prof. Bettina Frohnapfel (Karlsruhe Institute of Technology, Germany)

Prof. Matthew Gaunt (University of Cambridge, UK)

Prof. Joseph Keddie (University of Surrey, UK)

Prof. dr. Martin Möller (Leibniz Institute for Interactive Materials, Germany)

Prof. dr. Ferdi Schüth (Max-Planck-Institut für Kohlenforschung, Germany)

Prof. Timothy Swager (Massachusetts Institute of Technology, USA)

Prof. Guy Marin, Deputy Chair (Ghent University, Belgium)

Members

In 2018, our consortium has 37 scientific members. Together with researchers from our industrial partners, they have the day-to-day lead of our research projects.


MATTHIAS BICKELHAUPT
Professor
Free University Amsterdam


ALFONS VAN BLAADEREN
Professor
Utrecht University


WESLEY BROWNE
Professor
University of Groningen


PIETER BRUIJNINCX
Professor
Utrecht University


BAS DE BRUIN
Professor
University of Amsterdam


NIELS DEEN
Professor
Eindhoven University of Technology


MARJOLEIN DIJKSTRA
Professor
Utrecht University


CATARINA ESTEVES
Associate Professor
Eindhoven University of Technology


BEN FERINGA
Professor
University of Groningen


FRANK DE GROOT
Professor
Utrecht University


JASPER VAN DER GUCHT
Professor
Wageningen University & Research

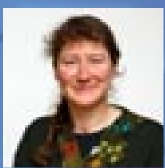

SYUZANNA HARUTYUNYAN
Professor
University of Groningen


EMIEL HENSEN
Professor
Eindhoven University of Technology

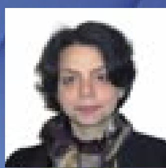

JAN VAN HEST
Professor
Eindhoven University of Technology


RENE JANSSEN
Professor
Eindhoven University of Technology


KRIJN DE JONG
Professor
Utrecht University


PETRA DE JONGH
Professor
Utrecht University


FREEK KAPTEIJN
Professor
Delft University of Technology


NATHALIE KATSONIS
Professor
University of Twente


MARC KOPER
Professor
Leiden University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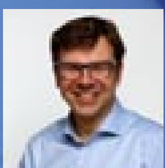
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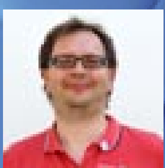
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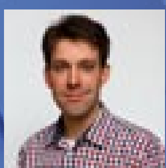
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