Towards a System Approach for Materials Research, Development and Innovation for Europe

Margarethe Hofmann-Amtenbrink, Heinrich Hofmann, Rudy Koopmans, Erik Schuring, Jan Meneve, Roland Gauss, Amaya Igartua, Paloma Fernández*

Dr. M.Hofmann-Amtenbrink FEMS President (2014-2015), Matsearch Consulting, 1009 Pully, Switzerland, E-mail: mhofmann@matsearch.ch (*corresponding author)

Prof.em. H.Hofmann, Institute of Materials, Ecole Polytechique Fédérale de Lausanne, EPFL, 1000 Lausanne, Switzerland E-mail: heinrich.hofmann@epfl.ch

Prof. R. Koopmans, Plastic Innovation Competence Center, Haut Ecole d'ingénierie et d'architecture Fribourg, 1700 Fribourg, Switzerland, E-mail: rudy.koopmans@gmail.com

Dr. E. Schuring, Energy Research Centre of the Netherlands, Part of TNO, NL-1755 ZG Petten, The Netherlands, E-mail: erik.schuring@tno.nl

J.Meneve, VITO N.V., 2400 Mol, Begium, E-mail: jan.meneve@vito.be

Dr. R.Gauss, EIT RawMaterials GmbH, 10789 Berlin, Germany, E-mail: roland.gauss@eitrawmaterials.eu

Dr. A.Igartua, EUMAT Co-secretary, IK4-TEKNIKER, 20600 Eibar, Spain, E-mail: amaya.igartua@tekniker.es

Prof. Paloma Fernández, FEMS President (2018-2019), Dept. Materials Physics, Faculty of Physics, University Complutense, 28040 Madrid, Spain, E-mail: arana@ucm.es

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Summary

The present model of a stand-alone materials research, development and innovation (R&D&I) is based on the 20th Century linear production-consumption concept. It does not align to effectively address complex 21st Century societal challenges. In HORIZON EUROPE, the ninth European Framework Programme, materials R&D&I becomes part of Mission Oriented Research and Innovation. The ambition of Missions is paradigmatically shifting science and technology development that impact the fabric of society. Advanced materials science and technology are key enablers to successfully conclude those Missions. However, the structuring a large-scale programme typically fragments the Materials R&D&I efforts. The engagement of multiple industrial sectors operating at different technology readiness levels and each with distinctive commercial ambitions and interests leads to loss of oversight and missing out on potential synergies to effectively advance future materials research. Thus, a European Materials Innovation Strategy is needed that monitors and coordinates the EU's investments into materials R&D&I. Alliance for Materials (A4M) was launched in December 2010, thanks to the collaboration of several European Technology Platforms (ETP's) and materials societies like the Federation of European Materials Societies (FEMS) and the European Materials Research Society (EMRS), sharing a strong Materials agenda. The main driving force was "*to ensure a Value Chain coverage to improve the speed of implementation of innovations in Europe that address the Grand Societal challenges*[1]". At this point, an update of A4M is required to ensure a strategy of oversight and enables information flow and knowledge transfer across fields of technology fields and industrial sectors. This update concerns the implementation of a functional European Materials & Engineering Advisory Group, EMEAG, in a reinforced A4M. Such an Advisory Group in the reinforced Alliance for Materials (A4M) can boost business creation, identify specific materials demands across technology fields, provide cross-fertilisation along the Technology Readiness Levels (TRLs), identify cases for industrial symbioses, remanufacturing, reuse and design for recycling. In brief, a reinforced A4M having a functional European Materials & Engineering Advisory Group can create solid knowledge base to ensure the implementation of true circular economy business models.

1. The Path Forward

Future materials R&D&I must deal with the major societal challenges as clearly articulated by many governmental and knowledge organisations. This relates to topics such as: Clean Energy, Health, Demographic Change and Well-Being, Population Growth, Food and Water Security, Green and Integrated Transport, and Climate Change. Today's materials R&D&I model of stand-alone thematic efforts is based on a 20th Century linear production-consumption-waste paradigm. Mainly, it has resulted in very specific evolutionary materials and materials processing advancements in the various industrial sectors. Characteristic projects have timelines that are typically very short- to medium-term (months, a few years) and are mostly driven by low risk taking and quick economic gains. They are by far inadequate vis-à-vis the required solutions and impacts. Therefore, it must be Europe's new Framework Programme (HORIZON EUROPE, FP9) mission, to engage for the longer term. Structural changes must be supported that focus on maximising the circularity of existing materials uses. Also exploration must be driven of novel avenues for renewable, biobased materials and smarter, recyclable metal and mineral based products manufactured and (re-)used at scale. Sole dependence on anticipated disruptive technologies as to bring novel materials and their manufacturing, processing, and uses, however, is inadequate even in the long term as demonstrated from past experiences. However, materials R&D&I that is mainly driven by improving performance and reducing costs at the other hand is equally faced with new challenges. For example, sustainable availability and access to critical raw materials and intermediates is an ever more important issue as mentioned in various reports by the European Commission[2-4]. Specific materials that are essential for the functioning of many communication technologies such as tantalum, indium, and rare earth elements ("scare metals") are essential and of strategic importance for entire industrial sectors[5]. Many of these raw materials are only mined in few (non-European) deposits worldwide or produced as by-products of other, base metals. To improve the understanding of the complex situation of raw and critical materials, Armin Reller[5] suggests that "the supply chain from raw material to the final product or device has to be transparent", in order to develop resilient supply chains for Key Enabling Technologies that are environmentally sustainable. Another issue is related to materials efficiency. Julian M. Allwood and Michael F. Ashby[6,7] discussed models for improved materials efficiency in an interdisciplinary approach, aiming to draw insights from economics, sociology, design and policy as much as from environmental or technical analysis". In his thesis in 2018 "Industry and policy implementation of material efficiency", Simone Cooper-Searle[8] concludes that for over 20 years, however, improvements in material efficiency via various strategies like including diverting manufacturing scrap; extending product lifetimes; using products more intensively and reusing material without remelting, has remained a potentially significant, though yet under-explored approach. Similar statements are published by the EU-Commission in the report "Critical raw materials for the EU" [2,3]

The present EU supported projects have a timespan of typical 3-4 year, have and can further generate innovative solutions to the specific challenges. Past experience indicates however that far too often the outcomes do not materialise into game-changing industrial implementations that address true societal challenges. When the funding stops the developments stop and the research team is disbanded in many cases. In one of its workshops of the FP7 Project MatVal [9], M. Basista and M. Hofmann-Amtenbrink reported on the various barriers for innovative materials R&D&I based on a survey of materials related industries and academia in Europe[10]. They mention among others i) the timescale disconnect in the transfer of knowledge from academia to industry, ii) the lack of continuity in R&D&I funding, iii) the lack of standards for measuring the targeted properties, iv) the lack of protocols and test equipment to assess materials durability during their lifecycle, v) the lack of knowledge of health and environmental hazards of new materials (e.g. issues related to nanomaterials), vi) no considerations for the material's recyclability after-use and requirements for the acceptability of secondary material, and vii) legislative and commercial barriers for introducing novel materials. The science and technology of materials R&D&I needs connectivity with product design, processing and manufacturing in the various industrial sectors. Furthermore, it needs to be coupled with economic, sociological, and political insights to enable the long term value creation for society.

