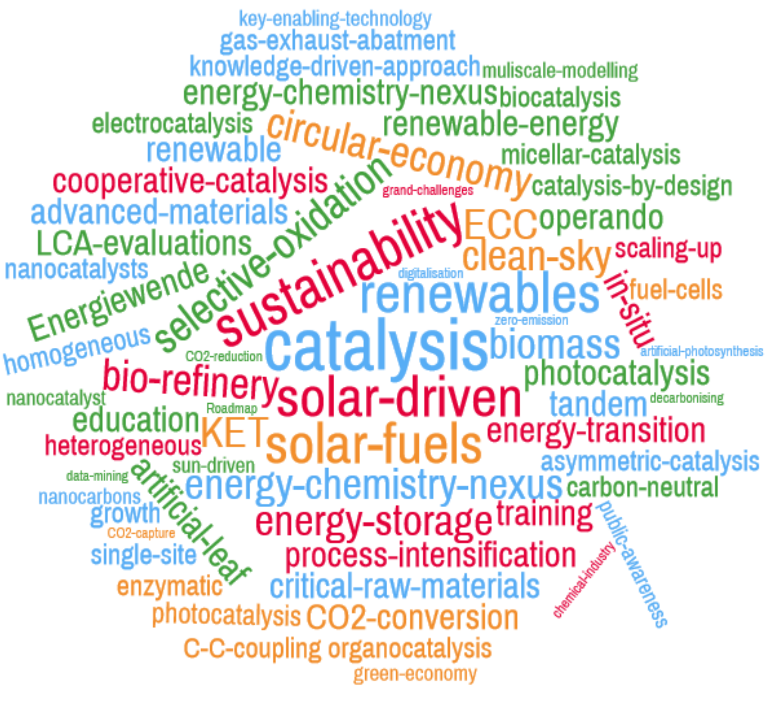
European Cluster on Catalysis

Catalysis Research towards FP9

Strategy Paper

February 2018



EXECUTIVE SUMMARY

Catalysis is a key technology for Europe

Catalysis is the **most interdisciplinary and overarching technology** in the process and chemical industry.

Catalysis research underpins several strategic industrial sectors: from energy to the manufacturing of materials and industrial processes, products as well as digital applications and devices. Catalysis has a **key enabling role** in environmental protection, particularly in recycling waste and reduction of greenhouse gases. Catalysis represents a key technology for the European economy. It also opens new routes to sustainable and environmentally friendly green processes and products.

Europe is still a leading player in both academic research and in the industrial implementation of catalysis technology. However, the European leadership in catalysis is progressively threatened by the present fragmentation, the insufficient coordination between European and national activities, the decrease of funds for fundamental research in many European countries, the lack of large-scale research infrastructures dedicated to catalysis and the strong competition from other mayor world regions.

The most current challenging endeavor is to explore a paradigm shift in better addressing innovation in catalysis at a European level. The European industrial leadership in manufacturing has been critically dependent on the innovation capability in catalysis and chemistry. Therefore, a European approach should enable the acquisition of knowledge, which is necessary to maintain the frontend capability in catalysis research in order to open new and sustainable paths of production, resulting in a true innovation capacity which is able to turn the progressive loss of manufacturing capacity in Europe.

The European catalysis research policy needs an **integrated and coordinated approach** to several disciplines along the value-chain in order to create and keep a critical mass to be more successful. Consequently, future European research funding efforts should reflect the complexity and interrelation among the different knowledge-based parts of the multifaceted world and should be coordinated at EU level.

Catalysis is a key technology for Europe and the world. As such, it should be further strongly supported through significant research financing allowing an in-depth and high-class research in Europe.

The present document is the main output of the third meeting of the European Cluster on Catalysis and is intended to provide the European Commission a strategy paper on the future of European catalysis research.

WORKSHOP OBJECTIVES AND MAIN OUTCOME

The workshop of the European Cluster on Catalysis was held at the European Commission in Brussels on 24th January 2018, gathering together participants and experts from academia and industry from all over Europe.

