"The role of Materials in the post-COVID society"

A reflection on how Materials will enable solutions for a healthy, safe, and resilient society to achieve a sustainable, stable, and stronger economy, able to respond to citizen's demands.

September 2020

Summary

This Reflection Paper addresses the role of materials in the post-COVID society and summarizes positioning, potential solutions, and recommendations that stem from the European Materials community (Alliance for Materials A4M) towards Horizon Europe in the Post-COVID scenario. The paper compiles existing Strategic Research Agendas (SRAs) of different materials stakeholders and address a specific reflection in the context of the current COVID19 pandemic. It puts forward proposals for strategic research and innovation activities to the European Commission, Member States, and the European Parliament, taking into account the objectives of the Green Deal Priorities and Recovery Plan.

About This Document

During the drafting process, the Commission Services have guided revisions of the Reflection Paper to facilitate its alignment with the overall EU political ambition. We acknowledge the support from the Unit Materials for Tomorrow, Barend Verachtert (Head of Unit) and Achilleas Stalios. This document is a solid draft, released with a view of ensuring transparency of information and contributing to the development of the Strategic Research and Innovation Agenda. It aims to facilitate further collaboration, synergies, and alignment between partnership candidates and relevant materials R&I stakeholders in the EU and beyond, were relevant. In case you would like to receive more information about this initiative, please contact:

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I. Introduction, motivation, overview

The outbreak of COVID-19 has affected all of us – our countries, our communities, our families. It has also affected all of Europe's manufacturing industries, which have been playing a crucial role in helping governments, other industrial sectors, and communities to tackle the crisis. The top priority has been to ensure citizens' health and safety and to secure materials supplies into medical, environmental and food supply chains amidst border closures and lockdown measures. We strongly believe in the EU's paradigm "Open to the world", and support globalisation with global sourcing, global co-operation, and global markets. However, we have recently experienced that global value chains can easily be disrupted, and that full dependence on imports and external supplies can have regrettable, negative effects on the functioning and wellbeing of our European society.

European industry has worked closely with the Commission and Member State authorities to help to strengthen critical supply chains during this unprecedented public health crisis, including providing the European Commission with recommendations to secure EU cross-border transport and guarantee

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supply chains of essential goods; identifying supply chain disruptions. During COVID-19, European industry has geared strategies to reconfigure their factories and ramp up production, with rapid reconfigurations to produce medical supplies. They have been facilitating biocide substances to cover reported shortages; non-woven fabrics for mouth/nose masks; surfaces with antiviral or antimicrobial properties, and waste treatments for drinking water. They have also been supporting manufacturers of active pharmaceutical ingredients (APIs) so that they could ramp up production of these substances to meet increasing demand. Such rapid production changes are not without their hurdles: sourcing of scarce supplies, regulatory approval, large differences in manufacturing processes, etc. During this period the EU Commission also created the CORONA Platform and COVID Data Portal to summarise the projects, the EU Call opportunities, activities and impact.

Europe faces several challenges derived from the pandemic. More than ever, investments and supportive measures in research and innovation are needed to create and deploy adapted solutions and to transform global threats into opportunities for European businesses, citizens, and society. In the "new normal", human social and economic impacts must be considered to define the best pathway forward and to apply the lessons learned during the crisis. This applies to general R&D&I, and to Materials research and innovation. Among other changes, the scope and the role of the European Technology Platforms will be re-defined. Reinforcing their synergies will be the best way to address the "new normal". Our society is more than ever demanding a more secure, healthy, and sustainable way of life, with a level of comfort not conflicting with planetary boundaries, global resource limitations, and environmental preservation. The crisis comes with opportunities for the future: as Parliament's Research Service (EPRS) published, "Ten opportunities for Europe post-coronavirus", creating lasting change, seizing opportunities, and nurturing the catalytic positive effects of the crisis will be the measure of Europe's resilience in liberal politics, the economy, and its people and society.

This Reflection Paper addresses these needs and summarises potential solutions that stem from the European Materials community (Alliance for Materials A4M) for the Post-COVID scenario. The paper is not meant to be a full SRA, but rather a specific reflection compiled in the context of the current COVID19 pandemic. It presents proposals for strategic research and innovation activities to the European Commission, Member States, and the European Parliament addressing the Green Deal Priorities and Recovery Plan.

II. The A4M community's response to the COVID pandemic

Rapidly responding to the challenges of the COVID pandemic, Materials-related platforms and organisations have expanded or modified their short and mid-term strategic agendas. A non-exhaustive list with examples of these responses from the A4M community is collected.

Before the COVID crisis the European Technology Platform for Advanced Materials and Technologies, EUMAT, published the EUMAT RoadMap , the RD Priorities in Advanced Materials, the EuMat Position Paper and a document highlighting the importance of "Materials Made in Europe" with the message that "Advanced Materials are essential", anticipating the demands of COVID crisis. EUMAT in cooperation with the Alliance for Materials (A4M) issued an important Memorandum, signed by 242 institutions and the "Alliance for Materials Position Paper ", explaining the role of the materials in the Green Deal and Digital Age, and the need and capacity of the materials community to provide solutions for Materials for tomorrow. EUMAT-A4M has collected project ideas and proposals as a response to the COVID-19 challenges. The Results are described in the ANNEX of this document, that includes research needs related to advanced surfaces, safe materials, testing methods, modelling and data integration, materials for digitalization, the circular economy and resilience.

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The European chemical industry (CEFIC) has been playing an essential role during the COVID-19 crisis, pushing their capacity to the limit to meet the exponential rise in demand for essential supplies in the EU. They increased production to support the surge in demand for critical supplies such as disinfectants, diagnostic tests, ventilators, protective masks, gloves and gowns, Intensive Care Unit medicines, protective clothing, and equipment. Chemical plants shifted their core production to be able to produce the necessary chemicals and biocides needed among others for disinfectants, hydroalcoholic gels, etc. EURATEX, The European Apparel and Textile Federation, is also working in the Post-COVID strategy and recovery plan.

EDA**,** the European Defence Agency is promoting Dual use (civil and defence) activities for instance with Smart Materials or additive manufacturing. EDA produced a food for thought paper, referring to defence materials and processes with strategic positioning in the post-COVID era. It includes contributions from the EDA working bodies concerned, such as Materials CapTech.

EIT Raw materials funds actions with the aim to develop raw materials into a major strength for Europe. In May 2020, EIT Raw materials launched a Booster Call in response to the COVID-19 crisis to provide support for high-impact,high-growth potential start-ups, scale-ups and SMEs during the crisis. Over 170 innovators from 25 countries applied for this Call. Furthermore online activities to boost new ideas bringing together members of the different EIT Innovation Communities have taken place. EIT Alumni ran the COVID-19 Map & Act online challenge using the Be-novative platform. The central challenge was *“What can European citizens and institutions do to mitigate and overcome the impacts of the COVID-19 crisis on our society?”*

EARTO (The European Association of Research and technology organisations) is actively supporting the health sector with upgrading of manufacturing capabilities, quality testing and distribution of key medical supplies and equipment, while supporting the pharmaceutical development of testing and diagnosis, as well as of new treatments and vaccines. Member RTOs are working alongside their governments in today’s crisis management thanks to their digital tools and data analysis capabilities.

At the **EUROPEAN PROJECT level**, the Nobel **Network** covers a wide range of sectors from precision engineering to smart connected HealthTech, and from academic research to healthcare practices. NOBEL is creating a European HealthTech ecosystem, for the convergence of nanomedicine with photonics, robotics, biomaterials, digitalization and textiles, addressing materials developments for healthcare. NOBEL is promoting a large partnership in health-related technologies called ESTHER. EU4Health is the EU’s response to COVID-19, which has had a major impact on medical and healthcare staff, patients, and health systems in Europe. By investing **€9.4 billion,** it has become the largest health programme ever in monetary terms. **EU4Health will provide funding to EU countries, health organisations and NGOs.** Funding will be open for applications in 2021.

The National Technical University of Athens (NTUA) promoted a Hub 3DP-NTUA Hub to work on the preparation of face shields and other consumables, in order to support healthcare. Two Horizon 2020 Research Projects M3DLoC and Repair3D, offered the equipment, experience and know-how, to produce protective face shields by additive manufacturing (AM). The M3DLoC is addressing 3D printing of biodegradable plastics for medical applications and responded promptly to critical shortages in Personal Protective Equipment (PPE) and REPAIR3D aims to recycle plastic components using new recycling routes for plastics and carbon fibre reinforced polymers. As an example of National initiatives, the Spanish materials Platform, MATERPLAT promoted in the “Health Sector”, the **Enterprise Europe Network International Platform initiative**, **“**Care & Industry together against CORONA**”** to put together offers and demands of services and products related to the fight against Coronavirus. The Platform will be open till the end of 2020, where companies, hospitals and residences involved in the COVID-19 crisis can upload their demands and offers of services and products.