The 17 Goals of the 2030 Agenda for Sustainable Development[11], adopted by world leaders in September 2015 at an historic UN Summit, are crucial to prepare societal changes. Many of these 17 goals, like health, water and sanitation, energy, infrastructure and industrialisation, liveable cities, sustainable consumption, and climate change cannot be realized without the supply of raw materials, the processing of advanced materials and their manufacturing into smart products. In addition to a long-term research and innovation policy for universities and research institutes, this in particular requires the improved implementation of research outcomes into sustainable technologies and products which should be reusable and/or recyclable as an important objective of research and development. A <u>*systems approach*</u> and <u>*innovation along the entire value chains*</u> is required in combination with a persistent and consistent 'long term' (more than the normal 3-4 years span of FP-projects) materials R&D&I direction that include the systematic evaluation of the business potential of the materials and technologies developed. For the new programme – HORIZON EUROPE – with a term from 2021 to

2027, the Commission is proposing €100 billion for research and innovation[12]. This new programme "*will build on the achievements and success of the previous research and innovation programme (Horizon 2020) and keep the EU at the forefront of global research and innovation*" and is the "*most ambitious research and innovation programme ever*"[9]. Commission Vice-President Jyrki Katainen, responsible for Jobs, Growth, Investment and Competitiveness, mentioned in this press release "*With Horizon Europe, we want to build on this success and continue to make a real difference in the lives of citizens and society as a whole*." Carlos Moedas, Commissioner for Research, Science and Innovation, added: …"*we want to increase funding for the European Research Council to strengthen the EU's global scientific leadership, and reengage citizens by setting ambitious new missions for EU research. We are also proposing a new European Innovation Council to modernise funding for ground-breaking innovation in Europe*"[9].

A mission approach for the longer term, in Europe's 9th Framework Programme (HORIZON EUROPE) can support paradigm shifts focussing on maximising the circularity of existing and new materials uses. Novel value chains must be created by pursuing interdisciplinary in the exploration of novel avenues towards renewable, bio-based materials, multi-materials, and sustainable metals and minerals uses in smarter products that can be manufactured and (re-) used at scale. The authors however fear that the Innovation Actions supported by the European Union as well as the structure of the new Framework Programme HORIZON EUROPE might increase the fragmentation of the Materials R&D&I. Serving various "Missions" with Materials R&D&I at different technology readiness levels in different industrial sectors might result in the duplication of efforts if no common materials use strategy is developed. Disruptive innovation, in particular, often evolves from using knowledge and experience from one field for solving challenges in another one or through a more integrated cross-value chain thinking. Overall, incremental as well as disruptive innovation are essential to sustain European welfare in a globally acting markets and to serve societal challenges, as identified by the United Nations and addressed by the EU Commission Framework Programmes. By definition, such new system solution approaches should at best be monitored by a multistakeholder group, integrating experts from across the raw materials value chains, enabling maximum materials circularity (**Figure 1**).

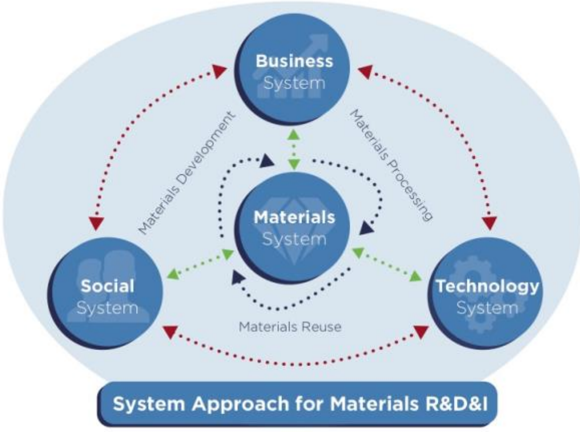

Figure 1. System Approach for Materials R&D&I (Research & Development & Innovation) after M. Hofmann-Amtenbrink

Materials science has been recognised in the FP8 (H2020) programme as a key enabling technology (KET). In 2009 six KETs were identified, which were dealing with materials (advanced manufacturing technologies, advanced materials, nanotechnology, micro- and nano-electronics, industrial biotechnology, and photonics) and chosen as second highest priority for R&I under the regional smart specialisation strategies. The "Report from the High-Level Strategy Group on Industrial Technologies" in February 2018[13] showed, however, that although the *"EU runs an overall trade surplus for manufactured goods a closer look at exports of high-tech products and KETs-based products reveals a deficit for these sectors. The largest deficit for high-tech products was with China."* The report also indicates the problems that companies have with digitalisation and the implementation of new technologies in an increasingly globalised value chain. Just materials development in seems to be no longer of highest importance as it was in the 1990s and the beginning of 2000, as the Industry 4.0 revolution is continuously changing its manufacturing (such as 3D printing, the Internet of Things, advanced robotics, mentioned in the report) and processing (for example, data-driven production, artificial intelligence and synthetic biology also mentioned in the report) approaches. The six KETs are still among the technologies that are most likely to disrupt economies and societies over the next 10-15 years. Materials R&D&I should answer more and more the industrial manufacturing and process needs while addressing societal challenges.

The HORIZON 2020 MATCH project (www.match-a4m.eu/) defined similarities between key industrial sectors and identified important cross-sectional relationships. Such continued monitoring would avoid the kind of silo materials research in separate missions that would only lead to duplication and insufficient valorisation of research results. It would stimulate cross-fertilization between the different materials design and modelling tools, characterization and processing techniques, over the entire HORIZON EUROPE programme, making the results available to each of the projects under the various missions. This is the only way to optimally serve our society within the available budgets. The experience gained with MATCH Project will serve the global aims intended from the relaunched A4M.

