Towards a sustainable route for the synthesis of chemical building blocks

ARC CBBC Annual Report 2017

Advanced Research Center
Chemical Building Blocks Consortium

Table of contents

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Foreword

On behalf of the Executive Board, I hereby present the ARC CBBC Annual Report. The report will provide you with an overview of the activities undertaken and the further development of our research programs throughout the second official year of our research center.

Our community has gathered several times. During these meetings, inspiring discussions brought us to a more definite formulation of our research topics. They have been reviewed by our Scientific Advisory Board in two rounds, one in April 2017 and the other quite recently, in April 2018.

The first projects of ARC CBBC have already started. PhD candidates and one postdoctoral fellow have been appointed on some of our bilateral projects. Furthermore, our first two flagship projects, on bio-based coatings and bimetallic catalysts, have been approved and will start soon. With those we are further defining the Strategic Agenda of ARC CBBC.

This public version of ARC CBBC's Annual Report 2017 will be accessible to everyone interested in our work.

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Scientific Director

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ARC CBBC in a nutshell

The Advanced Research Center Chemical Building Blocks Consortium (ARC CBBC) is a national research center officially launched in May 2016, based on strategic, long-term, public-private partnerships in the field of chemistry, physics, materials science and engineering. It brings together scientific excellence and leading industrial companies in a unique and powerful public-private partnership.

ARC CBBC facilitates scientific and technological breakthroughs with regard to its three main themes: Energy carriers, Functional materials & specialties, and Coatings. We expect to play a leading role in research into issues, such as the circular economy, sustainable chemical processes and clean energy.

Program lines

We distinguish two Program Lines: a Multilateral Program Line and a Bilateral Program Line, as shown in Figure 1.

The Bilateral Program Line consists of bilateral projects. Within each bilateral project, one of the full private partners participates with one or more of the selected academic researchers. Only partners that are directly involved in a particular project, have access to the results. Each bilateral project includes one or more PhD/PD positions.

The Multilateral Program Line exists of Flagships. Flagship, in turn, contains several multilateral projects which are larger in scope and scale than bilateral projects, providing private partners with the opportunity to collaborate with a multidisciplinary group of selected academic researchers. Flagships address long-term

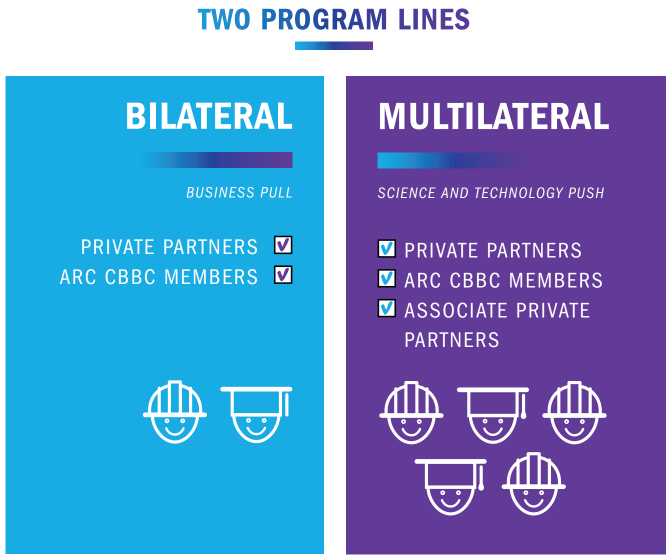


Figure 1: ARC CBBC Program Lines. They consist of Bilateral and Multilateral Programmes, each with their own characteristics, such as IP regulations.

Figure 2: Process of ARC CBBC project selection. In the Bilateral Program Line, 'company' refers to a Full Private Partner. Both Full Private Partners and Associate Private Partners can participate in the Multilateral Program Line.

joint scientific interests. They aim to provide new knowledge and to increase our fundamental understanding with long-term application perspectives. All partners have access to the results acquired within Flagships. A multilateral project typically includes five to ten PhD/PD positions.

Project selection

Project proposals are first evaluated by the Executive Board (EB) and then by the Scientific Advisory Board (SAB). The process of project selection is outlined in Figure 2. The allocation of projects further involves advice of the Supervisory Board (SB), and the procedures are described in the Strategic Plan of ARC CBBC.

Formulating project proposals

Projects within the Multilateral as well as the Bilateral Program Line are formulated by a multidisciplinary team of academic and industrial researchers. All project proposals are confidential and include:

- Scientific description both at the level of a coherent project and at the level of specific PhD/Postdoc positions.
- Composition of the project team, including project leader (a scientific member, employed by an academic partner), project managers (researcher of an industrial partner, responsible for the valorization process) and other members of the project team.
- Project objectives, milestones, deliverables and related planning.
- Involvement of industrial partner(s).
- Economic and societal impact.

Highlights of 2017

17 February 2017

First ARC CBBC community event

The research center got off to a flying start at the University Hall Utrecht, when partners and members meet for the first time to discuss their plans and ambitions regarding the Flagships "Small molecule activation" and "Fundamentals of catalysis".

16 March 2017

Second ARC CBBC community event

The Flagship "Coatings and functional materials" is discussed in-depth at this separate community event at the Sikkens Experience Center in Sassenheim, hosted by AkzoNobel.

Robert Terörde (BASF) on cooperating within ARC CBBC

"This consortium is different from other consortia. Whereas typically this type research collaborations are built around solving a particular scientific problem, ARC CBBC first of all brings together 37 excellent scientific members. Initially, the research subjects for the consortium were in that stage very broadly described. It was only together with these members that we started to explore the possibilities of having this unique combination of skillsets, and to select the challenges that we wanted to tackle. This was a very exciting process in which, as an industrial partner, we did not know on beforehand to what it would lead exactly."

Out-of-the-box

"We are interested in both the multilateral and the bilateral projects. The bilateral projects are closest to our direct commercial interests. The multilateral projects, on the other end, address long term, precompetitive topics. In these projects, scientists can think out-of-the box and share their wild ideas for research on socially relevant themes. It is the challenge to match those ideas with industrial interest. The academic partners use fundamental techniques that we, as a company, do not possess. It is their specialism to develop the methodology. For us, it is great to be able to cooperate with the worldwide specialists in their field."

Future talent

"Another important reason for us to participate in ARC CBBC is the recruitment of future talents for our company. In the end, the consortium educates people to do research in chemical topics that are very relevant to us. Moreover, the cooperation within such a research project is very natural and a good way to get to know each other. From other consortia, too, we have been able to recruit great colleagues. We expect to be able to do the same with the young researchers from ARC CBBC."