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III. Solutions for the challenges of the Post-COVID19 society

"Materials are everywhere!". Crises also create opportunities for re-directing our European R&D&I efforts. The Materials community supports the efforts towards the European Green Deal and the EU enhancements in digitalisation, Science and Technology integrating Education, and it offers a variety of solutions to overcome social, societal and economic challenges that stem from, or have been enhanced by the pandemic.

Circular Economy, materials cycles, and sustainable raw materials

COVID-19 has seriously affected the development of current strategies to face societal challenges and led to a reflection on a new global economic model where "Circular economy" will play a prominent role. **Circular economy** wants to keep the functionality of a product at the highest possible level and design waste out of the system. It calls for a move from consumerism and ownership to use and sharing. The introduction of circular economy business models urges companies to develop a different interaction with their customers, but also with suppliers and the extremes of the value chain. It is based on connectivity and interaction as a basis for materials management. Through the COVID-crisis a circular business model was shown to provide resilience to companies, to more easily react and adapt to unexpected events. Digital technologies can facilitate the transition from a linear to a circular economy: a) improving traceability and transparency during product lifetime, to monitor, control, analyse and optimise materials quality and product performance, b) enhancing end of life management practices, predictive and condition-based maintenance extending product lifetime or enable new business models such as product-service systems. The introduction of functional electronics into products shows clear potential for maintaining the value of materials and products for as long as possible, minimising resource use and waste by increasing resource efficiency, mitigating waste generation at production and use stages, enhancing repair (incl. self-healing), remanufacturing, recovery, reuse and recycling of materials and products. Blockchain, machine learning and digital twins are key concepts for the digital circular economy. Their implementation will rely on the introduction of digital technologies in the production system.

Materials recovery & waste re-/upcycling technologies are necessary while providing safe solutions for residues. Additive manufacturing technologies will be useful for recycled, re-designed and re-shaped materials manufacturing. Recycling of different type of materials components, to produce competitive, highly customised products at lower production costs, can generate new business activities. Gained knowledge and expertise in additive manufacturing could have a tremendous impact on rapid production of protective equipment to cover critical shortages in hospitals.

Durable and energy efficient materials and products are needed that are re-usable and repairable, with extended lifetime and functionality. Recycled materials can be upgraded for re-use as secondary materials using coatings. Materials design for use in demanding situations can be achieved with accelerated tribological, fatigue and corrosion studies. Technology exists to simulate, at a laboratory level (field to lab), the working conditions of the component in the system, and to reproduce potential failure mechanisms. This allows for a laboratory determination of the estimated lifetime of an unused component, or the remaining life of an ex-service part, which can be extrapolated (lab to field) to predict the behaviour of the materials in the real application. The Characterization and Modelling working group in EUMAT deals with these technologies.

Within EUMAT, the Working Group "**Materials for Circular Economy**" looks at raw and recycled materials for global sustainable development and our quality of life. EU is highly dependent on imports and securing supplies has therefore become crucial. Moving from the traditional, linear 'make, use, dispose' economy to a circular economy, where the value of products and materials is maintained for as long as possible; waste and material & energy resources usage are minimized. The objective of the group is to develop advanced materials and technologies for the zero-waste feeding, closing of material cycles in a viable, growing circular economy, with the key activities "sustainable mining; resource efficiency – 'do more with less'; substitution of critical raw materials (CRM) and use of bio-based, renewable materials, resource recovery & waste re-/upcycling."

SUSCHEM elaborated in collaboration with ECP4, EuPC and Plastics Europe, the "Plastics research and innovation agenda in a circular economy" on **sustainable plastics** that are highly aligned with the principles set by the EU. The document contemplates solutions on design spanning from the plastics design for circularity to the use of alternative feedstock (biobased, waste, CO_2).

European Aluminium EA has developed a Circular Aluminium Action Plan. Recycling saves 95% of the energy and 70% CO_2 emissions as compared to virgin aluminium. Collection of used Aluminium, e.g. from shredding of vehicles with cast and wrought aluminium, should be massively improved.

The Sustainable Process Industry through Resource and Energy Efficiency, SPIRE has a roadmap involving **materials processing** (steel, plastic, aluminium, ceramic, pulp and paper, glass) with a circular economy approach. SPIRE is promoting for Horizon Europe the creation of the Public Private Partnership (PPP) PROCESS4PLANET strongly focused on circularity of materials processing and the transformation of End of Life Products into new secondary raw materials to make new materials for products of the future. Dependence on the availability of new feedstocks from outside Europe is in that way strongly reduced. Their multiannual roadmap addresses research, development, and innovation activities as well as policy matters aimed at the realization of its 2030 targets. The cross-sectorial and holistic SPIRE research and innovation roadmap provides the pathway for the process industry to decouple human well-being from resource efficient consumption to achieve increased competitiveness in Europe. It is an extensive process of cooperation and coordination of the SPIRE industry sectors along and across their value chains with input from research and technology organizations (RTOs) and academia across disciplines, consultations with the European Commission and a wider audience through a public consultation. The Roadmap articulates sectorial innovation priorities and agendas to provide a synergistic effect compared to individual initiatives.

There is a direct relationship between the amount of raw materials used in industrial processes, the energy required and the associated GHG emissions. The concept of "resource efficiency" through greater recycling and re-use, as well as reduction of raw materials use must become key elements of climate policy in the context of the "circular economy". The European Academy of Science points out the relevance of "Green materials". This term refers to sustainable materials that, depending on the applications, can be considered as environmentally friendly, low-carbon emission, recycled or biobased materials. They may also offer unique properties including natural abundance, low toxicity, affordability, and versatility in terms of physical and chemical properties. They are the activators of an eco-sustainable economy serving all innovation sectors. Green materials can be applied in numerous scientific and technological applications including energy, electronics, building, construction and infrastructure, materials science and engineering applications and pollution management and technology. For instance, green materials can be developed for energy harvesting that will impact strongly on development, in areas such as hydrogen, synthetic fuels or the future exploitation of integrated nano-generators to apply in smart recyclable and disposable platforms for a plethora of applications. Biomass-based feedstocks can be developed as a source for biodiesel and bioethanol production. Biomass-based materials also can be transformed into advanced functionalized materials for applications such as the transformation of chitin into chitosan which can be further used for biomedicine, biomaterials, and tissue engineering applications. Recently, cellulose and lignocellulose-based materials, used as a source for developing functional materials, has attracted attention as bio-based-materials, reinforcing materials and for nanotechnology, as well as allowing the development of fully environmental-friendly products. Furthermore, the development of pigments using the green materials as a source due to their unique properties has gaining interest. Functional electronics are also a key vector concerning the integration of novel devices on conformable, flexible substrates with free-of-form surfaces for innovative product development. This will enhance European competitiveness in the mid- to long-term and ensure sustainability in line with the Green Deal. Here, we highlight the exploitation of functional electronics for emerging applications such as flexible large-area printed electronics and photonics which includes among others, hybrid thin film transistors (TFTs), printed electronics and circuitry, bio-sensors, in-vitro diagnostic platforms, photovoltaics (PV), nano-generators and energy storage media. These move away from silicon, being based on abundant, green materials that include inorganic oxides at the nanoscale, biocompatible polymers, paper and hybrid sustainable materials to maintain Europe's long-term leadership in this technology.

The EU can become the world's leading region in new, sustainable industries by encouraging the adoption of green recycling and circular technologies. Green materials should be durable and energy efficient with a low carbon footprint during material processing and consider recycling as a circular approach to preserve raw materials. Technologies should be developed by RTO and Universities, with subsequent implementation by SMEs and industry, to achieve the impact of a sustainable European society. To support the consolidation of this technological revolution, the establishment of new communities is a prerequisite, able to address this strong demand to drive EU prosperity.

Green and Clean Energy

Energy-efficient production requires the incorporation of green and clean energy in manufacturing processes for basic materials that are necessary in all areas, from metals and plastics to the built environment. There is a need to further develop and integrate: a) materials for storage (batteries, hydrogen, ammonia, molten salts, etc.) and b) materials for the generation of renewable energy such as photovoltaics, concentrated solar power (CSP) and wind energy. All the new energy sources should be closely linked with power-to-chemicals and carbon capture, storage, and utilization (CCS, CCU) solutions, as well as applications in energy efficient buildings and infrastructures. We are limited by the capacity of the planet and their resource limitations, and today, we must face these interconnected challenges. So far, European **low carbon emission strategies** have depended, firstly on the "energy efficiency" of the processes and services, secondly on promoting electricity from renewable energy sources, and thirdly, in the efficient and optimised storage of renewable energy to minimize the losses.