2. Innovation driven by Materials Research

New, advanced or smart materials and nanomaterials/nanotechnology laid the foundation for many creative ideas that stimulated innovation in communication, health and energy technologies. These R&D efforts resulted finally in material based innovations. However such technological progress has increased the demand for resources because of the increasing demand for complex materials in innovative products, as seen in **Figure 2**.

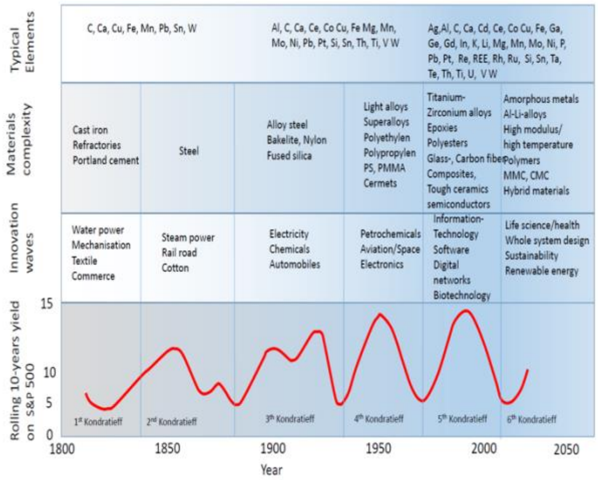

Figure 2: Development of key technologies, new materials and their complexity as well the economic development during the last 200 years. (Sources used: Reller[5], Allianz Global investors Report 2010[14])

This interaction between materials development, technological innovations and their economic impact is also shown in Figure 2 [5, 14], even though it is not evident which mechanism (market push or market pull) led to the observed materials development and increased material complexity.

Examples of research outcomes of Framework-Programmes FP3 to FP8 (HORIZON2020) which enabled innovations for the industry and finally for the citizens are manifold: lighter and more stable composite materials for wind turbine blades, better and more performant magnetic materials for their engines and modern concrete formulations to build highly durable wind turbine housings. Similar materials' innovations were made in photovoltaics, batteries, and other green energy storage or green mobility driven innovations. Self-healing materials have been developed based on materials science allowing for, e.g., reducing maintenance cost and increasing aesthetic performance. In the health sector, polymeric soft lenses, high-value glass and plastic individual progressive lenses, enabled people to keep their jobs by supporting their vision even at an old age, or by keeping their mobility with bio/tissue-engineered materials e.g. in cardiological, dermatological and orthopaedic applications. Better diagnostic agents and more active medicines based on nano-formulations in pharmaceutical products ensure a higher quality in life. While this list of materials driven innovations is far from complete and certainly goes on, materials solutions clearly accompany people every day but often disguised as the product and not as the enabler to the patient or consumer.

The research-outcome of the last 20 to 30 years have indeed led to impactful materials developments that improve people's everyday life. Since 1990 the European Commission has funded more than 13'000 projects dealing with materials[15], besides national and regional funded R&D&I in Europe. The project H2020 MATCH, which ran from 2015 until 2017, evaluated about 1'390 projects having an overall budget of 6.3 billion Euro (with 57% of the projects financed by FP7 and HORIZON2020, the other part by national/regional agencies). As seen in **Figure 3** the majority of projects is funded for 3 years (about 300), followed by those funded for 4 years (nearly 200).

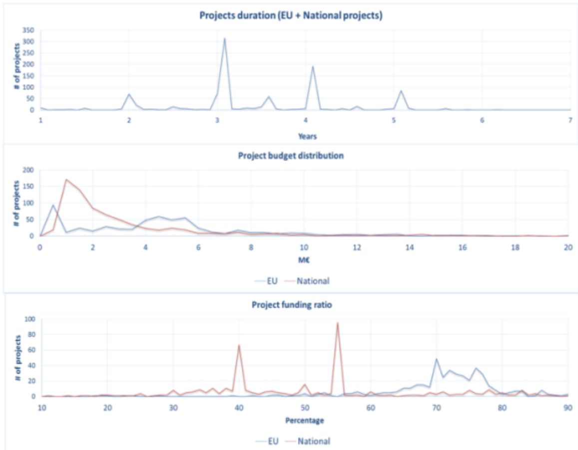

Figure 3: Funding schemes of about 1390 materials related R&D projects under European and national funding regimes and evaluated under the MATCH project in the years 2015 to 2017 (Data provided by Jérôme Gavillet, EU Project MATCH/Partner CEA Liten, France).

Less than 100 were funded for only 1 year or more than 5 years. The funding ratio (funding by agency to co-funding by project owners) of most of the EU projects was at around 40 or 55% and higher for national projects with funding ratios between 65 to 80%. **Figure 4a and b** highlights various other factors of evaluated R&D projects like coordination schemes, technology readiness level (a), and R&D&I scopes and involved KETS (b), demonstrating that 40% of the R&I projects are coordinated by academic institutions, having a technology readiness level (TRL) of 3 to 5 (42%) with main focus on performance (27%), durability and cost (13% each), while using Key Enabling Technologies (KETs) including advanced materials (42%), advanced manufacturing systems (20%) and nanotechnology (17%). Sustainability and life cycle assessment (LCA) issues played only a minor role in the R&D&I scopes of the projects (10%).

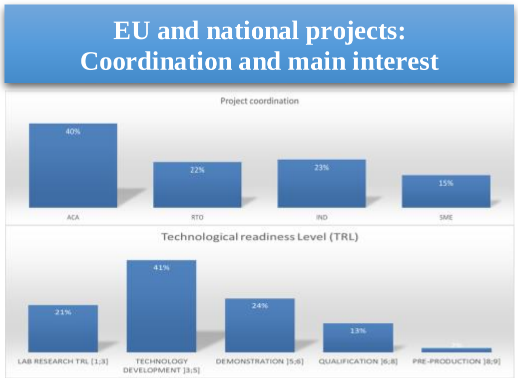

Figure 4a

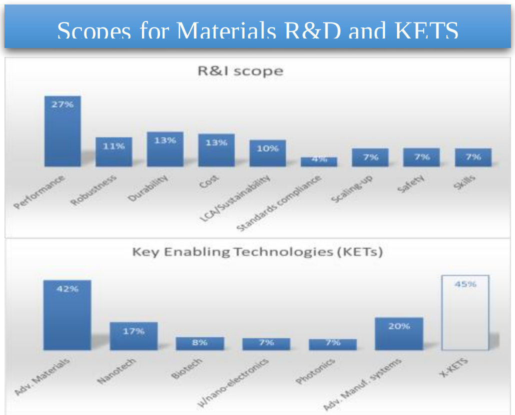

Figure 4b

Figure 4 a and b: Coordination schemes, technology readiness level (a), R&I Scopes and KETS (b) of about 1390 materials related R&D projects under European and national funding regimes and evaluated under the MATCH project in the years 2015 to 2017 (Data provided by Jérôme Gavillet, EU Project MATCH/Partner CEA Liten, France).