The main goals of the workshop were to:

- Define and implement actions to get better visibility and raise awareness for catalysis research among EU research policy makers, citizens and stakeholders.
- Provide strategic input for the future European research programme.

The following main policy challenges have been addressed during the workshop:

- Visibility and public awareness of the relevance of catalysis for the European economy, environment and public health.
- Communication towards EU research policy makers regarding the strategic opportunity to invest in catalysis in the forthcoming European Research Framework Programme (FP9).

As output of the workshop, this final report in the format of a **strategy paper** contains a number of recommendations and indications for EU research policy makers to define public research financing in the area of catalysis in future research programmes taking into account the key importance of catalysis for Europe.

This report is the result of the work of the workshop participants and more than 800 cluster stakeholders that have been consulted.

THE ROLE OF CATALYSIS IN EUROPE GROWTH AND COMPETITIVENESS

Catalysis has been a long-standing key enabling factor for sustainability as well as for the competiveness of the chemical and energy production vectors, and for this reason, it plays a **key critical role in shaping the future of these areas and of the energy transition**. Besides playing an outstanding role in many environmental technologies and dynamically addressing societal challenges, catalysis is one of the utmost cross-cutting and key enabling disciplines in chemical and energy industry, clean-up technologies and processes, as well as a key science to reduce climate change impact and improve sustainability of production. It can be stated without exaggerating that catalysis is the single most important and **pervasive interdisciplinary technology** in the chemical industry, and perhaps one of the disciplines having the largest societal impact, although this impact is often hidden, poorly recognised or underestimated. It still represents one of the research and development areas in which Europe is still a leading player, namely in academic research on catalysis, but especially in the industrial manufacture of catalysts, with a market value of several B€. Nevertheless, this leadership is increasingly being threatened by steeply growing economies such as China, or mature but still innovating economies such as the US or Japan. European leadership in catalysis is progressively eroded by the still present fragmentation, the insufficient coordination between European and country-based activities, leading to jeopardised efforts, the sometimes dramatic decrease of funds for fundamental research in many European countries, and the lack of large-scale infrastructures dedicated to catalysis.

Catalyst development is **intrinsically highly interdisciplinary**, because it requires knowledge ranging from surface science to reactor engineering, with the need to optimise the catalyst from the nano-level of active sites to the metre-level of reactor operations, and from the pico-second level of surface processes to the year-level of technical operations. For this reason, multiple and different disciplines are required in catalyst development, but for this reason catalysis is often not considered as a science in itself, but as a *tool* for other disciplines. This creates an intrinsic weakness in bridging the gaps from fundamental developments to applied ones. A **step-change** in this approach is necessary to accelerate the rate at which the large potential in research in catalysis in Europe could be fast applied from the leading companies in Europe, therefore turning into an outstanding market potential.

One of the most important objectives in catalysis should be to enhance innovation and wealth creation. This requires a **spectrum of connected activities and capabilities from**

fundamental science through development work to application in industrial processes and markets, with an efficient exchange of information and insights throughout.

Catalysis in the context of the European industry

The production of chemicals and energy vectors in Europe is changing very rapidly with the goal to enhance competitiveness and to address societal challenges, the foremost being the effort to transition to a clean and sustainable future. Traditional raw materials as well as, sometimes, critical raw materials have to be substituted with more sustainable resources; cleaner and more intensified processes have to be developed, new production concepts must be implemented to combine high efficiency with changing and more variable feedstocks (waste for instance), flexible and modular production and new ways to use energy in chemical transformations have to be realised. There is thus an evolving scenario to move to a new economic cycle characterised by a seamless interconnection between energy and materials science, implemented with Green Chemistry principles. Many economic indicators confirm the reality of this transition and it is therefore critical to intensify research and development to enable the transition and **exploit the energy-chemistry nexus**.