Catarina Esteves (Eindhoven University of Technology) on cooperating within an ARC CBBC flagship

"Within ARC CBBC, industries and universities really reinforce each other. Industries often tend to follow empirical approaches. If a certain chemical compound makes a product successful, it stays in the loop. Sometimes it is not always certain exactly what makes a specific product a success or how to solve a problem which may appear later. However, this information could be very useful for the optimization of materials. That is for example, where academic researchers can help, as we have more freedom and time to dedicate to the in-depth scientific investigation of such aspects. The main purpose of universities is to gain fundamental scientific knowledge. We do not necessarily have to deliver a new product ready for the market, but we enable industries to do so. The knowledge that we gain in our flagship programs, will be interesting to all the industrial partners involved."

Try out new scientific pathways

"In companies, it generally takes many years before research will lead to a product that can be taken to the market. At universities, the first part of the process can go faster as academic researchers are not restricted to certain topics. We can try out new scientific pathways more easily. That is why, in these first five years, we can provide industries with the tools to take the next step. Our consortium will thus impact the knowledge economy in several ways. In 2026, when ARC CBBC is finished, our publications and literature could be useful to companies outside the consortium as well. Further than that, the companies will also have young doctorate researchers with experience in the field which they can directly hire to reinforce their teams."

Interdisciplinary team

"What is also special about ARC CBBC, is that within the academic field, relatively many disciplines are involved. We can work on the whole process of designing new building blocks. Take for example new molecules for paints and coatings. As a materials scientist, I try to add new properties to the starting molecules. Other team members are for example engineers, who are improving the flow of the paint or upscaling it to larger batches. And process technologists will for instance try to make the production process more efficient and environmentally safe."

Research projects' progress

Multilateral Program Line

Our Multilateral Program Line currently consists of three Flagships:
- Coatings and functional materials
- Small molecule activation
- Fundamentals of catalysis

Each of the Flagships has been initiated by and broadly discussed within the community. The ideas have been shaped by the EB, which in turn has composed three executive summaries on the starting points of the Flagships. All principal investigators were then given the opportunity to show their interest in one or several Flagships.

They were all invited to pitch their project ideas. Based on these ideas, project teams consisting of different members as well as representatives from the participating industries were created by the EB. In interactive sessions, these project teams wrote proposals for each of the Flagships.

Table 1: (Pre)proposed multilateral projects in each of the three ARC CBBC Flagships. Each multilateral project is coordinated by two EB members, whose names are indicated in the table. The titles of the pre-proposed multilateral projects need to be confirmed.

	Coatings and functional materials	**Small molecule activation**	**Fundamentals of catalysis**
Multilateral project proposals (approved)	Crosslinking in waterborne coatings with new building blocks Lead: Ben Feringa and André van Linden	Pyrolytic upgrading of methane to ethylene, aromatics and carbon materials Lead: Hans Kuipers and Adrie Huesman	Ultimate control over nanoparticle structure, composition, size, and location in supported bimetallic catalysts Lead: Bert Weckhuysen and Robert Terörde
Multilateral project preproposals (under review and therefore not specified in this report)	Functional coatings and materials Lead: Ben Feringa and André van Linden		Catalyst engineering and process intensification Lead: Hans Kuipers and Marcel Schreuder Goedheijt
			Photo and redox catalysis: from catalyst to reactor Lead: Bert Weckhuysen and Marcel Schreuder Goedheijt

Highlights of 2017

12-13 April 2017

Scientific Advisory Board meeting

The SAB meets in Utrecht to discuss (and provide ARC CBBC's partners with valuable input about) the first round of bilateral project proposals (ten in total) and the three Flagship preproposals.

18 April 2017

Public Associate Partners confirmed

The EB confirms the accession of seven Public Associate Partners to the research center:

- Delft University of Technology
- Leiden University
- Radboud University
- University of Amsterdam
- University of Twente
- VU Amsterdam
- Wageningen University & Research

21 June 2017

Third ARC CBBC Community event

This meeting, held at Utrecht Science Park, aims to take the next step towards the creation of the three Flagships "Small molecule activation", "Fundamentals of catalysis" and "Coatings and functional materials". In a plenary session, three possible ideas for future (multilateral) projects are presented and discussed.

Flagship
Coatings and functional materials

Coatings are one of the pillars of ARC CBBC: the consortium has the intention to enable a 'greener' approach to the design and manufacturing of paints and coatings, thereby aiming for a more sustainable future. By rethinking the way chemical building blocks could be applied in future coatings, the consortium will explore new chemistries for the purpose of product enhancement, making the polymer films more durable and easier curable, adding functionalities as fouling prevention. Furthermore, it will enhance the purpose of enhancing the sustainability profile of paints and lacquers. This will also enable the replacement of crude oil-based chemicals for renewable resources, using environmentally-benign and human-friendly components.

Proposal multilateral project 'Crosslinking in waterborne coatings with new building blocks'

Aim

The project aims at the replacement of fossil-based feedstock with bio-based materials and at the further development of water-based paints, thereby reducing the market share of the traditional solvent-based paints and lacquers. Additionally, the project aims at improved product properties. AkzoNobel Paints and Coatings, BASF, and AkzoNobel Specialty Chemicals all contribute with their product knowledge on coatings and are hopeful that the expertise in chemical synthesis, chemical conversion and catalysis, colloid chemistry, and bio-based materials, all particular strengths of the academic research groups in the Netherlands, will contribute to design the coatings of the future.

Approach and scientific ambition

This multilateral project proposal will explore routes towards novel sustainable binders for use in paints, inks and lacquers that can be obtained by chemical conversion of bio-based polymers such as carbohydrates including cellulose, humins and chitins. These can be turned into active and functional oligosaccharides and related chemical building blocks that, in turn, will be

"At this moment, there is no large-scale application of bio-based compounds in the coatings industry. Such materials would have to meet two basic conditions: they will have to be both stable during the functional lifetime of the coating and fungi should not be able to affect them. Right now, we don't know which reactions we can use to make such a durable product. To be able to come up with really innovative solutions instead of compromises, it would be best to start from scratch. How can we selectively modify the bio-based polymers and produce a compound in which the natural variations in feedstock quality will not pose a problem?"

Two candidates

"We are aiming to investigate two groups of polymers. Our first candidates are lignins, the organic polymer that gives the cell walls of vascular plants their strength. However, the stability of lignin strongly depends on the weather conditions during growth. Another group of candidates are chitins, the building block of the exoskeleton of animals like insects and spiders. This polymer may be more stable than lignin, but less favorable on the large scale as its resources are smaller."

Basic set of possibilities

"We hope to have a basic set of possibilities within five years, the term of this flagship programme. Afterwards, several companies may be interested to set up bilateral projects with those scientific results. So, within the total ten years that our consortium will last, we may together be able to deliver several full-grown products within various types of industry."