Figure 5a and 5b show the materials investigated (Figure 5a) and the envisaged industrial applications (Figure 5b). With 31 % so called "smart materials" - the expression is used in a broader sense e.g. also for coatings - were of highest interest, followed by composites and metals. Regarding the applications targeted, energy, transport, manufacturing & processing, and consumer goods were of highest interest. The energy and the transportation sector cover about 35% in total, thereby addressing climate change, one of the societal challenges the world is facing.

In the various national and European programmes analysed, the approach taken is however not sustainable. Many technologically beneficial solutions did not consider the full consequences as to raw materials use and environmental impact (post-consumer). For example, fossil-fuel used plastic packages significantly contribute to energy saving, food preservation, health and safety, and convenience. They have, however, created a massive environmental issue. A systematic rethinking of the entire specific value chains and how their materials needs relate to those of others has become a must.

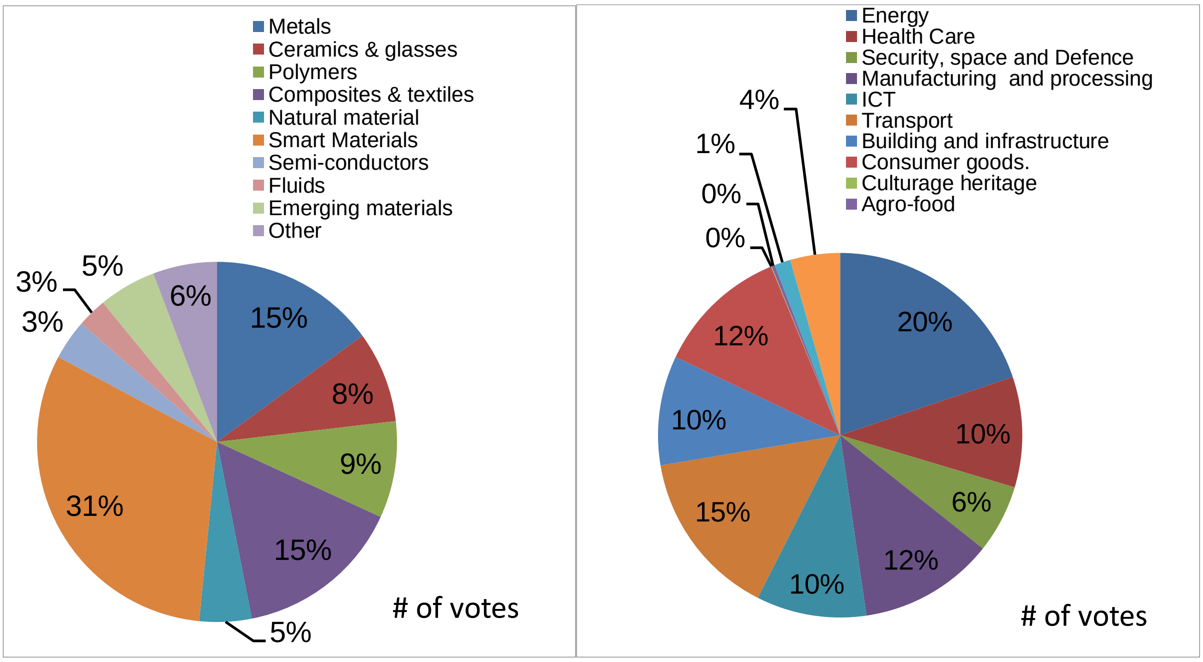

Figure. 5a

Figure. 5b

Figure 5 a and b: Materials R&I highlighted by the materials used (a) and the industrial applications, for which R&I is requested (Data provided by Jérôme Gavillet, EU Project MATCH/Partner CEA Liten, France)

3. A materials revolution is required

The materials R&D&I of the past 30 to 40 years has led to important material and material use developments that improved convenience and quality of life for many people. The linear approach taken is however not sustainable in view of population growth as reflected for example in the many environmental issues related to clean mobility and plastic-free oceans. To make Europe a front runner in market-creating innovation[16], as mentioned in the draft of the new EU *Horizon Europe Programme*, emphasis needs to be given on translating societal challenges into technological solutions. A materials revolution is therefore required that impacts the local and global societal challenges to sustain and further improve the quality of life of all people.

In the future Framework Programme HORIZON EUROPE a mission oriented R&D&I policy is foreseen and Mariana Mazzucato was invited to draw up strategic recommendations to maximise their impact. In her introduction to the EU document

„Mission-Oriented Research & Innovation in the European Union: A problem-solving approach to fuel innovation-led growth" Mazzucato pointed out *"that first an answer should be found on the critical question of how to direct innovation to solve the pressing global challenges of our time before finding a way to bring together the triple objectives of smart innovation-led growth, inclusion and sustainability."* [17] Starting from global challenges, which are mostly complex and that entail politically strategic visions, more concrete and feasible ideas and projects with achievable goals have to be designed, in which materials play a key role in some cases, and less prominent roles in other cases. Taking the example of Climate Change from the report of Mazzucato (**Figure. 6**), it becomes clear that the missions and mission projects can cover all kinds of industrial sectors and consumer applications (in this case, for example, energy systems, mobility (transport), construction materials (cities/infrastructure), and food). In this context, the need for a research project – in our case related to the material life cycles – is no longer driven by performance and cost reduction, but instead targeted to achieving a certain Mission related to specific societal challenges. Similar conclusions can be found in the example "Clean Ocean, a plastic free ocean" which shows very clearly how important design, waste management and circular material approaches are.