In the context of exploiting materials for efficient energy use, we must focus on "low-carbon emission materials" and technologies providing welfare and comfort to citizens, without compromising our environment or health. Sustainability will arise from the use **of renewable energy resources within the 21st century** and European industry must be prepared to take up this challenge to supply the necessary materials and devices. Without abundant and sustainable energy, all other societal challenges cannot be addressed or solved. Minimizing dependency on fossil energy sources requires important actions with the full alignment of all the actors, ranging from cities, policymakers, through to scientists, technologists and existing and new energy companies that develop and deploy the new technologies.

Thus, **new energy paradigm** requires the participation and contribution of all actors. Considering that the main source of CO_2 emissions comes from the transport sector, followed by the industrial sector and the tertiary and residential sector, the main challenges and steps to solutions are:

1. **Deployment of renewable energy sources** (e.g. photovoltaics, CSP, wind, hydroelectricity, etc.) integrated into energy supply systems. Energy storage must be carefully considered as one of the great challenges, including for example more efficient and sustainable batteries for electric mobility in light transport for enabling the grid of the future with integrated resiliency and flexibility, and chemical storage based on power-to-X (P2X).

2. **Fuel cell-based transport,** power plants and electricity generators will become prominent in the coming decades assisted by price reduction due to scale-up. The future development of electrolysis technologies for hydrogen production will involve different candidate technologies: (i) Alkaline Electrolysis Cells (AEC) at low temperature, shifting to (ii) Proton Exchange Membrane Electrolysis Cells (PEMEC) at low temperature, from 2020 to 2030, and (iii) Solid Oxide Electrolysis Cells at high temperature (SOEC). So far, the PEMEC is the only fuel cell found to be suitable for automobiles. One might expect that by combining PEMECs with rechargeable batteries, a hybrid vehicle could be developed, competitive with coupled batteries with and fossil fuel engines. All these technologies must be optimized through the development of new materials (e.g. electrodes, electrolytes, catalysts, etc.).

3. **Hydrogen and ammonia as energy vectors for a low carbon emission society,** both in heavy transport and in industry. Hydrogen-based technologies hold a key opportunity for the energy future of our planet. However, despite the abundance and attractive properties of hydrogen, major challenges to be overcome remain; these are the efficiency of functional hierarchical materials for hydrogen production and/or conversion, as well as the development of materials that behave favourably in contact with hydrogen, since it can be more aggressive in contact with structural materials than fossil fuels. Therefore, specific actions in eco-design and synthesis of functional hierarchical materials for electrodes and catalysts integrated in electrochemical systems for hydrogen production or conversion are necessary, supported by modelling tools. In the hydrogen economy, ammonia (a building block of many chemicals), has huge potential to store hydrogen while making carbon emission targets reduction a reality. Ammonia is the only carbon-free fuel as its molecule contains only hydrogen and nitrogen (NH_3). As a fuel, ammonia could allow the maritime sector to reduce its emissions by 95% by 2035 by direct use in the power units of sea-going vessels. The ammonia molecule is also one of the best alternatives for the mid/long-term storage of electricity as chemical energy. Renewables-based electricity can be transformed into hydrogen/ammonia when energy is abundant and cheap, and burned to produce electricity when needed.

4. **Fossil fuels play a large role in agricultural production**. These fuels are directly used in agricultural processes e.g. for heating, lighting, transport etc. They are also indirectly used for the manufacturing of fertilizer and pesticides, as well as for farm machinery and buildings. In fact, indirect energy use can contribute over 50% to the total energy use in agricultural production. Due to the increase of population (~ 10 billion in 2050), the intensification and industrialisation of agriculture will contribute to increase carbon emissions. However, this might change with the development a new generation of biofuels and fuels-cells. Energy efficiency of engines powered with biofuels, or mixtures of fossil fuels with biofuels, should also optimize their performance and reduce exhaust gas emissions, by implementation of catalytic reduction of exhaust gas. Compatibility of lubricants with exhaust gas emissions and

development of environmentally friendly lubricants to substitute fossil fuel derived ones will be also challenging.

5. **Synthetic fuels** and added value chemistry, based on biogenic carbon together with CO_2 capture and the deployment of the circular CO_2 economy should decrease the CO_2 concentration in the atmosphere. Research and innovation should be focussed on processes, such as artificial photosynthesis, in which solar energy is stored in chemical bonds as the most practical solution to circumvent daily and seasonal solar intermittency. This stored chemical energy can supply a convenient fuel, compatible with existing logistics (storage and transport) and eliminating most market barriers. Applications can be for space- and water-heating in buildings, as well as to replace fossil fuels in other current uses (industry, mobility, etc.). Importantly, using captured CO_2 (e.g. from exhaust fumes) as the carbon source makes artificial photosynthesis an environmentally beneficial process, enabling the re-use of emitted $CO_{2,}$ thus, establishing a closed loop for CO_2.

6. **Full energy transition** by implementing terrestrial, maritime and air transport without CO_2 emissions and reorganizing urban areas into smart cities, requires the integration sustainable and circular economy concepts. Alternative fuels represent a challenge to be addressed in the European Recovery plan.

SUSCHEM's SRA calls for Advanced Materials development for energy applications (materials for batteries, renewable energy infrastructures and energy storage, for solar-thermal, photovoltaic, wind energy and for energy efficient buildings, heating, and cooling). EUMAT has also a working group focussed on materials for energy applications.

EMIRI is pursuing advanced materials and technology development for low carbon energy and sustainable energy and mobility - see the EMIRI Technology Roadmap. This document addresses the needs for research in battery and hydrogen energy storage for mobility and stationary applications, in carbon capture and utilization, in solar and wind energy, in building energy performance and in light materials for mobility. The Roadmap focuses on the 21st century's global energy challenges, to drastically decrease greenhouse gas emissions to achieve a carbon-neutral economy by 2050. This will require a combination of different technologies within the energy system, from energy harvesting to energy storage, as well as technologies that improve energy production and use efficiency. The share of renewable energy technologies has increased from 8,5% in 2005 to 17,5% in 2017, involving harvesting and storage technologies, while energy production and use efficiency increased by 30% compared to 1990.

Achieving these ambitious targets will require further investments in advanced materials since they represent 80% of technology component costs. These investments will not only provide an environmental benefit but will also strengthen the economy. The RES and energy efficiency sectors employ more than 2million people in the EU and offer a competitive advantage for Europe in the future, where clean technologies will be indispensable.

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CO_2 Emissions Reductions and Climate Impacts

The multidisciplinary Materials R&D&I societies and European Technological Platforms (ETPs) are well suited to be in the driving seat for CO_2 neutrality and the fight to minimise world climate change. In Post-Corona times, our Materials community broadly pursues (more than ever) sustainable development, responsible advancement of science and technology to the benefit of the society and environment. More than before, the strategic Post-Corona R&D agendas from widely differing materials segments open avenues for materials solutions that minimize the CO_2 footprint. During COVID the use of masks by humans, has been a material solution created to reduce the transmission of the virus, but their use might also reduce the human CO_2 footprint. Partial exhaust gas recirculation has been a very useful technology to reduce emissions in combustion engines. The CO_2 emissions during human breathing can be slightly reduced when using masks while being harmless to the user.

The European Construction built environment and energy efficient building Technology Platform ECTP has an active Committee on Materials and Sustainability (M&S) which prepared a SRA on materials involving all construction stakeholders. The document deals with climate change, circular economy, competitiveness and economic viability, health and safety, user comfort and enabling fast innovation. In relation to climate change the following factors can be highlighted: a) a reduction in embodied energy in construction materials, b) a contribution from construction materials to reduce energy demand and CO_2 emissions (e.g. bio secondary based raw materials), and c) materials for the energy transition. The ECTP Platform promoted for Horizon Europe the Public-Private Partnership **PPP BUILT4PEOPLE,** pursuing these goals. For **SPIRE**, CO_2 neutrality is a major driver, and it is committed to the reduction of CO_2 emissions of traditional construction materials (glass, steel, bituminous binders, cement, composite materials, ceramics, and others) by applying new routes of production and/or low energy demand production technologies.

SUSCHEM elaborated in 2019 their Strategic research and innovation agenda, presenting research priorities addressing the long term European research and innovation policy goals and national priorities. SUSCHEM advanced materials technologies outline as main challenges the need for materials for low emission transport, materials for health and well-being of the aging population and materials for renewable energy infrastructures, as well as for energy production and storage. These innovation areas are envisaged to directly contribute to the European Green Deal goals as well as the EU recovery plan, with strategic priorities even more reinforced in the EU vision as the only way forward after the COVID crisis. The SUSCHEM proposed research priorities embrace materials designed for durability (composites and cellular materials, 3D-printable materials, biobased materials, the use of performance enhancing additives, biocompatible and smart materials, materials for electronics, coating materials and aerogels); materials designed for recyclability and produced from alternative feedstocks (such as from biomass, CO_2, urban, industrial or plastic waste); and, materials for sustainable water management (new membrane materials).