Prof. Wesley Browne (University of Groningen) **on bio-based coatings**

converted into functional coating polymers. For this to work, new processes as well as new catalysts will be designed. Furthermore, we will explore novel approaches for high quality coating film formation and novel chemistry for cross-linking of polymer coatings, both important to durable and functional coating. Advanced spectroscopy and microscopy will be exploited to follow the building block conversion processes in detail from the intramolecular level of functional chemical groups to the supramolecular level of waterborne coatings and the resulting coating films. With this multilateral project proposal, we aim for new concepts of design and synthesis for more sustainably produced water-based coatings.

The research project will also facilitate knowledge transfer from academia to industry and vice versa: the Dutch universities have an internationally renowned reputation in many of the fields covered in this program. Without any doubt, the industry will benefit from the insights and knowledge as well as from the infrastructure and research facilities in the academia. Currently, knowledge on coatings is, with a few exceptions, not widely available in the Dutch academic research community. At the same time world-leading groups in synthesis, catalysis, polymer chemistry, renewable chemistry and supramolecular chemistry are present. This Flagship will connect the two worlds and aims to bring valuable knowledge on coating science to the academic researchers in order to challenge them to come up with novel approaches on topics such as crosslinking reactions, coalescence, resin (polymer) synthesis, formulation science, and film formation. Furthermore, the expanding R&D capability in coating-related industries (from SMEs to big international companies) may become an increasingly interesting job market for young scientists.

Table 2: The multilateral project proposal 'Crosslinking in waterborne coatings with new building blocks' and its sub-projects.

PI	Affiliation	Sub-project
Wesley Browne	University of Groningen	Chemically switchable carbohydrate-based polymers
Bas de Bruin	University of Amsterdam	Novel cross-linking protocols for waterborne paint curing
Ben Feringa	University of Groningen	New reactions and cross-linking in water / photoactivation
Adri Minnaard	University of Groningen	Building blocks preparation through the selective catalytic oxidation of oligosaccharides
Bert Weckhuysen	Utrecht University	Controlled catalytic breakdown of humin and chitin to waterborne building blocks including spatially-resolved spectroscopy of film formation and drying processes
Catarina Esteves	Technical University Eindhoven	Inorganic nanoparticles for robust waterborne films
Nathalie Katsonis	University of Twente	Particle-enhanced coalescence and film formation
Wiebe de Vos and Jasper van der Gucht	University of Twente Wageningen University & Research	Hydrophilic-hydrophobic transitions using complexation chemistry

Flagship
Small molecule activation

Small molecule activation refers to the technology to drive a process of chemical conversion of abundantly available small molecules with rather inert bonds such as N_2, CO_2 and CH_4, to build up more complex and functionalised molecules of higher added-value to the chemical industry. The process yields basic chemicals in an opposite way that typical petrochemical conversions do. In the latter, non-renewable feedstock containing large molecules is catalytically cracked to the desired smaller molecules that form the feedstock of the chemical industry. The activation of small molecules involves running processes with significant energy barriers for which suitable catalysts, reactor technology and heat management are all required.

Proposal multilateral project 'Pyrolytic upgrading of methane to ethylene, aromatics and carbon materials'

Aim

Finding direct routes for the energy- and atom-efficient conversion of methane into chemical building blocks is one of the 'Holy Grails' in the field of chemistry. Methane is a molecule with one carbon atom for which it is challenging to activate the C-H bonds with high selectivity. It is a tremendous challenge to design methane pyrolysis such that there is full control over the products. Managing the harsh process conditions is crucial; the main focus in this proposal, however, is on developing improved catalysts and on increasing our fundamental understanding on active sites and related reaction mechanisms by using advanced characterization methods. Therefore, there is a clear link to the ARC CBCC multilateral project proposal 'Fundamental understanding of catalyst preparation processes', where catalyst synthesis is being studied via advanced in situ characterizations.

Approach and scientific ambition

Within this multilateral project, suitable solid catalysts for the pyrolytic conversion of methane into olefins, aromatics and structured carbons will be explored. Not only do we wish to design new or improved catalyst

Highlights of 2017

1 September 2017

First PhD student Lukas Wolzak (UvA) starts his work

From this date on PhD and Postdoc candidates are being recruited to work on ARC CBBC's bilateral projects.

16 October 2017

First ARC CBBC flagship team meeting

Selected principal investigators gather at the Utrecht University Hall to discuss and explain their desired contribution to the "Coatings and functional materials" Flagship.

1 November 2017

New SAB members and vice chairman appointed

The EB appoints two new members of the Scientific Advisory Board: Professor Bettina Frohnapfel (Karlsruher Institute of Technology) and Professor Rodney Fox (Iowa State University). Professor Guy Marin, who was already a SAB member, is appointed as vice chairman of the SAB, to assist Professor Mathias Beller in his duties as chairman.

Prof. Alfons van Blaaderen (Utrecht University) on spying on active catalysts

"The activation of methane over a catalyst happens at very high temperatures, but at this moment, the conversion of methane into products cannot be done efficiently. One of the reasons is that the exact chemical pathways at those high temperatures are not well known yet. We plan to observe this catalyst at work during the activation of methane."

Chemical fingerprint

"With the use of Raman spectroscopy, we can make chemical bonds within molecules visible by probing the vibrations within those molecules. It will result in a chemical 'fingerprint' of the molecules and their bonds present at a certain point in time. If we apply Raman spectroscopy to a working catalyst on its support material, we will be able to view the presence and the activity of chemical conversions at the catalyst surface while the reactions are in progress."

Zeolite and gold nanoparticles

"We are trying this for zeolite catalysts in a framework of gold nanoparticles that are shaped like rods. Those gold rods are typically 70 x 20 nm in length and the zeolite catalyst particles are present in between layers of these rods. With Raman spectroscopy, we are able to intensify the presence of light at the ends of the gold nanoparticles and make the light intensity a few hundred times stronger there. By doing this, we can greatly enhance the detection on those specific locations of the zeolite catalysts and the reactions taking place within them. If we learn more about the activity of the catalyst, we are optimistic that we will learn how to better control the activation of methane."

materials, we also seek to increase our fundamental knowledge on active catalytic sites and reaction mechanisms, the underlying principles by which activity can be steered, the product selectivity and catalyst stability as well as effective catalyst-reactor design combinations. For this purpose, new characterization tools will be developed that allow for evaluating the catalytic performance in real time. This will provide understanding of the activation mechanisms of methane and allows us to follow the chemical conversion chemistry under severe reaction conditions, including its time- and composition dependency. The initial structure and composition of the newly developed catalyst will be related to (time-dependent) actual structure, surface composition and performance under reaction conditions. The proposed project will specifically explore the activation and chemistry of methane as a first and significant step in energy transition efforts, preceding work on other small and stable molecules, notably CO_2 and N_2. 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. Despite the clear potential of methane, efficient and industrially applicable direct methane-to-products conversions are not yet available for the chemical industry. Disruptive scientific results for such conversions are expected to have a substantial impact on the companies involved in ARC CBBC: it would open up new outlets for methane (natural gas) resources, as well as price-competitive manufacturing routes for important bulk chemicals (e.g. lower olefins), and on top of that, the market for the catalysts that enable this conversion can be substantial itself. The product 'carbon' has its own appeal: not only does the production yield virtually 'CO_2 neutral' hydrogen, but novel carbon products are relevant in a more CO_2 neutral world, for instance as part of replacement of construction material: manufacturing of concrete is a very CO_2 intensive process. Also, high-value added products such as carbon nanotubes and carbon fibers fit well, e.g. in electric mobility as they have applications in batteries, light material (reduced mass for electric cars, planes, etc.), and have the potential for improved catalysts – as support and direct catalytically active material – pivotal for improving the energy and material efficiency of chemical processes.

