Progress in Natural Science: Materials International 31 (2021) 785–791

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Contents lists available at ScienceDirect

Progress in Natural Science: Materials International

journal homepage: www.elsevier.com/locate/pnsmi

Review

# Materials as activator of future global science and technology challenges

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ARTICLE INFO

*Keywords:*
Materials science and engineering
Green technologies and products
Materials activator
Materials accelerator of progress changes

ABSTRACT

The aim of this statement is to give a contribution towards the future, where for all, materials are the driven force for the transformations we aim to reach and for which a global common house is imperative to be established, as the International Union of Materials Research Societies, IUMRS aims to be the central vehicle for such, aiming to boost innovation to its maxima, without compromising vital global principles of opening science to the world. This is consolidated by 4 main principles: Circular Economy; Trans disciplinarity; Horizontal cross cutting synergy (the introduced Metro Station concept); look always to the Big Picture and not to silos. This means that the traditional vertical thematic topics that were essential to define so far, the so-called road maps for something should be revisited and reconverted towards much larger horizontal scenarios.

Today we are engaged in promoting science in favour of people comfort and welfare, together with prosperity to countries and regions. This implies to exploit the activators able to support these challenges as far creativity and innovation are concerned. In this respect, materials offer a variety of solutions that stem from or have been enhanced by the perception we have that “*Materials are everywhere even in our body!*“. Moreover, we must avoid residues as waste through reuse, recycling and circularity to serve a Green Agenda and bring an eco-sustainable environment, once we do not have planet B as alternative solution.

The pandemic times that are affecting our lives has been proving that the solution for our progress has to be though globally, on relevant details such as to ensure the health and safety and to secure supplies of critical materials and chemicals into medical, environmental and food supply chains amidst border closures and lockdown measures. Key examples include biocides for disinfectants, non-woven fabrics for mouth masks, surfaces with antiviral and antimicrobial properties and wastewater treatments for drinking water. Therefore, the missions of our future have materials as the heart of our progress and cannot be thought as an isolated cluster. It has to serve, as activator several sectors and we must exploit materials on their multiple latitudes and the outstanding functional applications of materials and exploiting them at a nanoscale. Like a metro station where in each station we can change the lines.

## 1. - Introduction

The COVID-19 pandemic has been one of the most defining moments in our lifetimes, as it has disrupted our lives and lifestyles. Indeed. It is still too early to say whether the new world after the pandemic will get “back to normal” and return to previous levels of consumption!

In this framework, Science and Technology integrating Education for which Materials play a major role, offer a variety of solutions to overcome (i) social, (ii) societal and (iii) economic challenges that stem from or have been enhanced by the pandemic. “Materials are everywhere even in our body!”

This strategy cannot be implemented without simultaneously taking into account the three interdependent challenges as depicted in Fig. 1 while respecting an objective balance between them (see Fig. 2).

Also, our future developments will be grounded by the new capabilities offered by digital and communication techniques that open the challenges of artificial intelligence, industry 4.0 technologies, or the Internet of Things, IoT, or internet of the everything, IoE, that brings new relationships in the labour world and its social implications.

## 2. – Materials and products circularity

The present crisis brought to us the identification that, besides circularity of the products, and to focus in the future in eco-sustainable technologies and products, where re-use, recycle, refurnishing and reformulation, including the way to find materials substitutes for the existing and exploiting technologies and products, we must be focused in establishing the proper value chain, going from raw materials to its transformation in products and systems, aiming to close the loop of our

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https://doi.org/10.1016/j.pnsc.2021.11.002
Received 17 October 2021; Received in revised form 2 November 2021; Accepted 3 November 2021