The Partnership BATTERIES "Towards a competitive European industrial battery value chain for stationary applications and e-mobility" aims to establish best-in-the-world sustainable and circular European battery value chain to drive transformation towards carbon-neutral society. The Partnership ambition is to prepare and equip Europe to commercialize the next-generation battery technologies by 2030, which will accompany the large-scale deployment of zero-emission mobility and renewable energy storage. It will also cover longer term research on future battery technologies which are essential for ensuring the competitiveness and global leadership of the European battery industry.

On a broader front, the EU is fighting climate change through ambitious policies internally and in close cooperation with international partners. Climate action is at the heart of the European Green Deal –

an ambitious package of measures ranging from ambitiously cutting greenhouse gas emissions, to investing in cutting-edge research and innovation, to preserving Europe's natural environment. However, to get a sustainable impact, it is necessary to work together worldwide on these initiatives. I we aim to reach the 2050 climate-neutrality objective, it is mandatory to engage citizens and all parts of society in climate action.

Only a multinational, multidisciplinary efforts can ultimately deliver globally effective mitigation technologies to address these major climate challenges. Realistic projections forewarn of a multi-decade, and therefore a multi-generational undertaking. One can expect a succession of ever more advanced solutions to the sustainability objective in general, and to a transition to carbon-free energy sources by the year 2050 and beyond. Although energy use and the environment are the direct beneficiaries, agriculture, water resources, and human health will also benefit from such advances.

Digitalisation and Artificial Intelligence

The COVID pandemic has highlighted and amplified the shortcomings, as well as the strengths, of modern society, its vulnerabilities to disruption in a globally connected world and its ability to adapt quickly and offer solutions in response to the challenges. In times of confinement and social distancing, our technological ability to support digital working has enabled organizations and their staff to maintain activities, minimizing traveling while carrying out substantial work (e.g. R&D by means of computational model-based approaches helped by digital deployment, reliable networks and energy). In fact, this increase of productivity will drive long lasting transformations ahead. The Digital Media Observatory was created in June 2020 to better understand and mitigate the effects of disinformation and to increase social resilience. Advanced materials and their processing on the nanoscale play a key role in the development of information and communication technologies (e.g. materials for high frequency applications for 5G networks to increase data storage capacity, and materials to reduce power demand in cloud computing). The EUMAT Platform has a working group in Materials for Information and Communication Technologies (ICT) and Quantum Computing. Materials modelling enables optimal solutions to be reached efficiently and rapidly. Europe can ensure independence and establish leadership in all these areas.

The European Materials Modelling Council **(EMMC)** brings together the relevant stakeholders and calls on policymakers, grant bodies and industries to support materials modelling and digitalization investments for a more sustainable and resilient European society. EMMC just published their RoadMap recommending continued advances for materials modelling and digitalisation and seting the criteria to enable a successful transfer and implementation to industry of the overall knowledge, experiences and tools accumulated during the last years. Materials modelling, and digitalization, play key roles in supporting solutions to societal challenges. EMMC also elaborated key points that underline the strategic importance of materials modelling and digitalization in European post-COVID Society. The research needs have been detailed in the ANNEX of this document and concerns to:

- Materials modelling for the design of antibacterial and antiviral surfaces, coatings, and paints
- Materials modelling for development of vaccines and drugs
- Materials modelling for understanding and predicting the behaviour of SARS-CoV-2 Virus
- Accelerated materials development
- Materials modelling for society
- Enabling cross disciplinary research

Materials modelling is inherently inter-disciplinary and facilitates cross-disciplinary research. During the COVID crisis, there have been increased cross-disciplinary interactions between life science and materials modelling, (e.g. materials modelling groups have started to work on biotechnology related problems). The experience and competence arising from these interactions will not only benefit the handling of the current COVID situation but will also facilitate involving materials modelling in other biology-related challenges with a great impact potential. The EUMAT working group on materials characterization and modelling, highlights the importance to combine models with appropriate experiments in order to increase the robustness of materials development, in cooperation with the European Materials Characterization Council (EMCC) activities and the European Project Pilot Network (EPPN).

Industry 4.0 and digital technology will provide information on materials, processes, products, and systems, with the complete history from raw or reused materials to end-of-life; Modular products with embedded sensors and data communication that enable new Product-as-a-Service (PaaS) business models for optimal 'using and sharing' (rather than owning) products. The benefits of Artificial Intelligence (AI) combined with databases, sensors and algorithms will help to give intelligence to condition monitoring of the materials and system components.

Materials Data and Databases - in any design process, the scientist and engineers, and the models they use, depend on reliable, repeatable materials data in order to select and apply the best, cost-effective materials for the component in question. However, materials data can vary in quality depending on its source, and the spread of the data (which may be materials composition dependent) is not always provided. In high integrity components for advanced operating conditions this problem is managed by applying design codes which provide safety margins to allow for the materials being used having lower properties than expected. These safety margins lead to 'over-design' of components (e.g. thicker walled vessels than necessary for pressure containment) and the excessive use of expensive materials, often containing strategic elements. Such instances not only consume more materials resources than necessary, but also increase energy use/CO_2 emissions and lead to higher-priced parts making EU industries uncompetitive. It is only in those cases where a company controls the materials supply, when this problem can be avoided. International standards for some property measurements have reduced the impact of this problem, but there is a tendency for such standards to reduce the voracity of testing methods to avoid excluding suppliers from less developed industries and countries. A new effort is required to ensure that designers have available to them, through qualified public-domain databases, the best available data, assisting access to new markets entrants in particular those smaller companies that often have new and exciting ideas. Materials data quality standards need to be improved so that designers can use 'design-by-analysis' approaches rather than relying on engineering standards with large safety margins, as small differences in a material's composition can lead to reduced component lives and unforeseen in-service failures, costing European industries more through the requirement for increased inspection and maintenance. Improving materials data quality and databases, integrating for example, friction and durability data for a certain application, will reduce costs and environmental impacts, allowing European industries to raise their game in international markets.

The European data strategy aims to make the EU a leader in developing a data-driven society, preserving the EU's role as the vanguard of privacy and a values-based digital society. Today, Materials Science and Technologies see new developments with (AI) and specifically with Machine/Active Learning. In the history of Materials Science, four paradigms can be identified: (i) Empirical science, (ii) Theoretical Science, (iii) Computational science and (iv) Data-driven science.

Big data and artificial intelligence are changing many aspects of our life, and materials science is not an exception. Machine learning (ML) offers the ability to gain new insights into materials by discovering new patterns and relationships in data (4th paradigm: big data-driven science). This addresses a strong need in materials science. Obviously, none of the previous paradigms became obsolete, as all the methods are complementary and contribute to the benefit of each other, but machine learning appears as the necessary tool to shape the needs of our future as far as materials functionality and exploitation in products and systems are concerned. For instance, it can support the realization of materials by design, which can provide multiple functionalities. These "stem" materials (1D-2D) will embed a concept of the "Internet of Things (IOT)", where their processing capacity will enable the systems to interact with the environment and express diverse functionalities. This is a new pathway to be considered as a way to evolve science from the transition of different events impacting on us today, towards a better sustainable green deal with prosperity in all senses: economic growth, respecting mother nature and giving the comfort people deserve.

Five high-impact research areas in Machine Learning (ML) highlighted by the **European Academy of Science for Materials (EASM)** can be summarized as follows:

1- **Validation by experiments** physics-based simulations to predict materials properties and discover new materials with superior properties.

2- **ML approaches** tailored for materials data and applications involving methodology developments for a wide range of materials and multidimensional data sets.

3- **High-Throughput data acquisition capabilities**. Materials informatics will help to synthesize, characterize, and simulate materials (e.g. high-throughput density functional theory calculations of materials properties, applications of robotics, automation, natural language processing (NLP) to extract materials data from text corpora).

4- **ML that makes us better scientists.** "ML will not replace scientists, but scientists who use ML will replace those who do not". ML has the potential to make scientists more effective, with more interesting and impactful work. ML can help model explain-ability and interpretability and to accelerate or simplify materials characterization.

5- **Integration of known physics** within ML, and ML with physics-based simulations to develop methods that guarantee certain desirable properties by construction, such a respecting invariances present in a physical system. ML can also be used to model the difference between simulation outputs and experimental results.