The role of catalysis will be partially reshaped by the spread of reliable electrical mobility, catalysis can contribute to many of the missions of Innovation Europe and to the main societal challenges (reduced and zero emission, de-carbonising transport by for instance the production of neutral fuels by power to liquid concepts or from waste valorisation, carbon-neutral economy, circular economy). In the production of many healthcare, pharmaceutical, and agrochemical products, catalysis is a core technology, thereby raising our living standards.

Main core characteristics: Catalysis is a **key enabling technology** for most of the seven societal challenges in the European Research Framework Programme Horizon 2020. In fact, as evidence for global climate change continues to grow, catalysis has moved to the front line of the struggle to obtain new, sustainable technologies for the future. Catalysis technology is intimately intertwined with new and emerging solutions for our current and future supply of energy.

Therefore, a **green and sustainable future economy** is critically dependent on continued advances in the field of catalysis, which are directed to improve energy efficiency, to enhance and open up new pathways for energy conversion and storage and to reduce the environmental impacts related to industrial production and transport. In the current "from sun to fossil fuels and back again" transition, catalysis may play a primary role in many of the solar-powered technical routes for the **production of renewable materials and energy vectors**. This approach should also be extended to the wind-powered technical route.

Catalysis and catalytic processes account, directly or indirectly, for 20-30 % of world Gross Domestic Product (GDP). Furthermore, the manufacture of catalysts in Europe has a large economic impact equal to 3-4 B€ (global market for catalysts: US$ 16.3 billion in 2012, chemical processing accounting ~ 75%, petroleum refining ~ 25%). Of the 50 largest volume chemicals currently produced, 30 are produced via catalytic routes, and most of the others are subsequently used in catalytic processes to manufacture derivatives. These 50 highest volume processes account for more than 20 billion tons of carbon dioxide emitted to the atmosphere each year. The manufacture of 18 products (among thousands) accounts for 80% of the energy demand and 75% of greenhouse gas (GHG) emissions in the chemical industry. Technical improvements in catalyst and catalyst-related processes could reduce energy intensity for these products by 20% to 40% as a whole by 2050.

More than 85% of all of today's chemical products are produced using catalytic processes, and catalytic processes enable the modern refining of fuels. Nevertheless, catalysis goes far beyond the chemical and pharmaceutical industries and petroleum refineries. It has a critical role in **enabling a sustainable use of energy**, for example in fuel cells and batteries, in the production of fossil- and bio-fuels, as well as in many consumer-orientated applications (for instance, washing powders), in addition to protecting our environment and climate. Catalysis is thus **at the core of the European process industry**, one of the economic roots of the European economy (by transforming raw materials into intermediate and end-user products).

Catalysis must be placed among the core enabling sciences and technologies to achieve the strategic goals defined by the European Commission in the Europe 2020 strategy and across its various flagship initiatives beyond Horizon 2020.

Industrial potential. The EU manufacturing sector remains strong, but production of commodities is rapidly moving towards China, where manpower is much cheaper and where the goods are actually sold, as manufacturing products locally helps to lower their carbon footprint. Additionally, traditional production of chemicals is moving towards countries where the feedstocks are cheaper. Therefore, progress in catalysis is required to support the redesign of the chemical industry and manufacturing in Europe, and to increase its, potentially very large, market potential. Many SMEs have their core-business in bioenergy or biomass, but highly specialised SMEs are not able to address the grand challenges in catalysis related to these specific fields. Therefore, **an effort at the European level**, able to support and structure research in the field of catalysis, is required.

In addition, and more importantly, catalysis **underpins several European industrial strategic sectors** (from energy to manufacture of materials and products), including its enabling role for environmental protection (from air/water industrial and municipal emissions, to the treatment of mobile emissions), recycling of waste and reduction of GHGs (Green House Gases). Catalysis thus represents a true key technology for Europe's economy, job creation, industry, growth and sustainable future.

Due to the on-going energy transition, the demand for catalysts will change radically since completely new methods to store electric energy and replace our feedstocks for chemical products, fuels and energy are being established. A further opportunity in this field arises from the **use and application of unconventional feedstocks**.