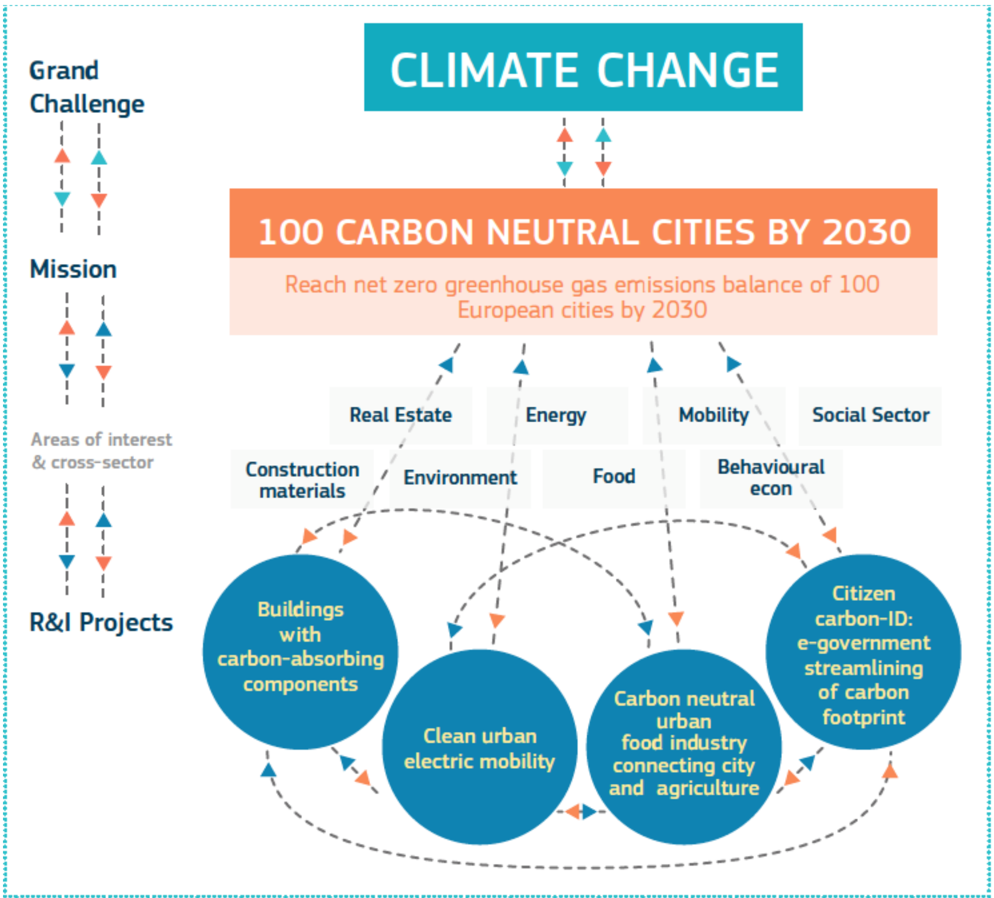

Figure 6: From Challenges to Missions Image for the example Climate Challenge (based on Mazzucato [17]).

The significant step away from the linear approach and towards a systems or circular approach entails innovation along and across entire value chains, and requires a persistent and consistent long term strategy for materials R&D&I. The challenges are complex and require new system solution approaches as visualized in Figure 1, and as mentioned in the Lamy report: "*to bring research and innovation together in a single programme*", *"do not look at individual sectors or scientific disciplines*" and take into account „*the need to change in the future*". Mazzucato mentions in her report "*To solve them (societal challenges) requires attention to the ways in which socio-economic issues interact with politics and technology, to the need for smart regulation, and to the critical feedback processes that take place across the entire innovation chain*"[18].

Materials R&D&I is actually one of the best areas to look „at the whole system", from feedstock to use and back to feedstock. It brings people of multiple disciplines together, coming up with new ideas for more renewable, eco-friendly products and services. The "whole system" starts with raw materials challenges (the exploration, extraction and processing of ores, minerals, substitution of elements) and how to create materials and their functions that can be used by designers to address product functionality needs. Their materials' choices and the way materials and components are assembled and manufactured, define how easy materials can be reused and recycled again and again. The latter requires a new way of thinking: „*design for disassembly*". Materials efficiency in processing and manufacturing is typically being addressed by enterprises seeking specific solutions. Furthermore, non-technological, new business concepts can also greatly support the effective use of raw materials. With the increased provision of services instead of products, product and material loops can be closed shorter than recycling. Advanced engineering materials can play a major role here as well, e.g. by extending the life time of products by improving the wear and corrosion resistance (shortest cycle), or providing controlled adhesion/release properties to facilitate remanufacturing. Moreover, material technologies may enable the building-in of sensors and communication systems in an Internet of Things approach, to monitor the status of products in a sharing economy. Finally, these aspects have to be in compliance with legislations and business logics, or vice versa, legislations and business logics need to be adapted to new developments. This can only be done by a holistic understanding through collaborative efforts along and across value chains, while involving all societal actors.

4. The system approach using "big Data"

A new holistic thinking (system approach) in Materials R&D&I is needed, in which researchers in basic science, material scientist and engineers, designers and process engineers are working together in one project. If the new HORIZON EUROPE missionary strategy would be focusing on solutions in a particular industry sector, a) similar solutions for other sectors may be lost and b) the circular approach will receive less attention as the solution may only cover part of the value chain. It is important to avoid this.

Therefore the proposed holistic approach considers the design of products from conception to post-consumption that use less energy, less (critical) materials, is social and environmentally benign and compatible, and that benefits all people, i.e. using a circular approach. Modelling as a tool to reduce research time and to optimize processing is one important "block" in this chain and could be one of the key links between the various mission projects under a certain "challenge", as it is truly a cross-field activity at all material life cycle levels, from product and process design and up-scaling to modelling use phases, and end-of-life re-use and recycling. Another key tool is characterization of the materials in all of its life cycle phases. Both are essential to monitor progress and to interact with the different projects when necessary.