Materials modelling, artificial intelligence, machine learning and materials development for ICT and quantum technologies are key to achieve the necessary degrees of digitalization and solve the pressing challenges as well as realising the opportunities of a post-COVID society. Europe is in a leading position in all the above areas, i.e. in fundamental and applied materials science, in academic development of modelling and digitalization as well as in commercial software, Europe being the home of some of the largest as well as most innovative companies in the field.

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[1] The adjective "stem" has originally been attributed to living cells that can differentiate into other types of cells. By analogy, the concept of "stem" materials has been proposed for the use of blocks of non-specialized materials capable of change allowing them to adapt to specific requirements.

[2] P. F. Moretti *et al*, BMC Mater. **1**, 3 (2019), https://doi.org/10.1186/s42833-019-0004-4

Resilience against future emergencies; less critical dependencies "by design"

The COVID pandemic reinforced the urgency and desire to address sustainability challenges and put even greater emphasis on the actions outlined, e.g. in the European Green Deal. **One major Lesson learned from the Corona crisis is the need to create a less dependent, more resilient European economy by guaranteeing raw materials supplies, by ensuring higher materials durability, higher energy efficiency, higher degrees of materials re-cycling and re-use, and by materials-saving through optimised products "by design" with enhanced repair.**

EIT Raw materials funded by the European Institute of Innovation and Technology (EIT) has the vision to develop raw materials into a major strength for Europe. It is the world's largest network in the raw materials sector connecting industry, research, and education. This makes EIT Raw materials a key contributor to secure sustainable access and supply of raw materials for a green, digital and competitive Europe after COVID. As a case study, it has analysed the vulnerability of European industries to the supply of Rare Earth Elements. Among their various industrial uses, rare elements (REEs) are essential for the manufacturing of permanent magnets, that are critical components in electric and fuel cell vehicles and wind turbines. Reliable and sustainable sources of REEs exit in Europe and elsewhere but the supply chain is controlled by China, a further effort is required to carry out a further case study in recycling and reuse. **EIT Raw materials** elaborated a Post COVID-19 position paper, to secure a sustainable supply of raw materials and advanced materials for Europe's green future competitiveness. The current COVID-19 pandemic has caused profound effects at the global macroeconomic scale. In the automotive sector, the halt in production created a demand-side shock for Tier 1 and 2 suppliers; the supply chain steps located in countries strongly affected by the virus were hampered, leading to the breakdown of entire international supply chains. This makes it clearer than ever before that the security of the supply of strategic raw materials needed for the long-term competitiveness and job security in key industries, is of prime importance for the European Union.

Materials can specifically **address healthcare challenges** arising from the coronavirus pandemic, such as: a) long-lasting paints, coatings, surfaces to avoid infection in frequented areas (office buildings, schools, transports, elderly homes, etc.) b) improved air and water filtration, c) biodegradable selective packaging materials with antimicrobial properties, d) selectively-active coatings and surfaces for medical devices, e) low cost, ultra-fast scalable detection methods for viral particles, f) enhanced personal protection equipment (PPE) including facemasks (single-use, active and biodegradable) and rapidly deployable, ultrathin sanitary partition walls. The **facemask of the future** could have antiviral and antibacterial properties, be transparent and less restrictive to breathing with embodied filtration. It should also indicate if it has already been in contact with the virus. Future diagnostic devices could be integrated in the form of a patch (like a diabetic catheter). Such devices can have long life adapted to the required use (several days) with real time, rapid response and with communication capacity via wireless.

In the EU's industrial strategy, the Commission states that Europe needs to bring more manufacturing back to the EU, and the pandemic could accelerate reshoring, as companies seek to improve the predictability of supply chains. Meanwhile, the pressure for further reshoring within national boundaries could potentially be eased by ensuring an EU framework for trade flows in the event of disruptions, such as green lanes. In line with this, the EPRS paper lists "incentivise EU manufacturing (eg. medicines, devices, etc.) and create strategic stockpiles" as one of its "ten opportunities". The paper asks for strategic autonomy and technological sovereignty in strong and resilient value chains. It adds an interesting viewpoint linked to the Corona crisis: the principles of resilience, preparedness and co-operation in the current pandemic could be applied to preparedness for the effects of climate change too.

The EU Green deal targets 2050 for climate neutrality recognise access to resources as a strategic security question to fulfil this ambition. The new Industrial Strategy for Europe sees raw materials as key enablers for a globally competitive, green, and digital Europe and highlights the importance of industrial ecosystems for accelerating innovation and growth in Europe. A more resilient, productive, sovereign, and inclusive economic model that aligns with the Green Deal has been prioritised by the recently launched WBCSD Green Recovery Alliance.

Enabling efficient, prudent, frugal quick response and spontaneous innovation in emergency situations

The COVID-19 pandemic has shown an **amazing degree of flexibility and short-term help in unexpected challenges**, but also a lack of preparedness for the unexpected. The materials community wishes to systemise the swift response to unforeseen crisis modes and elaborate a risk analysis. This chapter highlight the role materials has played through the action of professors, technicians, makers, volunteers, students, DIY scientists etc., during the critical phase of the emergency to provide frugal and efficient solutions to many different citizens' needs.

The use of readily available materials has been the source of ingenious solutions. Flexibility is key: quick fixes and solutions to urgent problems without large investments and long lead times; re-directed and extended usage of existing (but re-directed) means, materials, and tools; and spontaneous innovation. These are essential elements of resilience. It requires a way of thinking and a flexibility that will help us weather future emergencies and pandemics. This mind-set should enjoy EU-wide encouragement, approval, and acknowledgement.

Materials Made in Europe: European industry has rapidly increased production of critical materials and equipment. At the beginning of the pandemic, imports of protective face masks and the necessary materials for medical-grade masks suddenly came to a halt. Many SMEs and local textile enterprises temporarily converted their production facilities to make face masks for medical personnel in the COVID-19 front line. Several big companies have transformed their production capacities to provide the necessary materials and devices, e.g., a) SEAT started ventilator production, b) AIRBUS, 3D printed hospital visors, c) leather workshop (e.g. Louis Vuitton) converted into mask factory, d) AIR LIQUIDE produced 10.000 ventilators in 50 days. Such rapid production changes are not without their hurdles: sourcing scarce supplies, regulatory approval, large differences in manufacturing processes, etc.

In the meantime, mass deliveries of face masks (mostly from China) resumed and European mask manufacturers have ceased their operations as they are not commercially competitive. Market forces alone cannot provide security of supply and independence in emergency situations. Self-sufficient autonomy for critical materials and technology in critical times is highly desirable. In the future, regulations and provisions for materials storage and manufacturing capacities, and the costs for this independence, will need to be managed at EU level.

Key facts about major deadly diseases (ISBN 978-92-4-156553-0, Managing epidemics, edited by the World Health Organization 2018) indicate that history will repeat itself. Other emergencies and critical situations will occur too. Resilience against these future events (man-made or natural), and quick responses to the unexpected, must be enabled and prepared for.

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Stepping up to a safer future, there are some aspects to consider: a) are we able to manufacture the required products in several parts of Europe? b) are we sovereign over the materials needed in emergency cases? c) do we have strategic stocks? d) are the supply chains resilient? e) can the industry (even the traditional ones, textiles, metal and plastic converters) **quickly reconfigure and expand capacities? f) are we able to mobilize skills quickly?** (e.g. scientists to develop specific tests, biologists, chemists, microfluidics experts, etc.) **and transfer this to manufacturers? and g) do we have a policy about strategic materials for health?**

Social, societal, education and political impacts in post-COVID times

The coronavirus pandemic is reshaping and transforming the world. It is already clear that the world is entering its deepest recession since the great depression. More than ever before, there is an urgent need for increased global cooperation and actions that would boost multilateralism as we all seek collective, sustainable, fair, democratic and human-centric solutions. The EU empowers democracies across the world, particularly in the EU's neighbourhood and the western Balkans. Post-COVID materials solutions must therefore be essential parts of a common house approach where the central vector is humans that require safety, comfort and welfare provided by a society that may depend on different types of organizations and demands. Science and technology should not be just focused on how the economy can grow but also on how this can be done better in a well-educated and harmonious society that would sustain all the innovations and progress that we are looking for.

Adopting a new paradigm requires overcoming barriers. For example, machine learning - a tool which can guide researchers and engineers in an unbiased way (beyond their intuition) towards the best materials and the best synthetic strategies, hence saving time and money (e.g. in terms of computational costs, optimization of parameters controlling manufacturing etc) – requires not only new concepts and techniques to be learned but also new best practices (such as data and metadata sharing) need to be accepted. The materials science and technology communities require a new mindset in its broadest sense. Higher Education at both master and doctoral levels is crucial to develop a new generation of materials scientists able to use, for example, data-mining techniques and to build open databases which, unlike published literature, contain not only a   subset of successful data but also failed experiments from laboratory notebooks that are generally inaccessible. Machine learning is in its infancy and to progress, education and training should be integrated into Research and Innovation programs with a longer-term perspective. Teaching methods should mainly rely on 'learning by doing', based on problems arising from dealing with practical applications.