The role of catalysis in **Circular Economy** is also relevant, since, for instance, catalysis can solve the problem of waste (biogenic, fossil, municipal, industrial, etc.) by targeting either the recycling of high value building blocks or the degradation and rebuilding of molecules of interest. As such, the possibility is emerging for a unified energy and chemical production, based only on renewable sources for both energy and materials. Here, waste carbon sources (in integration and symbiosis with biomass-derived raw materials) will be the dominant, if not exclusive, source for the latter.

Threats and opportunities. Despite its outstanding relevance, the importance of catalysis in Europe is nevertheless often **underestimated**. In addition, it is often just considered a tool, rather than an enabling science. The fragmentation and lack of coordination in R&D efforts in catalysis exacerbates this situation. Efforts should be made to enhance the visibility of catalysis, which should be much higher than now.

Very recently, the High-Level Strategy Group on Industrial Technology of the European Commission[1], in its Conference Document "Re-finding industry", has provided a new and broader definition of **Key Enabling Technology (KET)**, which encompasses i. impact, ii. relevance, iii. key capacity and iv. enabling power.

Catalysis represents a crucial element for the proposed two KETs "Advanced Manufacturing Technologies" and "Advanced Materials and Nanotechnologies" and related missions,

[1] "Re-finding industry" Conference Document of the High-Level Strategy Group on Industrial Technology of the European Commission, February, 23th, 2018.

notably among which “Industry renewal”, “Circular economy – shift to de-production and re-production”, “Carbon re-use - from climate killer to industry asset” and “Energy independence - affordable renewables”, although roles can also be identified in other proposed missions.

Because of this broad impact among these many horizontal KETS and missions, catalysis should be a **vertical sub-KET** to which **specific support actions** should be defined to enable its full role and effectiveness. Catalysis has i) a substantial impact in creating high quality jobs, improving the life of the people, ii) a systemic relevance for all phases of product development, ensuring the leadership of Europe across the whole value chain, iii) the capacity, through the development of pharmaceuticals, automotive catalysts, cosmetics, better materials, etc. to foster sustainable growth and improve the health, safety, security of people and iv) the potential to enable multiple and cross-sectoral industrial applications, which can promote global excellence of European research, new knowledge.

A suitable funding scheme could be a **flagship focussed on catalysis intelligence and innovation for the energy transition global challenge or other large dedicated initiatives**. These actions should be implemented by the European Commission in the forthcoming FP9, to support efforts throughout the whole spectrum, from fundamental to industrial research and market. In order to meet the COP goals (see www.cop21paris.org/about/cop21), a much more substantial effort in terms of budget is needed to develop the energy technologies that will enable the clean energy transition. Catalysis will play the pivotal role of Key Enabling Technology in many of the technological solutions to be developed in the context of the energy transition.

> The impact of catalysis for environmental sustainability and societal benefits should be fostered in a more effective way, since of even larger importance than the economic benefits.

The advent of **digitalisation** (big data analysis, data mining) and machine learning technologies combined with high-throughput, promises to revolutionise the rational design of catalysts, leading to unprecedented breakthrough technologies.

Besides investments in R&D, catalysis also deserves attention from the point of view of its **economic impact**. The market is changing rapidly and the embedded contribution of catalysis in many manufacturing-related sectors is often overlooked. Most catalyst producers (a market of over 12 B€) have headquarters located in Europe, but the ongoing transition may **decrease the current market by up to 70%** if new opportunities are not identified. This will have a large impact on employment, which can be estimated in over 200.000 **lost jobs**, often by highly qualified people (either directly or indirectly). In addition, the **overall economic value of catalysis** should be fully recognised, encompassing not only the direct catalyst market, but also the relevant share of markets enabled by catalysis.

In this regard, a dedicated action (Coordinated and Support Action - CSA) to estimate the effective impact of catalysis on the European economy is recommended based on thorough data provided by market analysis and surveys. This study should determine the optimal strategies, with recommendations for companies, on how to reconvert the actual S&T capabilities in catalysis to new market opportunities and industrial needs. At the same time, academic research on catalysis in Europe should be aligned to these new directions.