Table 3: The multilateral project proposal 'Pyrolytic upgrading of methane to ethylene, aromatics and carbon materials' and its sub-projects.

PI	Affiliation	Sub-project	Topic
Emiel Hensen	Technical University Eindhoven	Catalyst design and testing for tailoring the reaction selectivity and intermediate formation, including in situ characterization of the solid-phase	Selective conversion of methane into ethylene and aromatics
Bert Weckhuysen	Utrecht University	Catalyst design and testing for tailoring the selectivity of reactions, including in situ characterisation of the solid- and gas-phase	Selective conversion of methane into ethylene and aromatics
Alfons van Blaaderen	Utrecht University	Development of surface enhanced Raman spectroscopy for product analysis	Selective conversion of methane into ethylene and aromatics
Krijn de Jong	Utrecht University	Nanoscale study of methane decomposition at the metal surface using in situ TEM	Decomposition of methane to hydrogen and solid carbon
Petra de Jongh	Utrecht University	Design of nickel-based bimetallic catalysts and insight into the influence of catalyst composition and morphology on carbon yield and structure	Decomposition of methane to hydrogen and solid carbon
Hans Kuipers	Technical University Eindhoven	Proof of concept and modelling of a gas-fluidized bed reactor	Decomposition of methane to hydrogen and solid carbon

Highlights of 2017

1 December 2017

Second and third ARC CBBC flagship team meetings

The teams selected for the "Small molecule activation" and "Fundamentals of catalysis" Flagships meet in Utrecht to prepare for joint proposals for both flagships.

15 March 2018

The ARC CBBC Hub laboratories of Utrecht University are ready to be equipped

The first dedicated laboratories of the ARC CBBC Hub at Utrecht University was turned over to us by the Utrecht University Real Estate department. The two newly appointed lab technicians of the Utrecht Hub can now start to equip the lab, in close consultation with the ARC CBBC researchers at Utrecht University, and with the lab technicians of our other two Hubs at the Technical University of Eindhoven and University of Groningen. According to the current time path, the lab and office spaces will be ready for use in September 2018. The recruitment of the two tenure track positions at Utrecht University has also started.

Flagship
Fundamentals of catalysis

Catalysts are highly complex, multi-scale and multi-component materials, which have to be precisely designed and manufactured to obtain their proper functionality. This Flagship will bring together principal investigators from various disciplines ranging from heterogeneous catalysis and supramolecular chemistry to organic chemistry, transport modelling and colloidal science. It aims to increase our knowledge on the fundamentals of catalyst preparation, design, application and catalytic reactor technology.

Proposal multilateral project 'Ultimate control over nanoparticle structure, composition, size, and location in supported bimetallic catalysts'

Aim

It is important to acquire detailed fundamental insights into and full control over the structure, composition, size and location of bimetallic nanoparticles on porous support oxides. By bringing together different disciplines that are covered by the selected principal investigators of ARC CBBC, together we aim to make significant steps forward in the synthesis of supported bimetallic nanoparticles for important catalytic reactions, including but not limited to the hydrogenation of CO_2. By including the latter catalytic reaction as a model test reaction, we actively link this multilateral project to another research theme, namely energy carriers, and in particular the Flagship "Small molecule activation".

Approach and scientific ambition

The focus will be on the preparation of supported bimetallic catalysts, such as silica-supported Pd-Ni systems, with the main objective to make these catalysts as uniform as possible at all length scales. Such catalyst systems will be made by using conventional methods (i.e. impregnation, drying, calcination and reduction) as well as by entirely new synthesis routes. The latter will make use of well-defined supraparticles and organometallic clusters, for which the chemical composition per particle can be controlled more precisely. Detailed insights into the various preparation steps will be obtained by using a combination of electron, laser and X-ray methods that covers different length scales; i.e., on the one hand the length scales of atoms and atom clusters present in the pores of oxide supports; and on the other hand the length scales of single catalyst grains and extrudates, which are of the order of (sub)millimeters. The materials prepared will be tested in three showcase hydrogenation reactions, known to be dependent on the bimetallic nanoparticle composition and structure; namely the hydrogenation of substituted phenolics, cinnamaldehyde as well as CO_2.

Current and future energy and chemical industries 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. Such synergies can lead to fundamentally different catalytic performance which by itself already may have value as it may lead to more product 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.
By focusing on the synthesis and in-depth characterization of new or improved bimetallic hydrogenation catalysts in combination with the selective hydrogenation of CO_2 into either methane, methanol or CO/H_2 as well as the hydrogenation of more complex organic molecules such as guaiacol and cinnamaldehyde we can translate the obtained physicochemical insight as well as synthesis protocols into a wide variety of catalytic applications of interest to the involved chemical companies.

Table 4: The multilateral project proposal 'Ultimate control over nanoparticle structure, composition, size, and location in supported bimetallic catalysts' and its sub-projects.

PI	Affiliation	Sub-project
Krijn de Jong	Utrecht University	Catalyst synthesis studied in real-time with spatially-resolved TEM and EDX
Bert Weckhuysen	Utrecht University	Characterization of bimetallic catalysts: size, structure and composition during synthesis and at work
Emiel Hensen	Technical University Eindhoven	Active phase genesis in supported bimetallic nanoparticle catalysts: following drying, calcination and reduction in real-time with surface-sensitive spectroscopy
Hans Kuipers	Technical University Eindhoven	Catalyst preparation modeling: flow, diffusion and adsorption
Joost Reek	University of Amsterdam	Nanosphere complex-mediated synthesis of bimetallic particles
Nathalie Katsonis	University Twente	Light-responsive ligands controlling bimetallic catalyst formation
Alfons van Blaaderen	Utrecht University	Binary Supraparticles: using self-assembly to control the supramolecular structure in bimetallic catalysts

Prof. Nathalie Katsonis (Utrecht of Twente) on exploring the full potential of bimetallic catalysts

"The overall idea of this flagship program is to pioneer routes to synthesize bimetallic catalysts with unmatched catalytic performance. Catalysts that are composed of two metals carry potential to not only combine the activity of both individual metals, but ultimately to bring around an emergent catalytic behavior. Our mutual goal is to decipher the process of the catalyst growth and its catalytic activity by looking at these bimetallic particles with an atomic resolution and in real time. This will give us ultimate control over the structure, size, and composition of the catalysts."