FEMS is a federation of about 30 national materials societies distributed throughout Europe, all echoing the same challenges but working on national position papers. It is of utmost importance, therefore, to build upon the shared expertise and to emphasize the main topics of common interest (e.g. tailored cleanness of materials and surfaces (antiviral), the role of nanomaterials in virology, the equipment needed for their detection and membranes for air filtering). The COVID crisis revealed the importance of adopting additive manufacturing to achieve high quality production on a smaller scale. At the same time, lessons learned on what could have been done differently in the critical period need to be analysed and applied to forthcoming actions. A case in hand, is the uncontrolled growth of packaging waste, a consequence of the massive surge in the production of single-use protective items (facemasks, gloves, etc) with no foreseen collection, treatment, or recycling methods put in place.[3]

[3] Rethinking and optimising plastic waste management under COVID-19 pandemic: Policy solutions based on redesign and reduction of single-use plastics and personal protective equipment https://www.sciencedirect.com/science/article/pii/S0048969720340870

COVID-19 preventive measures have resulted in increased waste generation and negatively disrupted waste management strategies. The shift in consumer behaviour driven by hygiene concerns has led to a significant increase in the demand for food packaging. In addition, concerns over contamination caused by reusable containers and bags have led to withdrawals or postponements of Single Use Plastic (SUP) bans and fees. For example, some governments (e.g. the United Kingdom and Portugal) delayed SUP bans due to COVID-19 concerns and in other countries the deposit return scheme for soft plastics was postponed. The increased use and consumption of SUPs during the COVID-19 pandemic resulted in an abnormally increased generation of waste. Moreover, the price of petroleum was lower due to the decrease in land and air transport demands, which favoured the manufacturing of virgin plastics over recycled plastics. The demand for SUPs substantially increased not only during the COVID-19 pandemic crisis but mostly after confinement and this situation may hold into the near future.

The mandatory use of Personal Protection Equipment (PPE) by the public (at start only for frontline healthcare workers) increased significantly. Over 50 countries worldwide required the use of masks in public places and transports. Similar to SUP, PPE demand led to increased production (in China facemask production grew by 450% in a month and demand for N95 respirators from about 200,000 to 1.6 M). The use of masks by ordinary citizens became controversial due to the lack of correct handling and disposal. Surgical masks should not be worn longer than a few hours (e.g. 3 h) and should be adequately discarded to avoid cross-contamination (in sealed bags). Despite being a public health concern, incorrect disposal of PPE spread around public places and natural environments has become a common occurrence. Masks are made of nonwoven materials often incorporating polypropylene and polyethylene, which are likely to degrade into smaller microplastic pieces. Furthermore, other SUPs are likely to be used extensively in a post-pandemic scenario. Some examples include microfibre wipes for cleaning, disposable feet protection, single-use head caps and cuffs in healthcare clinics and beauty salons; protective plastic films/protectors in chairs, payment machines and desks which are replaced within hours to avoid potential contamination.

The substantial increase in the consumption of both SUPs and PPE, along with the increase in medical waste in the pandemic is disrupting viable options of proper waste management. Due to the persistence and contagiousness of SARS-CoV-2, many countries have classified all hospital and household waste as infectious (2020), which should be incinerated under high temperatures followed by landfilling of residual ash. While some countries/municipalities can manage such waste properly, others with fewer resources apply inappropriate management strategies such as direct landfills or open burnings. The withdrawal of SUP policies was reacted against by many consumers who have already adjusted to using alternatives. The contribution of reusable grocery bags in the transmission of SARS-CoV-2 remain questionable, especially when coupled with proper hygiene practices, as regular hand washing and frequent laundering of the reusable bags.

It has been largely proven that full circularity is idealistic but unachievable. The limitations of closed loop of materials can be addressed by the emerging approach of **"design FROM recycling,"** not opposed to but complementary to the long-time existing **"design FOR recycling**". *Design from Recycling* is a rather unexplored subject**.** In-depth knowledge of the (diminished) properties/characteristics of existing recycled material/feedstock, together with the user perceptions on those, will allow successful applications/grades and value chains to be defined and anticipated. To overcome current low % of recyclates in mixtures with virgin materials (which are rather symbolic), a comprehensive assessment prior to design and optimisation, using testing and material modelling for envisioning new applications, are essential. A process of smart deconstruction of complex materials into elementary materials to foster their reuse in technical applications is an expected impact of this approach. Consumer perception is very important to design the secondary (recycled products specifications) and involve them in the recycling chain. Recycling regulations in different countries should involve different member states.

All the short-term and inadequate solutions applied during the pandemic need to be reconsidered taking into account the "design for and from recycling" approaches, as well as adequate EU regulations to achieve more sustainable alternatives that fit into the Green Deal goals and the EU circular Economy. Science and "Ethics in Science", will help society to recreate but to be successful it is necessary to consider the opinion of the citizens.

IV. Recommendations for future publicly funded materials-related research (based on the above) at European, national or regional level

We have the technological basis in Europe to develop more efficient, local solutions but we need validity at a whole EU dimension. Several materials and functions are very advanced, but we need an "All in One" approach to make the products of tomorrow. We must gather forces to design, develop and manufacture tomorrow's solutions and make our industry and supply chains more resilient.

Advanced materials, advanced functionality, and novel applications are at the heart of the innovations of today and tomorrow. The post-Corona economy of Europe, kick-started by massive stimulus programmes, will need both intensive and innovative economic growths to re-pay these funds in the years to come.

The Materials community stands ready to intensify innovation and growth based on R&D&I actions:
- To discuss the strategy on COVID-19, highlighting the role of Materials in post-Corona scenario.
- To define the objectives and milestones of a coherent Materials R&D&I.
- To help to co-ordinate the materials-related efforts in R&D&I and post corona-investments Europe-wide at national and EU level.

While we are entering the Post-Covid era, we would like to highlight **the 10 most relevant recommendations from the Materials community**:

1. Need to **coordinate at EU Level Materials research** with a common strategy able to define complementary and multidisciplinary research benefiting and providing cross sectoral synergies.
2. **Development of freely available common EU Regulations and Standards,** to facilitate product development and scale-up and to reduce manufacturing costs in Europe.
3. **Materials should be durable and energy efficient** with a low carbon footprint during material processing and use. A circular approach is needed to minimize the use of raw materials in Europe.
4. **Intensive investment in materials for decarbonised and renewable energy production, storage and supply,** without forgetting the need for alternative fuels, efficiency of mixtures and emissions reduction.
5. **Materials modelling, artificial intelligence, machine learning and materials development for ICT and quantum technologies** are key to achieving the necessary digital transition of our society.

6. **A more resilient European economy by guaranteeing raw materials supplies,** can be achieved with sustainable sourcing, combined with higher materials durability, higher energy efficiency, higher degrees of materials recovery, repair, reuse, recycling and **by materials-saving products "by design" during their complete lifecycle.**
7. **A safer future,** will be guaranteed by production of tailored quality in several parts of Europe, building supply chain resilience, enhancing production flexibility and reconfigurability with common regulations**.**
8. A stable and sustainable green economy will require **"design for and from recycling" and adequate EU regulations to achieve more sustainable alternatives that fit into the Green Deal goals**
9. **Development of new functional, green, stem, quantum, smart materials and surfaces** for products, with embedded sensors, will be necessary to enable the circular economy and achieve the challenges for the society.
10. **Science and ethics in Science,** can help **society to recreate in cooperation with citizens and member states.**

In this Reflection Paper, we have highlighted the role of materials and the importance of materials R&D&I in Horizon Europe. We engage in an inclusive, multicultural, societal research arena answering to society demands with collaboration and foresight. Concrete proposals for project ideas have been collated between EUMAT and A4M members and are **described in ANNEX** following the structure below:

- Advanced surfaces
- Advanced and safe materials
- Testing methods, modelling and data integration
- Materials for ICT enabling Digitalization
- Circular Economy and Resilience

Attachments:

- **ANNEX.-** Concrete proposals by EUMAT and A4M (short / medium term R&D)

- **APPENDIX:** 1) Abbreviations, 2) Organisations etc.