All research, development and innovation steps produce a large volume of materials related data. Many of them are preserved in excel sheets or publication documents and will only fit the needs of their developers, the characterisation tools or the process technologies used. It is a very challenging to manage such "multivariate, multidimensional and mixed- media data sets being generated from the experimental, characterisation, testing and post-processing steps associated with their search for new materials" and "to access large publicly available databases containing: crystallographic structure data; thermodynamic data; phase stability data and ionic conduction data"[19]. However, a new system approach can only be used if the data can be easily retrieved, processed, correlated and evaluated. For this purpose, the data exchange must be more transparent, and the sources of data / information and their emergence should be documented in detail. Ultimately, such a tool should be able to quickly answer questions about a material development or a process so that it can intervene and improve at every point in the value chain. It is therefore important that one can (i) trust the data used, (ii) use the same expressions for the same materials/processes throughout the value chain, and (iii) consider standard operating procedures, even in the development phase, especially also for those partners in the system, which are not dealing on an everyday basis with such technical terms. The European Materials Modelling Council EMMC has discussed a European Materials Modelling Ontology (EMMO) at a first workshop end of June 2018 in Brussels and it became clear that "ontologies support the intermediate structuring and meaningful storage of data, enabling and speeding up Artificial Intelligence. Mr. Peter Dröll, acting Director of the Directorate General for Research and Innovation of the European Commission gave a clear message for the experts gathered "that the status of only about 1% of data generated being used needs to be addressed and that we are called upon to make data more valuable, i.e to add value by structuring and organising data for their use and for reasoning, Hélène Chraye, Head of Unit of Advanced Materials and Nanotechnologies, emphasised the importance of a wide agreement leading to standards[20].

Retrieving big data in the materials processing, modelling and characterization is part of the complex systems approach in which materials play a role. For such common approach to function in the proposed mission strategy, the compatibility of economic, environmental and societal yardsticks must be ensured.

Materials data systems should also inform stakeholders on how to handle products and what the consequences are of using the products. Therefore, information about product ingredients, raw material consumption (mineral/renewable resources, energy, water, virgin/secondary use), their durability under different working conditions, etc. should be made available. A kind of "bill of materials (BoM)" - partially used already in manufacturing, but in this case containing all the necessary data from raw materials to recycling and re-use - could be produced to support researchers, engineers and managers when preparing project applications, in conducting their projects and in evaluating the outcome of projects, in view of the impact on our society and economy.

5. The new role of a reinforced Alliance for Materials (A4M+)

Under HORIZON EUROPE (FP9), the new KETs programme should indeed underpin and complement a mission-oriented approach. Therefore, the update of the concept of a European Materials & Engineering Advisory Group under a reinforced Alliance for Materials (AM4+) is proposed to assist HORIZON EUROPE management with advice and information for all questions related to materials R&D&I. The experts from the ETPs, FEMS and EMRS would be joined in fields like design, modelling and characterization through the interaction with the European Materials Modelling Council, EMMC and the European Materials Characterization Council, EMCC and a sustainable materials development, manufacturing and processing and recycling as well supported by experts from EIT Raw Materials, The European Technology Platform on Sustainable Mineral Resources, ETP SMR, ETP ManuFuture, ETP EuMaT and materials societies like FEMS and EMRS. The setting-up of the reinforced A4M with an Advisory Group from such organisations is based on the idea that the materials and processes developed and used in various industrial sectors, like energy, transport, construction, health, ICT etc., and for the various societal challenges show a lot of common issues also called "***commonalities***" (see also Box 2), that are useful in more than only one mission or only one targeted area/sector. This idea of "steering and making use of commonalities" in materials R&D&I was developed in three workshops during the HORIZON 2020 Project MATCH by more than 70 experts from industry, RTOs, European Technology Platforms and universities.

Therefore it would be favourable to relate the European Technology Platform for Advanced Engineering Materials and Technologies (ETP EuMaT), the European Materials Modelling Council (EMMC), the European Materials Characterisation Council (EMCC), and the EIT Raw Materials network to a reinforced *A4+*, to break down the present silo thinking and actions in Materials R&D&I. FEMS with its networks of researchers and engineers in national societies of 28 European countries represent other important stakeholders. Today, industrial sectors have prepared individually their own strategic research agenda's, while a collective approach of exchange and collaboration through common materials interests can save and more effectively use EC funding for achieving truly important solutions to our societal challenges. Materials science and knowledge can act as the spinning wheel in this system approach as depicted in Figure 1, and will also act as a kind of "market place" that is of use to whole system.

A4M+ will focus first of all on the critical Societal Challenges mentioned below:

1. Secure *Clean Energy*
2. *Health, Demographic Change and Well-being*
3. *Food and water security*
4. *Smart, Green and Integrated Transport (related to Energy topics)*

Other Societal Challenges, like Climate Action and Environment, or Secured Society may form part of these main five challenges. In Box 1 and 2 some topics are proposed which could be taken up by FP9 missions. Some of these ideas came also up during the presentations and discussion at two MATCH workshops in spring 2017 at Leuven, Belgium [21], and the MATCH succession workshop organised by EPFL, MatSearch and FEMS in Lausanne, Switzerland, November 2017[22].

Various issues, from materials selection to processing and re-use are important to be discussed by such an Advisory Group, to make science based recommendations for the different missions.

Material horizontal commonalities along the value chain addressing the above challenges while securing circularity are:

- exploration and sustainable mining
- smart material & product design for remanufacturing and recycling
- resource efficiency – 'do more with less'
- substitution of toxic inter alia by renewable materials and substitution of critical raw material (CRM) by coatings.
- resource recovery & waste re-/upcycling providing safe sinks for (toxic) residues
- secondary use of recycled material
- materials micro- and nanotech for micro-sensors enabling new business models like sharing products in a circular economy.

A reinforced A4M+ will also serve to bring expertise in legislation and standardisation, both important to implement for a sustainable materials choice, production and use in our European system.

"Research needs time to generate results, while speed is essential for successful innovation"[18]: The *A4M+* would help to fulfil such statements of the Lamy report by linking the various stakeholders with their different aims and objectives to speed up innovation by providing materials related knowledge and information coming from the various projects and partners. Such an approach which will link the

various materials activities in the missions and will reduce challenges and risks of stand-alone activities, boosting industrial action "beyond the possible" in the materials R&D&I field.

The *Alliance for Materials-Plus, A4M+*, acting with its experts as an *European Materials & Engineering Advisory Group,* may manage material-relevant information in kind of a (virtual) market place by involving young dynamic researchers and engineers, start-ups and SMEs, designers and raw materials & environmental engineers, venture capitalists and NGOs, who represent the consumers/citizens and their needs. Such a Materials market place not only captures the public imagination but sets the standard for new and creative solutions (EuMaT position in BOX 3).

6. Recommendations

Future materials related innovation actions supported by the European Union should be monitored by a reinforced Alliance for Materials that ensures an information flow and knowledge transfer across fields of technology, value chains and industrial sectors to boost innovation and business creation. The focus of such reinforced A4M+ Group is to i) identify the specific materials demands along the TRL scale across industrial sectors and stimulate cross-fertilization of materials R&D&I addressing EU and global societal challenges, ii) identify opportunities for design/modelling for recycling and remanufacturing, industrial symbioses, re-use, remanufacturing, and optimum materials circularity in general, iii) support the introduction of standards for a structured materials knowledge use, and facilitate systematic analytics for quality data integration and use. The latter two are the focus of the European Materials Modelling and Characterization Councils, thereby promoting a European Materials Modelling Ontology development in collaboration with industrial experts. The 3 legged systems approach to materials - development, characterisation, and modelling - can pave the way for making circular economy business models come true in industrial sectors critical to Europe's progress.