Stimulate unconventional approaches

"This flagship brings together two communities that have different sets of expertise. One group seeks to achieve a holistic insight into the formation and operation of nanoparticulate catalysts, so the functioning of each atom can be deciphered eventually. Next, there are researchers from the fields of colloidal and supramolecular chemistry – I belong to the latter. Traditionally these two communities do not overlap so much, but the challenge we took up here, is to work together, as to stimulate unconventional approaches for the design and synthesis of new bimetallic catalysts that cannot be accessed by traditional synthetic methods."

Control the molecule instead of its environment

"When making nanoparticulate catalysts, we have to control their composition, structure and growth. In the conventional way, you achieve this control by adjusting the environment, like the temperature and acidity of the solution, the concentration of the organometallic precursors, and the solvents. I want to explore how to reach beyond this level of control. Instead of controlling the environment, I would like to bring the control to the molecular level. More specifically, by using molecular switches that respond to light. This is not much different from the strategies that nature has developed, in different settings, to form some of its most exquisite nano-sized mineral structures. With such a strategy, I hope to readily influence the number of atoms on a nanoparticle and how fast it grows. If you can achieve this level of control, you will be able to effectively modulate the catalytic activity to your best liking."

Bilateral Program Line

The first round of bilateral projects has been evaluated by the SAB in 2017. The program directors made the final decisions, allocating eight bilateral projects in 2017. In 2018, this process has run again. Along with two multilateral projects, five bilateral projects have been allocated.

Allocated projects

In the first round, eight bilateral project proposals were finalized and allocated, consisting of thirteen four-year PhD positions and three two-year Postdoc positions in total. Of those, eight PhD and two PD candidates were appointed in 2017.

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

Bilateral project 2016.001

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

Project leader: **Wesley Browne** (University of Groningen)
Project manager: **Jitte Flapper** (AkzoNobel Coatings)
PhD candidates: **Johan Bootsma** (University of Amsterdam)
Linda Eijsink (University of Groningen)

Polyester synthesis using novel and efficient esterification catalysts

Bilateral project 2016.002

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.

Project leader: **Adri Minnaard** (University of Groningen)
Project manager: **Keimpe van den Berg** (AkzoNobel Coatings)
PhD candidates: **Lukas Wolzak** (University of Amsterdam)
One PhD student to be appointed (University of Groningen)

Perovskite crystallization for stable and large-scale printable solar cells

Bilateral project 2016.003

The project aims at obtaining fundamental insights in the processes that govern perovskite thin film formation and crystallization for photovoltaic applications. Crystallite size, crystallite orientation, surface coverage, surface roughness and interaction with the receiving surface are crucial parameters that determine the solar cell performance. One of the principal issues in perovskites currently revolves around stability. The significant strides made in recent time provide the opportunity to comfortably think of large scale deployment.
Scale-up of printing technology to GWp/a scale, necessary to impact global energy systems, requires intimate knowledge on the crystallization processes and their dependence on process conditions. Using a range of in-situ spectroscopic and X-ray diffraction techniques the mechanisms and kinetics of crystallization of organometal perovskite layers will be investigated in real time during film formation. This will provide guidelines to develop large scale and fast roll-to-roll printing processes for this promising new energy technology.

Project leader: **René Janssen** (Eindhoven University of Technology)
Project manager: **Sipke Wadman** (Shell)
PhD candidates: One PhD student to be appointed
(Eindhoven University of Technology)

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

Bilateral project 2016.004

For AkzoNobel, 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 will need to be developed.

Project leader: **Bert Weckhuysen** (Utrecht University)
Project manager: **Coert van Lare** (AkzoNobel Chemicals)
PhD candidates: **Bas Terlingen** (Utrecht University)

Fundamentals of reduction of Ni-based catalysts

Bilateral project 2016.005

Heterogeneous metal catalysts are amongst the most important industrial catalysts. During catalyst preparation it is of high interest to yield a stable and highly dispersed active metal phase. The reduction of these catalysts is a vital step in the catalyst preparation as it determines the dispersion and thereby activity. There has been a wealth of investigations on the mechanism of reduction, however, most studies were performed either ex-situ or with model systems.

This project focuses on gaining 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.

Project leader: **Krijn de Jong** (Utrecht University)
Project manager: **Bennie Reesink** (BASF)
PhD candidates: **Savannah Turner** (Utrecht University)

Unravelling structure sensitivity in CO_2 hydrogenation over nickel

Bilateral project 2016.006

Efforts in the fields of materials science have allowed us to create smaller and smaller metal nanoparticles, creating new opportunities to study catalytic properties that depend on the metal particle size. Structure sensitivity is the phenomenon where not all surface atoms in a supported metal catalyst have the same activity. Understanding the structure sensitivity can assist in the rational design of heterogeneous catalysts allowing to control mechanisms, activity and selectivity.

By making use of advanced characterization methods and a set of well-defined silica-supported Ni clusters (ranging from 1 Ni atom to ~ 10 nm Ni nanoparticles), we wish to investigate how structure sensitivity influences hydrogenation catalysis by taking CO_2 reduction as a showcase. These findings may bring new understanding in selective reactant adsorption (e.g. H_2, CO_2 and olefins) and allow controlling both activity and selectivity hydrogenation catalysis over supported Ni catalysts, which can be a means for CO_2 emission abatement.

Project leader: **Bert Weckhuysen** (Utrecht University)
Project manager: **Peter Berben** (BASF)
Postdoc: **Matteo Monai** (Utrecht University)

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

Bilateral project 2016.007

Zeolites are widely used solid catalysts. Although there are more than 235 zeolite frameworks reported, almost all zeolite-based catalytic processes are performed by a limited number of frameworks. These are the so-called Big Five: FAU, MFI, FER, MOR and BEA. More recently, SAPO-34 and SSZ-13 with the CHA structure became important catalysts in e.g. methanol-to-hydrocarbon process and selective catalytic reduction of NO_x.

Since industry wishes to develop more sustainable conversion processes, it is crucial to explore the properties of less conventional zeolite frameworks. In this research project, several non-commodity zeolite

"Bilateral projects within ARC CBBC are typically initiated by the industrial partners. They may in some cases be using certain catalytic processes for years already, but may not have scientific explanations for the success of these processes. Why do some reactions work, while others fail? The input of academic researchers is to provide fundamental knowledge on those reactions. Both science and the involved industrial partner will be able to profit from the knowledge that we gain within our bilateral projects."