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ANNEX
CONCRETE PROPOSALS by EUMAT & Alliance for Materials (A4M)
Ideas for projects

Materials research needs for Post COVID EU resilience

The received ideas for some suggested topics for future calls have been divided into 5 areas:

- **Advanced surfaces**
- **Advanced and safe materials**
- **Testing methods, modelling and data integration**
- **Materials for ICT enabling Digitalization**
- **Circular Economy and Resilience**

Advanced surfaces

Antiviral surfaces for multi-usage clothing and protective materials for the medical sector
Challenge: Development of highly effective and reliable antiviral surfaces primarily for the medical sector with long-lasting properties.
R&I topic to address that challenge: Development of safe facial shield protection materials and protective textile clothing for the medical sector for multiple use by appropriate sterile treatments. Establish efficient simulation and characterisation techniques for concept proof.
Expected impact: Secure multi utilisation of medical protective clothing and other protective materials in hospitals and surgeries. Significant reduction of virus contaminated medical waste arising from single use materials.

Reduce virus contamination from frequently used surfaces
Challenge: Create durable antiviral/antimicrobial coatings on materials, such as cloth membranes on packaging or to be applied on hard materials such as wood or metal; characterize them under various conditions.
R&I topic to address that challenge: Development of antiviral, antimicrobial, hygienic and biocide surfaces increasing adhesion and durability. Assess the durability in different working conditions. Development of microbiological testing. Up scaling, standardization, and regulation.
Expected impact: Reduce cross-contamination of the virus; reduce waste by the avoidance of single-use materials. Safer materials should play a big role in terms of sociosanitary and economic impact to prevent future spreading of virus and pandemics.

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Long-lasting intelligent anti-viral and anti-microbial surfaces
Challenge: Accelerate the inactivation of viruses or germs deposited on doorknobs, touch screens, countertops, and other areas inside hospitals and homes to minimize use of material and energy resources.
R&I topic: Nano-engineered stimuli-responsive surfaces using intelligent coatings or additives with controlled and selective heating properties. Durability of functional surfaces is an issue and it is necessary to increase the lifetime of the active surfaces. Protocols should be developed to assess the functionality during the lifetime.
Impact: Easy sterilization and sanitization of objects of complex structure.

Surface treatments with germicide effects
Challenge: In this moment, not only hospitals but also all industrial sectors are extremely worried about the possibility of infections of workers and customers. The development of new materials/coatings/surface treatments with germicide effects are crucial to returning to the “new normality” post-covid
R&I topic to address that challenge: New materials characterization techniques (biological, mechanical, environmental resistance characterization)
Expected impact: Better, faster characterization to put in service newly developed materials.

Modelling metallic nanocluster virucidal action on filtration air devices and surfaces
Challenge: modelling of metal (eg. silver) nanocluster action on coronavirus analysing also the spread of the metallic nanoparticles in the environment.
R&I topic to address that challenge: sputtering of metal (silver) nanocluster doped oxide-based coatings on air filtration devices and other surfaces
Expected impact: **virucidal action** of these Coatings

Sustainable antiviral surfaces for applications in multiple sectors
Challenge: Development of efficient eco- and cyto-toxicologically-safe antiviral surfaces
R&I topic to address that challenge: Development of materials combinations combining durable antiviral properties, low sensitization effect and based on bio-based components and eco-friendly manufacturing processes. Efficient and cost-effective manufacturing processes for industrial scale application.
Expected impact: Development of reusable safe personal protective equipment (PPE) for consumers and professionals (e.g. in the medical sector) with durable antiviral properties. Sustainable antiviral solutions targeting multiple substrates for valuable consumer applications. Reduction of the ecological footprint throughout the entire product life cycle.

Advanced and safe materials

Polymeric Materials to avoid spread of diseases
Challenge: On the surface of polymeric materials the lifetime of bacterial action is significantly longer than on metallic surfaces, increasing significantly the risk of spreading of diseases in public places.
R&I topic to address that challenge: Bringing together the anti-bacterial properties combined with wear resistance by tailoring the functionality of polymeric surfaces with versatile filler selections.
Expected impact: Less spreading of diseases via polymeric surfaces in public places in the future

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Antimicrobial and antiviral protection for medical devices
Challenge: Development of medical devices (masks, protection equipment, ventilators...), homologation of masks for medical use and manufacturing facilities for prototyping polymeric based products and textiles.
R&I topic: co-sputtered antimicrobial/viricidal coatings for tailored surfaces and materials (textiles, gloves, masks, etc.), with improved resistance to COVID-19 survival. Controlled pattern of electrostatically charged polymeric nanofibers to confer virus filtering capacity to protection masks. Physical and chemical evaluation of antimicrobial functional surfaces and materials. Investigation on disinfection methods.
Impact: Minimize the effect of virus or antimicrobial contamination in society.

Shared mobility in COVID19 times
Challenge: public has lost confidence in the use of shared mobility options, as they fear infection.
R&I topic: study the risk of infection through touching of plastic in commonly used and shared goods and find remedies. Methods for detection and monitoring should be also developed.
Impact: recovery of the participation of citizens in bike and car sharing systems.

Testing methods, modelling and data integration

Cheap rapid tests. Nanofabrication of filters for use with Surface Enhanced Raman Scattering (SERS); Aerosol flow characterization for the nanoparticle and virus deposition to protect people.
Challenge: Cheap rapid test
R&I topic to address that challenge: Proposal SERS4SARS (https://devpost.com/software/sers4sars) winner of the https://www.euvsvirus.org/results/, under "Cheap rapid tests"). Nanofabrication of filters for use with Surface Enhanced Raman Scattering (SERS); advanced characterization of the aerosol flows for the nanoparticle and virus deposition.
Expected impact: Enable the safe gathering people in large buildings again, etc. Make safer the working space in hospitals etc.

Materials modelling for the design of antibacterial and antiviral surfaces, coatings and paints
Challenge: In an ever crowded, global world, cross contamination and spread of viruses can be very rapid unless drastic measures such as lockdowns are imposed. Designing surface coating and paints that are sustainable and have properties that can attract and eliminate hazardous particles can be very efficient in limiting propagation. Further research is needed into a) paints, coatings and surface structuring, b) to create models from experiments for how such surfaces can limit the spread and c) molecular level engineering combining with system engineering on how to position the surfaces optimally.
Expected impact: New self-cleaning surfaces with an important impact on energy saving.

Materials modelling for development of vaccines and drugs
Challenge: The development of vaccines and drugs is not only a question of biology and clinical testing but also one of chemistry and materials. Modelling materials and particle stability, polymorphism, solubility, and biopharmaceutical behaviour play a big role in ensuring that development times can be kept to a minimum. Materials modelling also contribute to the material sparing approach, whereby development programs can be carried out with a minimum available material, a factor that has actually become crucial in the COVID scenario, due to lack of time, resources and issues with global supply chains.
Expected impact: Reduction of the time and necessary resources for vaccine and drug development.

Materials modelling predicting the behaviour of the SARS-CoV-2 virus
Challenge: fundamental understanding of materials behaviour is needed. In particular, the ability to make decisions that affect our lives requires sound physics-based materials models. The debate around the behaviour of SARS-CoV-2 virus (nano) particles in different environments, how far they can travel, on what they adhere better, what surfaces can eliminate them, etc., demonstrates a need and opportunity for complex multiscale simulations to shed more light on the situation. It highlights the need for both immediate, applied efforts as well as long-term research into modelling of complex material systems, maintaining a healthy mix of fundamental and applied research to ensure a continuous outflow of new insights and knowledge, improved materials and more reliable, efficient and robust methods and tools.
Expected impact: Models to predict the materials behaviour and delivers answers to "what if" questions reliably and accurately.

Multiscale Modelling applied in research environment and Clinical reality (2-way integration)
Challenge: Integration of Multiscale Modelling, Experimentation, Testing in the Research Environment and in the Clinical Reality (two-way integration)
R&I topic to address that challenge: New Multiscale Multi-Methodology Strategies and Frameworks to integrate, inside a coherent conceptual, methodological and application context the full spectrum of scientific and engineering methodological and technological approaches
Expected impact: better understanding of diseases origin, development and evaluation of effectiveness therapies: Rational Integration of Computational, Experimental, Characterization, Testing, and Clinical Reality Analysis and Design Strategies

Accelerated materials development
Challenge: New levels of expectation for research and development timelines and practices have been set because of the pandemic experience. The speed of development of anything from ventilators and other treatment devices to new vaccines has shown the power of many computation and digital approaches that were brought to bear. It demonstrated the impact of a change from purely physical to more model-based design and development of materials and products that has already taken place over the last decade, with the pandemic highlighting and amplifying its advantage. New and improved formulations (eg. washing liquids) are already developed without the need for extensive physical testing. All relevant properties are predicted by modelling, making the process much more agile. Digital twins predict the status of production lines before their physical presence. New drugs can be developed with higher confidence, greater speed and much reduced wastage of valuable chemicals. Further investment into materials modelling and digitalization will provide organizations with a significant competitive advantage and a much-reduced risk profile to potential future pandemic disruptions.
Expected impact: Reduction of time to market for different products predicting the behaviour of the materials and components before scaling up production, to reduce risk.