BOX 1: Topics of Materials R&D&I related to four Societal Challenges

- **Secure Clean Energy:** Low carbon energy and energy efficiency technologies like e.g. windmills, grids, solar energy, rechargeable batteries for energy storage, energy efficient buildings, CO_2 storage and use and various other technologies will be further developed and such outcome has also impact on various other industry sectors as e.g. transportation, infrastructure in smart cities, rural areas which can be re-activated through smart energy solutions, etc. This area is also covered by the Energy Materials Industrial Research Initiative (EMIRI). Therefore this topic should be advised in close cooperation with the experts from EMIRI. Further on the European Energy Research Alliance, EERA and EuMaT have referred to the importance of "materials for high temperature energy applications to be crucial". [23]
- **Health, Demographic Change and Well-being:** Besides diseases like cancer or chronic autoimmune diseases like Parkinson, MS or arthritis, the resistance of microorganisms to antibiotics is declared an urgent global problem. Concerning the latter, the question is now: how to avoid infections in clinics (e.g. catheters), during prosthesis installation, in public areas; cleaner water and food, good sanitary conditions can be achieved through materials (surface engineering of materials, antibiotic and antimicrobial coatings). Other important fields are related to the monitoring of the health status of people (digital based products, sensor based products), support aids for physically challenged people (orthopaedic products like shoe inlays, wheelchairs, bandages, catheter), increased durability of prosthesis and physically enhanced body parts (artificial heart). Light weight external skeletons can be achieved by new biobased or resorbable composites and additive manufacturing.
- **Food and water security:** covers all areas of consumer goods like e.g. light weighting of food packaging, antimicrobials for increased shelf-life, shelf-life indicators, and security of data storage and transport in which smart materials play an essential role (The latter topics are in turn mixed with other challenges).
- **Smart, Green and Integrated Transport and Energy related topics**: making public transport more accessible for all people by improving materials surface functions (antibacterial, more information through "touch materials", avoid non-recyclable materials, easy identifiable and recyclable materials especially in transport vehicles). Transport means also infrastructure, streets, buildings a sector in need of huge amounts of material that are more sustainable, need for increasing durability, more bio-based and smart systems. Reduced battery weight with combined increase in capacity and life time.

BOX 2: Materials Commonalities

1. **Materials Selection and Characterisation**: To address the challenges in the short and medium time range (less then 10 years) existing or novel materials[24] have to be optimised and adapted for the design, processing steps and use, simulating the working conditions of the system. Steps like materials design, -microstructure, -modelling and materials characterisation and tribology are crucial and need additionally standardised procedures, Standard Operating Procedure (SOP) or even ISO standards and regulations (REACH).
2. **Processing and Manufacturing:** Materials properties are developed during the manufacturing and processing. Optimisation and adaptation of a chosen process to fit the material to the desired function/properties and working conditions. All kinds of processing/manufacturing methods are considered: sintering, additive manufacturing, casting, rolling, coating, surface engineering, joining, and many more. , These should be optimised inter alia by simulating their behaviour and using methodologies like sustainability assessment (see topic 3, page 3).
3. **Life Cycle Assessment, recycling and re-use:** The steps in 1. and 2. should be assessed by techniques to get the environmental impacts associated with raw material extraction through materials processing and manufacture to allow full recycling/re-use of materials or components (circular economy, Bill of Materials[25]). The life-cycle and related sustainability assessments allow the monitoring of all development and manufacturing steps in view of the reduction of critical raw materials, energy and other material consumption and by this enables the eco-friendly development for a next generation of products and systems.

BOX 3: EuMaT Position: Advanced Engineering Materials in Horizon Europe (FP9)

EuMaT is supporting a European Materials & Engineering *Advisory Group.* The authors of the position paper [26] draw a similar picture of future materials research in future FP9 missions and emphasize that "*Whatever the Missions and the Societal Challenges (or Clusters) in FP9 will look like, we strongly believe that each end, every of these new challenges will have large needs in MATERIALS research and innovation*." They fear that „*Limiting the field of advanced Materials research to specific bordered parts/structures of the programme implies the risks of lacking critical mass in certain important Materials R&D&I topics, as well as the risk of duplicate work and consequent funding, if similar research is carried out in different parts/structures without any cross-coordination, leading to less efficiency in public funding use. Consequently, we see the urgent need for the creation of a horizontal and interdisciplinary Advanced Materials research coordination structure in the future FP9, acting as a single hub for Materials research and innovation; supporting a broad field of applications and industries, for the development of advanced new materials in many areas, including when appropriate, also dual use (civil vs military). This is of particular relevance for enabling aspects, such as Materials Modelling and Characterization with their related Test Beds. This approach is also functional to the new European Innovation Council (EIC), which should be able to create an ecosystem where a friendly and effective access to enabling cross-sectorial and interdisciplinary techniques have to be offered to support products and process innovation and to offer specific services with high quality*." EuMaT as European Technology Platform involving different materials related stakeholders like FEMS, EMRS, EMIRI, European Technology Platforms (SUSCHEM, EuraTex, Construction, Manufuture, Nanomedicine, Steel, EAA), the European Materials Modelling and Characterisation Councils (EMMC, EMCC), the European Pilot Project Network (EPPN), and other further Clusters, Networks or Associations (KMM, ECP4, CLEPA, CFCP) could be the right organisation to establish, in close co-operation with the European Commission, such a reinforced Alliance for Materials (A4M).

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[24] Materials can come from materials research funded by the European Research Council, ERC or EU funded research or industrial research laboratories. Most of materials will come from the "shelf". However, these should prove to be environmentally friendly - supply chain and pre-processing should meet the societal challenges (limited energy consumption, positive footprint, no "sweatshops" in the countries of origin of the raw materials). They can also develop more positively during a project to meet the mission's expectations, and should then be processed in such a way that a kind of "eco-design label" can be awarded to the final product (there is already a kind of label that expresses the CO2 footprint of materials).