Lower temperature

"For example, in the project that I am in, we are trying to find a new catalyst that can make the production of a coating more sustainable. Currently, this is done at a temperature of at least 200, maybe even 300 degrees Celsius. We would like to bring this down to 100 to 150 degrees Celsius. The alternatives that have been suggested in the past, are not ideal: apart from being active at a lower temperature, our catalyst also has to be colourless."

Strongly connected

"The industries may have already had some ideas about the course that their projects would take. Members from the ARC CBBC consortium were involved based on these first ideas. Last year, we spoke with them in various interactive sessions. The projects were set up based on the outcomes of those discussions. During the various PhD projects of which some have already started, the industries will remain strongly connected."

Industrial experience

"To the PhD candidates, bilateral projects may be particularly interesting as they get to know the industrial environment, too. To them, it may be nice to see what their work could eventually lead to. They even get the chance to work in the industrial labs for a certain period of time and experience the ambiance there. The PhD candidates see the direct relevance and application of their, sometimes very fundamental, work."

Moniek Tromp (University of Amsterdam*) on cooperating within a bilateral project

* As of 1 July 2018, Moniek Tromp will be employed as a professor of Materials Chemistry at University of Groningen.

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 showcase. The latter allows making comparisons with current MTO catalysts.

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

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

Bilateral project 2016.008

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.

Project leader: **Wilson Smith** (Delft University of Technology)
Project manager: **Emanuela Negro** (Shell)
PhD candidates: **Akanska Goyal** (Leiden University)
Sobhan Neyrizi (University of Twente)
Sanjana Chandrashekar (Delft University of Technology)
One more PhD student to be appointed (Utrecht University)
Postdocs: **Christoph Bondü** (Leiden University)
One more Postdoc to be appointed (Delft University of Technology)

12 April 2018

First ARC CBBC symposium

In museum Catharijne Convent in Utrecht, a mini symposium for all principal investigators, Postdocs, PhD students and other invitees from e.g. the participating industries proceeds the second SAB meeting. Three members of our SAB give presentations on the link between their own work and the research within ARC CBBC. Furthermore, our academic and industrial researchers once more get a chance to exchange their ideas.

13 April 2018

SAB meeting

The consortium's international Scientific Advisory Board meets in Utrecht to discuss and give their advice on the second round of bilateral projects and the first three Flagships "Coatings and functional materials", "Small molecule activation" and "Fundamentals of catalysis".

Scientific excellence

Considerable progress has been made in building the scientific program of ARC CBBC and setting up and starting the first projects in collaboration between academia and industry. As the majority of research projects is still being shaped, we would like to draw attention to some results of the community so far.

Publications

The Art of building small: From molecular switches to motors (Nobel Lecture)
B.L. Feringa
Angew. Chem. Int. Ed. 2017
DOI: 10.1002/anie.201702979

Dynamic control of chirality and self-assembly of double-stranded helicates with light
D. Zhao, T. van Leeuwen, J. Cheng and B.L. Feringa
Nat. Chem. 2017, *9*
DOI: 10.1038/nchem.2668

Eight-coordinate fluoride in a silicate double-four-ring
M.G. Goesten, R. Hoffmann, F.M. Bickelhaupt and E.J.M. Hensen
Proc. Nat. Acad. Sci. 2017, *114*
DOI: 10.1073/pnas.1615742114

Manufacture of highly loaded silica-supported cobalt Fischer–Tropsch catalysts from a metal organic framework
X. Sun, A.I. Olivos Suarez, M. Meijerink, T. van Deelen, S. Ould-Chikh, J. Zečević, K.P. de Jong, F. Kapteijn and J. Gascon
Nat. Commun. 2017, *8*
DOI: 10.1038/s41467-017-01910-9

Interfacial water reorganization as a pH-dependent descriptor of the hydrogen evolution rate on platinum electrodes
I. Ledezma-Yanez, W.D.Z. Wallace, P. Sebastián-Pascual, V. Climent, J.M. Feliu and M.T.M. Koper
Nat. Energy 2017, *2*
DOI:10.1038/nenergy.2017.31

Rational Optimization of Supramolecular Catalysts for the Rhodium Catalyzed Asymmetric Hydrogenation Reaction
J. Daubignard, R.J. Detz, A.C.H. Jans, B. de Bruin and J.N.H. Reek
Angew. Chem. Int. Ed. 2017, *56*
DOI: 10.1002/anie.201707670

Interfacial engineering of metal-insulator-semiconductor junctions for efficient and stable photoelectrochemical water oxidation
I.A. Digdaya, G. Adhyaksa, B.J. Trzesniewski, E. Garnett and W.A. Smith
Nat. Commun. 2017, *8*
DOI: doi:10.1038/ncomms15968

Structure-activity relationships in hydrogenation reactions over supported nickel nanoparticles
C. Vogt, E. Groeneveld, G. Kamsma, M. Nachtegaal, L. Lu, C.J. Kiely, P.H. Berben, F. Meirer and B.M. Weckhuysen
Nat. Catal. 2018, *1*
DOI:10.1038/s41929-017-0016-y

Prestigious Research Grants

- ERC Advanced Grant for Detlef Lohse (April 2017)
- ERC Advanced Grant for Sijbren Otto (April 2017)
- Vici Grant for Syuzanna Harutyunyan (February 2018)
- ERC Advanced Grant for Bert Meijer (April 2018)

Scientific Awards

- Moniek Tromp wins NWO Athena Prize
- Syuzanna Harutyunyan receives the Homogeneous Catalysis Award by the Royal Society of Chemistry
- Detlef Lohse receives the Fluid Dynamics Prize
- Freek Kapteijn awarded with the Hoogewerff Gold Medal
- Nathalie Katsonis awarded the KNCV Gold Medal
- Krijn de Jong receives the François Gault Lectureship Award
- Bert Weckhuysen wins the Tanabe Prize for Acid-Base Catalysis and Robert B. Anderson Award in Catalysis
- Bert Meijer awarded the Nagoya Gold Medal and Chirality Medal
- Ben Feringa receives the first European Chemistry Gold Medal by the European Chemical Society

Visibility and collaboration

During the year, we increased our visibility with various events. At this moment, we aim to become known by the scientific community in particular.

Mission to China

12-17 November 2017

ARC CBBC participated in an innovation mission to China, organised by the Top Sector Chemistry, in cooperation with the Netherlands Ministry of Economic Affairs and Climate (EZK), NWO and two other national innovation initiatives for the chemical industry. The mission visited Shanghai and Beijing, and met with several of the highest-ranked universities within China, as well as policy makers. At the moment, discussions are ongoing for a collaboration between public bodies of the Netherlands and the Ministry of Science and Technology of China (MoST) and, in particular, to establish a joint program of research on chemical building blocks in which ARC CBBC and a Chinese public private partnership can take part.