Concerning the involvement of the industry in large collaborative projects on catalysis, which is still scarce and for which better models are required, possible corrective actions can be outlined. There is a strong emphasis on demonstration scale/moving to higher Technology Readiness Level (TRL), which is partly driven by the chemical industry being less active at TRL5-7 themselves. Nevertheless, efforts to better coordinate innovative ERC-type (TRL1-3) research to the NMBP-type. research (TRL $\geq$ 5) should be undertaken, and development work at the interface of TRL3-5 should be safeguarded.

An important element remarked is that the on-going transition in energy and chemical production determines the entrance in the marked of catalysis and related devices of new market player, **especially SMEs**, for example in the manufacture of catalytic electrodes and energy (nano)materials for solar and electro cells. These companies need to redefine the relation actually present between academy and research Institutions and large catalyst producers. The Cluster of Catalysis and the proposed CSA could play a crucial role in this direction.

NEW VISIONS AND GRAND CHALLENGES FOR EUROPEAN CATALYSIS

Currently, the science of catalysis is moving **from description to prediction**, supported by ever more powerful **computational, analytical and *in situ/operando* techniques**. Each time new tools have become available, catalysis has made a significant step forward, hence this interplay needs to be tightened. Faster and more effective approaches to the development of innovative catalytic materials for new or evolving chemical processes (see societal, ecological and economic constraints analysed above) are in demand. However, translation into economic and societal benefits will require a continuum of connected activities from fundamental research to commercial catalyst manufacture and operation, with a thorough exchange of information, ideas and insights across this spectrum. International competitive advantage is likely to depend upon the effectiveness of this <u>ecosystem for technology transfer</u>.

Important elements of such new approaches include **computational modelling** of catalytic processes at various size- and time-scales (i.e. **multiscale modelling**), hierarchical understanding at all levels, from the atomic to the macroscale; this in addition to advanced or unconventional synthetic approaches, which have to be sustainable and scalable, aimed at delivering materials with improved catalytic performance, preferably starting from cheap, earth-abundant, easily accessible and low ecological impact-raw materials. Accelerating the development cycle for catalysts by computational methods is a viable approach, which could be pursued in tight synergy with the European Materials Modelling Council (emmc.info/), also established by the European Commission within the Cluster initiative. "**Catalyst intelligence**", e.g. the creation of smarter, faster and more effective ways to develop catalysts, is a further key concept in the multi-scale development of new and better performing catalysts. This will include computational modelling and in principle a digital twin.

Analogously, since the testing and the functional assessment of produced catalysts is very relevant to catalyst development, interactions and synergies can also be envisioned with the recently established European Materials Characterisation Council (EMCC) (characterisation.eu/).

The catalytic site economy, maximising the use of resources and atom economy, should become a research target. In this regard, **catalysis by design**, design of catalysts <u>at the atomic level,</u> and multifunctionality should be pursued by harnessing the creativity of the **excellent European research landscape**. Furthermore, new approaches are required to accelerate the transfer of ‘catalysis by design’ to practical commercial catalyst manufacture and industrial operation to support the above-mentioned transition. This also includes the transfer of tools available at large-scale facilities (synchrotron radiation sources, neutron sources, new electron microscopy centres) to the field of catalysis and lab infrastructures to those facilities. Completely new prospects will become possible with newly built, planned and upgraded sources.

The emerging opportunity for ‘catalysis by design’ created by advances in atomic scale understanding, analytical and in-*situ/operando* tools, computational methods is very exciting and represents a potential source of future competitive advantage. However, this still requires a much stronger link with practical and cost effective catalyst manufacturing and commercial operation in order to realise these potential economic, societal and competitive advantages.