Materials modelling for society
Challenges: Materials modelling has been making very significant contributions to improve materials and discovering new materials to enable renewable and sustainable energy supplies. These include wind turbine and their lubrication systems that can run for extended period of times in order to make their use in harsh conditions (offshore) viable, solar materials that have increased conversion efficiency and battery materials with higher energy density, while being safe and sustainable. It also includes improved catalyst for lower energy, higher efficiency processes as well as reducing the impact of catalyst for lower energy, higher efficient processes as well as reducing the impact of the catalyst materials themselves. Furthermore, in a crisis, reliable primary energy is critical. Advanced modular

nuclear reactors will play their part and materials modelling plays a key role to create safe and sustainable engineering solutions for these advanced designs. A sustainable and circular economy relies on making the best of the valuable materials resources we have. That means optimizing their use which in turn means deep understanding and multidisciplinary optimization based on tribological studies and sound models.
Impact: A digital record for each material/product that tells users and machines, how to use, maintain and re-use the materials, an approach that requires tribology and models that depends on the materials, components and systems environment.

Materials for ICT as enable for Digitalization

Increase of Data storage capacity
Challenge: increase power electronics efficiency in electric vehicles
R&I topic to address that challenge: transition from Silicon based power electronics to Silicon Carbide (SiC) based power electronics by reducing defectivity and increasing manufacturing yield of SiC wafers.
Expected impact: reduce the cost of SiC wafers to enable the adoption of SiC based power electronics in electric vehicles whereby a higher mileage compared to Silicon technologies can be achieved. Expected market increase of 19% p.a.

Reduce power demand in cloud computing
Challenge: Reduce energy demand from cloud computing. The demand of energy consumption of networks (Wireless and wired) is projected to increase 20,9%, reaching a total 9000Terawatt hours (TWh)
R&I topic to address that challenge: develop emerging resistive memory devices through new materials and modelling to enable Edge computing among the billions of IoT devices that are expected.
Expected impact: Reduce energy consumption of ICT while supporting the development and growth of billions of IoT devices in combination with Edge computing

Advanced Manufacturing needs

Availability of EU-Manufacturing resources (short term)
Challenge: Design and development of materials solutions and medical devices to support the request of systems for contamination prevention and for healthcare**.**
R&I topic: Sharing data, competences and communication of new developments in the field. Collaborative actions among competence areas to design and develop solutions for the environment, safety and contamination prevention (e.g. functional Coatings, sanitisation, sterilization technologies and products).
Impact: Availability in Europe of medical protection and devices for COVID 19 mitigation

Assuring EU-Manufacturing autonomy (medium term)
Challenge: New materials (e.g. functionalized Cu).
R&I topic: a) R&D initiatives for the exploration, integration and validation of available and new material/technology systems, innovative solutions (e.g. parts for healthcare, knowledge and technologies for other fields). b) Methodologies for rapid validation of materials for additive manufacturing: biocompatibility and functionalities of innovative engineering solutions. c) Supporting the development of biomaterials and multifunctional material solutions to be easy separated for their use and recycling. d) Integration with technologies for the improvement of materials recycling properties. e) supporting the development of new devices for cleaning, sanitization and sterilizing.

Impact: Availability in Europe of the necessary technology to combat not only COVID 19 but also any other type of virus and bacteria.

Advanced Manufacturing technologies
Challenge: Additive Manufacturing (AM) has a high potential for improvement due to their flexibility in terms of geometry and possibility to tailor end users' requirements.
R&I Needs: a) availability of raw materials overcoming limitations from machine suppliers. b) limitations on raw material characteristics (e.g. possibility to process high temperature thermoplastics), c) quality of the produced items (mechanical properties, surface properties) d) size of the products and machines.
Impact: Just in time production of parts minimizing stocks. Tailor production for consumer needs.

Circular Economy and Resilience

Raw Materials: Security of supply and more sustainable practices in EU raw materials supply chains
Challenge: Strengthen the EU-based raw materials supply chains of primary raw materials due to volume dependence on supply chains outside of the EU, which can be cut off or severely reduced without warning by global or regional crisis or geo-political tensions (more long-term impacts than short term).
R&I topic: Two-faceted approach required: 1) research efforts into new, innovative exploration methods/tools, in particular to assess deep seated deposits, and improving harmonization and standardization of data on potential deposits of mineral resources across Europe, including their economic viability; 2) research into improved and more coordinated material recovery alongside innovation in reuse and recycling technologies adapted to complex, durable or miniaturized products.
Impact: Security of supply and more sustainable practices in EU raw materials supply chains, as well as a more resilient sector

Durability: Game change for boundary lubrication at multilevel research
Challenge: Controlling the **wear and friction in machinery operating** in demanding boundary lubricated conditions, such as in wind turbine gears and bearings, is difficult due to dispersed pieces of information and to many unsolved questions on the area of boundary lubrication.
R&I topic to address that challenge: Developing **new approaches** and combining (1) modeling, (2) characterization of tribofilms, and (3) evaluation of lubrication performance and wear in boundary lubrication regime has huge potential to answer the unsolved questions but **requires innovative and multi-level research.**
Expected impact: **Bringing new knowledge** and solutions to boundary lubrication regime will bring great **impact to machine design**, new lubrication techniques and new application areas.

Sensors: Maintain the value of products and materials for as long as possible, thereby reducing our dependence on the supply of raw materials
Challenge: Need of prolonging the life span of high-value materials such as composites, saving raw-material costs.
R&I topic: Development of intelligent self-sensing materials able to identify surface microcracks and their propagation in a simple and visual way at an early stage of failure of the structure.
Impact: Extend the life of structural components, thus reducing the carbon footprint, and offer alternatives to non-destructive testing (NDT) of high-valued materials.

Recycling: Reduce the import of strategic products and materials by recycling and urban mining
Challenge: the crisis has demonstrated clearly what it means to be import dependent for certain materials. In this instance it was materials for face masks, but the challenge is similar for critical raw materials.
R&I topic: re-initiate programmes to secure the recycling and reuse of critical raw materials in EU through urban mining.
Impact: increase of recycling rates for metal containing products, set up of new logistics and treatment cycles for CRM-containing materials.

Scale up: Relaunch the circular daredevil companies
Challenge: the (economic) crisis affects most small and young enterprises that operate in (circular) niches of the existing (largely linear) system.
R&I topic: evaluate the factors that affect resilience of circular enterprises against sudden economic shocks or crises, study whether and how circular business models can generate more economic resilience
Impact: higher survival rate of small circular enterprises when a new crisis hits the EU.

APPENDIX 1

Abbreviations

A4M - Alliance for Materials
AEC - Alkaline Electrolysis cells
AI - Artificial Intelligence
AM - Additive Manufacturing
BUILT4PEOPLE PPP - Promoted by European Construction Platform
CCU - Carbon Capture and Utilization
CEFIC - The European chemical industry
CEN - European Committee for Standardization
CRM - Critical Raw Materials
EA - European Aluminium
EARTO - European Association of Research and technology organisations
ECHA - European Chemicals Agency
ECP4 - The European Plastics and Composites Network
ECTP - European Construction Technology Platform
EDA - European Defence Agency
EIT Raw materials - European Institute on Innovation Technologies in Raw Materials
ETP - European Technology Platforms
EuPC - European Plastics Converters Association
EMIRI - The Energy Materials Industrial Research Initiative
EMMC - European Materials Modelling Council
EASM - European Academy of Science for Materials
ESTHER - Nanomedicine initiative involving materials and nanotechnologies
EUMAT - The European Materials Platform
FEMS - The Federation of European Materials Societies
ICT - Information and Communication Technologies
NOBEL - Smarter Health tech in Europe. CSA financed by EU Commission.
MATERPLAT - Spanish Materials Platform
MDD - Material Driven Design
ML - Machine Learning
PEMFC - Proton Exchange Membrane Electrolysis Cells
PPE - Personal Protection Equipment
PV - Photovoltaics
PROCESS4PLANET - SPIRE initiative in sustainable and low footprint materials production processes
P2X - Power to X (chemicals)
SME - Small and Medium Enterprise
SOEC - Solid Oxide Electrolysis Cells
SUP – Single-use plastic
SUSCHEM - Sustainable Chemicals Platform
RES - Renewable Energy Sector
RTO - Research and Technological Organization
TFTs - Hybrid thin film transistors

APPENDIX 2

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