VSNU Impact Festival

23 November 2017

At the yearly conference of the Association of Universities in the Netherlands (VSNU), ARC CBBC performed as an expert on public-private partnerships. In 2017, this topic was high on the agenda of universities throughout the Netherlands. ARC CBBC gave a presentation and an interactive workshop on the cooperation between fundamental science, industries and governmental organizations.

CHAINS Conference

5-7 December 2017

At this annual NWO chemistry event, ARC CBBC was present at the Innovation Platform. With a stand, we aimed to inform the scientific community and other interested parties about our activities.

Visit to Utrecht University by Members of Parliament

19 January 2018

ARC CBBC's Scientific Director Bert Weckhuysen received those Members of the Dutch Parliament, who are responsible for policy on Education, Culture and Science. The delegation was informed about the research on, among others, sustainable materials and energy.


Advanced
Research Center
Chemical Building
Blocks Consortium

Organization and governance

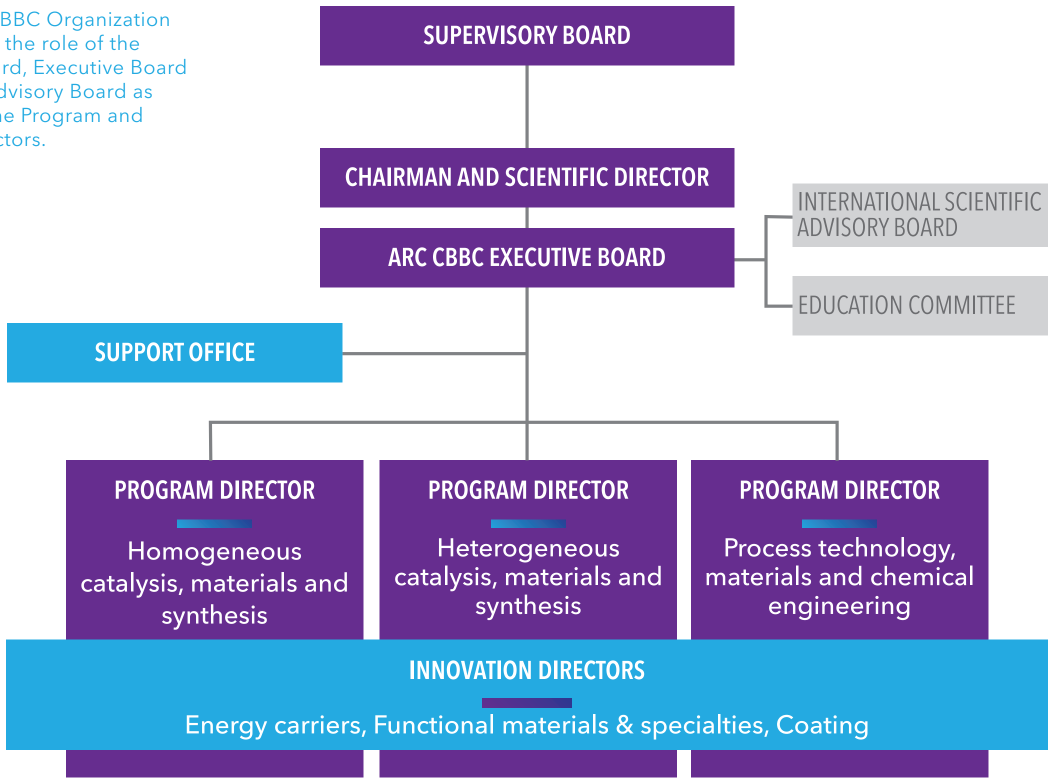
ARC CBBC's organization and management structure remains unchanged with respect to the Strategic Plan and arrangements underlying the Consortium Agreement.

ARC CBBC is led by the Executive Board (EB), with Chairman Ben Feringa (RUG) and Scientific Director Bert Weckhuysen (UU). The center is supported by the ARC CBBC Support Office. The EB meets four to six times a year and is responsible for the management of the research programs. The Supervisory Board (SB) meets at least twice a year and decides on intended decisions regarding project allocations prepared by the EB, monitors program progress, advises the EB concerning long-term strategy and safeguards the national character of the research center.

So far, the SB has had three meetings: on 13 January 2017, to discuss the progress of the research center, and on 3 July 2017 (teleconference) to discuss the future partnership growth model, and on 27 November 2017. The next two meetings are scheduled for 28 May 2018 and 19 November 2018.

The EB has held four meetings in 2017 and (at the moment of writing) two in 2018. There are three other meetings planned in 2018. Besides the formal meetings, the EB has frequently teleconferenced or

Figure 3: 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.



met in person. Additionally, its members have met at several community events and are actively involved in the intensive processes of writing Flagship proposals. All SB and EB meetings are formally announced and the minutes are recorded for reference and archival purposes.

As of 1 December 2017, Floris Rutjes stepped down as NWO-observer in the Executive Board after accepting the ARC CBBC membership. Initially NWO suggested to point out a successor but confirmed later in a letter of 13 December 2017 that this position will not be continued. On behalf of NWO, Mark Schmets has been appointed as liaison and attend all Executive Board meetings.

Supervisory Board (SB)
LLM. Marjan Oudeman, Chair (Utrecht University)
Prof. Anton Pijpers (Utrecht University)
Prof. Jasper Knoester (University of Groningen)
Ir. Jan Mengelers (Eindhoven University of Technology)
Prof. Stan Gielen (Netherlands Organisation for Scientific Research, NWO)
Prof. Emmo Meijer (Holland Chemistry)
Drs. Michiel Sweers (Ministry of Economic Affairs and Climate Policy)
Drs. Yuri Sebregts (Shell)
Dr. Peter Nieuwenhuizen (AkzoNobel)
Dr. Klaus Harth (BASF)

Executive Board (EB)
Prof. Bert Weckhuysen, Scientific Director (Utrecht University)
Prof. Ben Feringa, Chair (University of Groningen)
Prof. Hans Kuipers (Eindhoven University of Technology)
Ir. Adrie Huesman (Shell)
Ir. André van Linden (AkzoNobel Decorative Paints)
Dr. Marcel Schreuder Goedheijt (AkzoNobel Specialty Chemicals)
Dr. Robert Terörde (BASF)
Drs. Mark Schmets (Liaison NWO)

Scientific Advisory Board (SAB)
Prof. Matthias Beller, Chair (Leibniz-Institut für Katalyse, Germany)
Prof. Guy Marin, Chair (Ghent University, Belgium)
Prof. Markus Antonietti (Max-Planck Institute of Colloids and Interfaces, Germany)
Prof. Ib Chorkendorff (Technical University of Denmark, Denmark)
Prof. 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. Martin Möller (Leibniz Institute for Interactive Materials, Germany)
Prof. Ferdi Schüth (Max-Planck-Institut für Kohlenforschung, Germany)
Prof. Timothy Swager (Massachusetts Institute of Technology, USA)

Prof. Klavs Jensen (Massachusetts Institute of Technology) until 1 April 2017

Associate Public Partners

In 2017, seven universities have been approached to become Associate Public Partners and all seven have signed the Accession Agreement. Together with the three Full Public Partners Utrecht University, University of Groningen and Eindhoven University of Technology, the consortium has now reached nationwide presence. In addition to that, Associate Public Partners Delft University of Technology and University of Amsterdam have expressed their interest to become a Full Public Partner of ARC CBBC. The Chair and the Scientific Director are discussing the terms in consultation with the SB.