To cope with these challenges, it is essential to foster and enhance the **synergy between fundamental research and technological applications**. Relevant aspects here include the integration of new catalytic materials, molecular chemistry and biosciences. Successful realisation of new catalytic solutions and technologies requires integration (in an inter- and multidisciplinary approach) of knowledge and expertise from fundamental areas (chemistry, physics, biology, mathematics, etc.), engineering (chemical and material engineering) and applied (industrial chemistry, etc.) aspects. Integration of *a priori* theoretical modelling with *in-situ/ operando* studies to understand the reaction mechanisms, science of catalyst preparation at the nanoscale level, advanced micro-kinetics and reactor modelling are examples of current trends in catalysis, which need to be raised to an enhanced level, along with eventual transferral into commercial catalyst manufacturing and operation. Another challenge is to pursue a unified approach for homogeneous, heterogeneous and bio-catalysis. All these aspects are elements of the generic “catalysis by design” challenge that are supported by new large-scale facilities in Europe providing high-energy neutron and X-ray radiation.

In this broad development framework, Life Cycle analysis (LCA) and Life Cycle Cost (LCC) could aid in the exploration of innovative routes to more sustainable and efficient generations of catalysts. However, **dedicated methodologies and metrics** for catalysis studies should be developed.

In parallel with new paradigms for catalyst developments, there is a need to **redesign chemical processes to minimise the use of fossil fuels**, essentially by directly using renewable energy sources (eventually through the intermediate production of solar or wind fuels/chemicals) or indirectly via renewable carbon sources (see the previous analysis on renewable biogenic sources of energy), rather than heat produced from fossil fuels combustion, to drive the chemical conversion. This means the development of novel processes driven by electrons, photons, electromagnetic radiation (e.g. microwaves), plasma-generated reactive species, etc. or adapted to new renewable feedstocks (biogenic types). This will require, for example, **conceptually new types of catalysts**, which are able to control selectively the reaction pathways in the presence of these highly-energy inputs. Energy selectivity will be a sustainability factor reinforcing carbon-selectivity and, for this reason, new approaches to catalyst and process design will be necessary. In the medium-term, new catalytic materials for efficient solar light harvesting and power-to-X conversion technologies are necessary, with biomass finding its niche as a source of biofuels (for transport, especially aviation and heavy trucks) and green materials.

Among the emerging fields in catalysis, **electro-catalysis** is a very challenging one that could nevertheless enable a more competitive and efficient production and use of renewable energy; efforts in this field would therefore be justified.

Although **heterogeneous (solid) catalysis** will likely still dominate future industrial applications of this science, it is evident that many of the new challenges facing catalysis, from the use of solar energy to the use of bio-mass, require **integrating homogeneous, heterogeneous, enzymatic and bio-catalysis**. It is thus of critical relevance to foster this integration and develop a common vision between these scientific areas and overcome the remaining barriers.

Nowadays, catalysis is facing **further important challenges with respect to energy transition**, converting different forms of energy (electrical, light, thermal) to chemicals and *vice-versa*. This also leads to important questions with respect to the intermittent operation of catalysts, and the replacement of critical raw materials such as noble metals by earth-abundant, less polluting and cost effective materials. Additionally, challenges with respect to chemical reaction engineering (process intensification, electrochemical reaction engineering) have to be effectively addressed. Traditional interfaces with the chemical and manufacturing industries will remain important, but new approaches and synergies are required. Energy stakeholders (energy producers, network owners) should be involved in the process of redefining the future of catalysis, and connection to smart city initiatives are also needed. CO_2 capture will become more important, leading to challenges in materials design and in the development of more efficient catalysts. Despite the general trend towards

Electromobility, combustion engines will still be the prevailing technology for individual transport over the next decades. Recent discussions demonstrate that there are still significant issues to be solved by catalysis in the field of automotive exhaust gas cleaning in order to achieve clean air in urban areas.

From a **strategic point of view**, open innovation models should be explored such as, but not limited to, innovation hubs and the Energy Lab 2.0 at KIT (elab2.kit.edu/english/index.php). Similar initiatives, as well as a better integration and coordination between Framework Program and the European Structural Funds (ESF) distributed at regional level, should also foster regional-wide cooperation schemes in which innovation hubs with specific focus should be established in the different EU Regions.