[25] The data which are gathered throughout the development cycle (from materials towards a demonstrator) should be given into a databank, which aims to establish a "Bill of Materials, BoM" to enable the improvement of the products, systems or services by understanding the different steps from the design idea – materials development-processing/production and by this to allow rapid standardization, present a more detailed customer information about the product/system/service and its supply chains.

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Authors

Paloma Fernández

Professor at University Complutense

Paloma Fernández graduated in Materials Physics at University Complutense and did a Post-Doc at Technische Universität in. She then obtained a tenure at Department of Materials Physics in the Faculty of Physics of University Complutense in Madrid, where became a Full Professor in 2007. Her main research interests include the investigation of defects and optical and electronic properties of semiconductors, being also very active in educational research, mainly focused on Materials Science. Since February 2006, Paloma is President of the Spanish Society of Materials, and since 2018 President of FEMS GA. She has been Chair of the Managing Committee and Member of Scientific Committee for the last EUROMAT 2013 held in Seville. Since 2011 she is Responsible for Physics and Chemistry Speciality in the Master for Secondary and High School Teachers formation at Complutense University and Member of Advisory Committee for the Project ENCIENDE (Promotion of Science at Schools) from Confederation of Spanish Scientific Societies (COSCE).

Roland Gauss

Thematic Officer at EIT RawMaterials

Dr Roland Gauß is responsible for the fields of recycling as well as of substitution of critical, toxic, and low performance materials. He joined from Fraunhofer Project Group Materials Recycling and Resource Strategies IWKS in Hanau, Germany where he worked as Head of Department Functional Materials with the Business Units Magnetic Materials, Energy Materials, and Lighting. His personal research interest is related to metallurgy, the life cycles of materials, and how innovation processes are triggered and pursued by society. Roland Gauß was a research fellow at TU Bergakademie Freiberg (2004) and a Marie-Curie- Research-Fellow at University College London (2006). He received his PhD from the University of Tübingen in 2008 in the fields of economic geology of copper and extractive metallurgy in prehistoric societies.

	**Margarethe Hofmann-Amtenbrink** CEO at Mat Search Consulting Hofmann Margarethe Hofmann-Amtenbrink studied foundry technology in Duisburg and then materials science in Berlin and received her PhD in materials science at the Max Planck Institute Stuttgart and Technical University Berlin, Germany. In 1987 she started her own business (Mat Search Consulting Hofmann) in Switzerland in 1987 and since then she is working as CEO for various associations, foundations, governmental organisations and industry. She was also involved as scientific coordination in two large EU research projects on nanoparticles for biomedical applications, was partner of the HORIZON Project FORAM and involved in MATCH through FEMS, as Vice President, President and Immediate Past President of FEMS.
	**Heinrich Hofmann** Professor em. EPFL Heinrich Hofmann got his PhD in Material Science with a thesis prepared at the Powder Metallurgy Laboratory at the Max Planck Institute in Stuttgart. In 1985 he joined the R&D center of Alusuisse-Lonza Services AG, at Neuhausen-am-Rheinfall. In 1993 he joined the Swiss Federal Institute of Technology as Professor and Director of the Powder Technology Laboratory at the Department of Materials science and engineering. His research area included the synthesis of nanostructured materials based on nanoparticles and the modification of surfaces with nanoparticles using colloidal methods. The fields of application of such materials are medical and biological, (drug delivery, hyperthermia, cell separation, biosensors), electronics and sensors.
	**Amaya Igartua** Head of Tribology Unit at IK4-TEKNIKER Dr. Amaya Igartua has worked for IK4-TEKNIKER since 1988 and has been the head of Tribology Unit during the last 10 years,. She has been the Spanish representative of COST of Tribology, tribotechnology of engines and transmissions and biotribology. She promoted the creation of the Virtual Tribology Institute, the Eureka Umbrella ENIWEP about wear prevention, the Eureka Umbrella E-Surf about coatings. She participates in the SC of EUMAT coordinating the modelling and simulation activities, and in MATCH Network.

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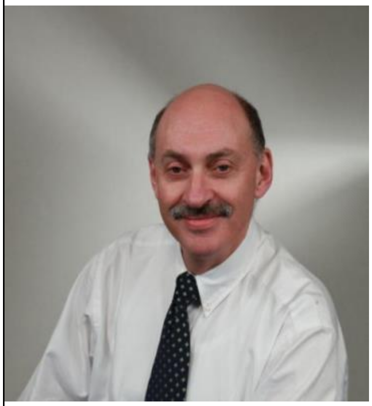
<tr><td></td><td>

Rudy Koopmans

Director of the Plastics Innovation Competence Center (PICC)

Dr. Rudy Koopmans fosters creative thinking that stimulates innovative science and technology and application development that impacts industry and contributes to a sustainable society.

- Director of Plastics Innovation Competence Center (PICC)
- Director of Institute for Applied Plastics Research (iRAP)
- Lecturer ETH-Zurich – Department of Materials – Zürich
- Former R&D Fellow at The Dow Chemical Company
- PhD in Physical & Macromolecular Chemistry – University Antwerp (B)
- Master in Business Adminstration – University Leuven (B)

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Jan Meneve

Research manager Sustainable Materials Management at VITO

Jan Meneve obtained his master in science and metallurgical engineering at the University of Ghent in 1989. He is responsible for managing strategic research activities at VITO, particularly in the sustainable materials & chemistry technology fields. Jan Meneve is particularly sympathetic towards advanced material technologies including nanotech and their vast yet largely unexplored role in closing material loops and enabling the circular economy.

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Erik Schuring

Principal Research Assistant, Materials, Testing & Analysis at ECN/TNO

Erik Schuring is a materials scientist and has been working at the TNO-Metal Research Institute (today TNO Industry & Technology) for 9 years. Prior to that he worked at ECN (Energy Research Centre of the Netherlands) in Petten in the fields of damage analysis, materials consulting, corrosion and wear, coating technology, brazing and soldering, welding (aluminium, steel and stainless steels). He is familiar with microscopy techniques (optical, scanning electron microscopy, atomic force microscopy (AFM), confocal microscopy), mechanical testing and physical analysis.

In addition to his work at TNO, he works as a secretary for various organizations, such as Bond voor Materialenkennis (www.materialenkennis.nl) for VeMet (Vereniging Metalen) and Fractograpy within VetMet, Contactgroup High Temperature Vacuum Brazing and member of the Creep Committee of the Bond voor Materialenkennis and Corrosion. He was responsible for (sub)projects in the areas of damage analysis, thermal spraying, coating technology.

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