Associate Public Partners

- Delft University of Technology
- Leiden University
- Radboud University Nijmegen
- University of Amsterdam
- University of Twente
- Free University Amsterdam
- Wageningen University & Research

Fig. 4: All current ARC CBBC partners

Education committee

The Education Committee will have the task to set up an education program that meets the ambition of the research center. In addition, the committee will exchange knowledge with the Education Committee of the two gravitation programs MCEC (mcec-researchcenter.nl) and FMS (fmsresearch.nl) to find out how collaboration can be beneficial. The EB discussed the focus of ARC CBBC's education program on 3 April 2018, led by Hans Kuipers (Chair of ARC CBBC Education Committee). The Education Committee will be formed by the summer of 2018, based on the proposals of each EB member and led by Hans Kuipers. During the second half of 2018 the ARC CBBC Education Committee will start planning the educational activities.

The aimed PhD training program contains the following aspects:

Learning by doing

A major part of the training of the PhDs and PDs is through learning-by-doing. Their research project is conducted in a multidisciplinary environment in which they develop their academic skills:

- through experienced and expert research guidance by the promotor and involved supervisor(s);
- through expert guidance by senior R&D researcher(s) of an industrial partner;
- in an excellent research environment in multidisciplinary teams and international collaborations;
- using state-of-the-art facilities, equipment and research setups;
- with support from highly qualified research support staff to learn a broad range of techniques.

Disciplinary courses

Each PhD is enrolled in the local graduate program of the host university. In addition, ARC CBBC expects its PhDs and PDs to make use of the broad set of courses that have been developed in the framework of the KNAW accredited interuniversity research schools (if there is one in their field of disciplines). Finally, each PhD and PD will participate in at least one summer or winter school in his/her scientific field. To this end, each PhD and PD receives a personal schooling budget (part of the tariff as agreed in the ARC CBBC Consortium Agreement). The ARC CBBC PhDs and PDs are required to take courses outside their own discipline to broaden their knowledge; paving the way for multidisciplinary project collaborations.

Training in multidisciplinary and multiscale science approaches

To be able to work in the Flagships and multilateral projects as well as in the bilateral projects with their multidisciplinary approach, PhDs and PDs need to obtain knowledge on more than just their field of expertise. To this end, ARC CBBC will developed several activities.

- ARC CBBC Summer School for each Flagship
- Lab tours at the three hub-locations: which can be combined with a mini symposium and expanded to visit other locations.
- Personal development and transferable skills: additional to the courses that the universities provide, ARC CBBC will (co-)organize additional workshops and activities related to transferrable skills that are specifically needed to work in or participate with the industry. Examples are entrepreneurship, IP rights and confidentiality, valorization possibilities, patent applications, startup possibilities, open access of publications and data, and storytelling. To gain more insight into the work of related industries, ARC CBBC will organize excursions and company visits.
- Industrial secondment

ARC CBBC Membership

ARC CBBC strives to create an active, well-connected community; a multidisciplinary network based on sharing information and insights concerning fundamental research and technology development between various scientific disciplines and industrial partners.

In December 2016, the first group of 39 members have been appointed, after careful review by the SAB of applications of interested researchers within the Netherlands. In 2017, all of the appointed members were able to participate in ARC CBBC as their seven research institutions that were not founding partners joined the consortium as public associate partners. The members participated in several events and represented sufficient fields of expertise for the current bilateral projects and Flagships. The EB decided not to open a new call for member applications, in order to provide all current members the opportunity to be involved in projects before further expanding the community. In the future, ARC CBBC expects to open new membership application rounds, aiming in particular or the new generations of researchers.

Terminated memberships

Jorge Gascon left his appointment at Technical University Delft to take up a new position at the Catalysis Center of KAUST in Saudi Arabia. As a consequence, his membership is terminated as of 1 January 2018.

Volker Hessel left Eindhoven University of Technology to take up a position a Deputy Dean Research and Level E academic in the School of Chemical Engineering at the University of Adelaide in Australia. As a consequence, his membership is terminated as of 15 April 2018.

Support Office

The ARC CBBC Support Office is formally accommodated by Utrecht University. The current composition of the Support Office is:

Support office
Drs. Emke Molnar, Managing Director
Dr. Maurice Mourad, Program Coordinator
Drs. Anne-Claire Hoenson, Office Manager
Drs. Tjitske Visscher, Communication Officer
Ron Gunneweg, Financial Officer

New Full Private Partners

ARC CBBC aims to take up new Full Private Partners. Several large companies have expressed their interest in joining the consortium. ARC CBBC is now discussing options with those potential Full Private Partners. In this matter, the ARC CBBC Chair and Scientific Director operate in close coordination with the SB, that has developed a proposal in which the conditions of Private Partnership are outlined. During the next months, this proposal will be discussed in both the EB and the SB.

Associate Private Partners

The EB decided on guidelines for enabling Small and Medium sized Enterprises (SME) to become an Associate Partner to the consortium. It is foreseen that SME will directly be involved in the research projects. Project participation is currently being discussed with several SMEs. The EB has provided for private companies, including SMEs, to become future Associate Private Partners of ARC CBBC through participation in both the Bilateral as well as the Multilateral Program. The EB has decided on the accession procedure and ways new partners can be involved which should be acceptable to both candidates and the consortium.

List of abbreviations

EB	Executive Board
EZK	Ministry of Economic Affairs and Climate Policy (www.government.nl/ministries/ministry-of-economic-affairs-and-climate-policy')
FMS	Research Center for Functional Molecular Systems (www.fmsresearch.nl)
MCEC	Netherlands Center for Multiscale Catalytic Energy Conversion (www.mcec-researchcenter.nl)
NWO	Netherlands Organisation for Scientific Research (www.nwo.nl/en)
OCW	Ministry of Education, Culture and Science (www.government.nl/ministries/ministry-of-education-culture-and-science)
PD	Postdoc
PI	Principal Investigator
SAB	Scientific Advisory Board
SB	Supervisory Board
TU/e	Eindhoven University of Technology
UU	Utrecht University
RUG	University of Groningen

Advanced Research Center
Chemical Building Blocks Consortium

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ARC CBBC is co-founded and co-financed by the Netherlands Organisation for Scientific Research (NWO) and the Ministry of Economic Affairs and Climate Policy.