Educational and training efforts, devised and structured based on the current directions of catalysis, should be undertaken at the European level, training a new generation of scientists able to work in a highly interdisciplinary, pervasive and trans-sectoral field. In this regard, the support of public funding becomes mandatory to foster this cultural transition

BACKGROUND: A MOVE TO COORDINATE CATALYSIS RESEARCH IN EUROPE - THE EUROPEAN CLUSTER ON CATALYSIS

The European leadership in catalysis is progressively eroded by still present **fragmentation, insufficient coordination** between European and National-based activities, the sometimes dramatic decrease of funds for fundamental research in many European countries, and the lack of large-scale infrastructures dedicated to catalysis.

To cope with these issues, and to address further strategic challenges for Europe, the European Commission launched, at the beginning of 2015, a thematic **European Cluster on Catalysis**, bringing together EU funded projects and other stakeholders in this field as well as closely related ones. The main aims of this Cluster initiative are to better integrate fragmented activities in Europe, create synergies between EU funded projects and other stakeholders, and provide inputs on potential future research needs to the EU.

The Cluster, numbering more than 800 affiliate scientists from all over Europe, is conceived as an open and dynamic platform accessible to all players and stakeholders, both from academia and industry, whose activity is focused on catalysis and applications thereof.

EUROPEAN ROADMAP ON SCIENCE AND TECHNOLOGY OF CATALYSIS

One of the main outputs of the Cluster was a **"European Roadmap on Science and Technology of Catalysis** (ISBN 979-12-200-1453-3; 2016)**. A path to create a sustainable future".** The initial comprehensive draft was subject to extensive public consultation involving many universities, research institutes, organisations, companies and individual scientists from all over Europe, committed to improve the Roadmap and pursue a shared European vision.

The Roadmap is organised into three main sections, plus three thematic Annexes. The first part is dedicated to vision and scenario analysis. Catalysis is an **enabling technology for chemical production and sustainable energy by leading to a carbon-neutral society**, therefore this first part of the Roadmap necessarily has a broader scope beyond catalysis itself, and addresses possible scenarios (from sustainability and competiveness perspectives) for the chemicals, transport and energy sectors.

The second part of the Roadmap is dedicated to the identification of high-level goals for catalysis, and for this reason focussed on discussing of the "**grand challenges for catalysis**":

1. To address the evolving energy and chemical scenario;
2. To pursue a cleaner and a more sustainable future;
3. To address catalysis complexity, which can be subdivided into four topics: (i) advanced design of novel catalysts, (ii) understanding catalysts from molecular to material scale and from model to realistic reaction conditions with novel upcoming tools, (iii) expanding catalysis concepts and (iv) theory, multiscale engineering concepts.

The third part is dedicated to the strategic research agenda and implementation plan for the grand-challenges for catalysis. This section is based on the previous existing roadmaps and documents on catalysis, but provides a new integrated approach based on the identified high-level goals.

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ANNEX

Agenda: European Cluster on Catalysis Meeting, European Commission, Brussels, 24th January 2018

Agenda

13:30-14:00	Arrival, registration, coffee	
14:00-14:15	Introduction to the meeting	Dr. Helge Wessel European Commission
14:15-14:45	FP9: Strategy and indicative structure	Dr. Debby De Roover European Commission (RTD/A3)
14:45-15:00	European Cluster on Catalysis: Motivation, history, impact	Prof. Silvia Gross University of Padova
15:00-15:15	Review: Science and Technology Roadmap on Catalysis for Europe – a valuable input for policy making	Prof. Gabriele Centi University of Messina
15:15-16:15	Future activities of the Cluster - to strengthen the Cluster impact within a medium / long term vision - to increase participation of industrial stakeholders Catalysis research in FP9, input from the Cluster: Challenges, instruments, resources…	Introduction: Prof. Gabriele Centi Open discussion among participants
16:15-16:45	Timeline, tasks, format of input Synergies with other Clusters	Gabriele Centi, Silvia Gross
16:45	End of the meeting	