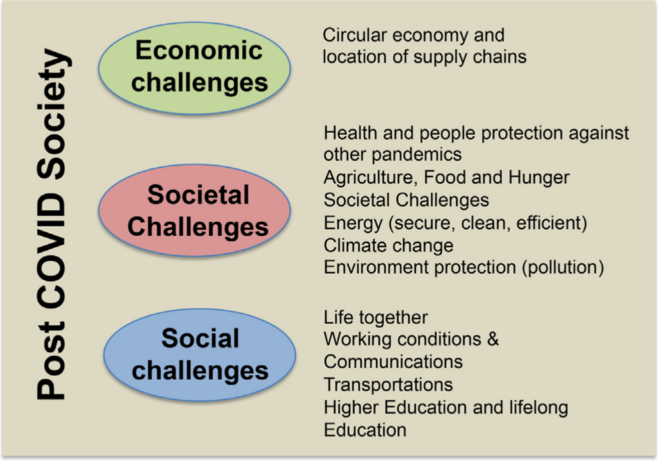

**Fig. 1.** Sketch of our 3 key challenges for the future for the post COVID society challenges.

needs for the challenges of the future. Therefore, actions are needed to serve the basic and *applied science challenges along the material-process-product chain* to achieve most relevant sustainable research and technology targets, to address relevant societal challenges, which became global and so, demanding cross-sectoral cooperation and networking. That is, the existence of a proper value chain is the pre-requisite to better serve society and to better sustain any crises as the current pandemic, which clearly evidenced our flaws: lack of sustainable value chain able to serve our needs starting from raw materials and end up on products and systems we need for our prosperity, wellbeing, and comfort. Therefore, we must be focused on collective approach with competitive advantages involving physical exchange of ideas, materials, and technologies. Moreover, they should be focused on circularity aspects in the full value chains of the three key actions of the future, which are: “recycle”, “reuse”, “renewable recourses”, “repair”, and “self-healing” concepts as pillars of grown future strategy, for a friendly future prosper economy. Therefore, materials recovery and waste re-/upcycling technologies are necessary while providing safe solutions for residues, for which additive manufacturing technologies are highly relevant, to support their redesign, re-shape, and re-use. In this respect, durable efficient materials and products are required, with extended lifetimes and functionalities that can be fully reconditioned. We have today at lab scale the tools able to simulate the working conditions of the materials and to reproduce potential failure mechanisms in systems where they are introduced. This allows a laboratory determination of the estimated lifetime of an unused component, or the remaining life of an ex-service part, which can be extrapolated to predict the behaviour of the materials in the real application. Moreover, to support advances towards zero-waste feeding, novel designs and architectures must be foreseen impacting the recovery of raw materials from end-of-life products to serve a plethora of applications, function their origin. Indeed, here, the aim to do more with less and substitution of critical materials and the use of bio-based, renewable ones must be a priority, whatever the field of application we are envisaging.

The concept of “resource efficiency” through greater recycling and re-use, as well as reduction of raw materials use, must become key elements in the context of the “circular economy”, besides selecting sustainable materials that, depending on the applications, can be considered as environmentally friendly, low-carbon emission, recycled or biobased, offering unique properties including natural abundance, low toxicity, affordability, and versatility in terms of physical and chemical properties.

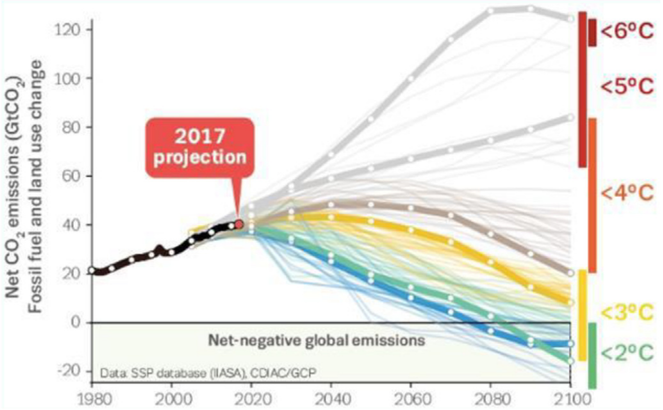

**Fig. 2.** Global $CO_2$ emissions since 1980 (solid black) compared to a high emissions scenario (red/orange) and a scenario compatible with limiting warming to 2 °C above preindustrial levels (green). Source: Global Carbon Budget, 2017.[31]

## 3. Societal challenges

### 3.1. Climate changes, $CO_2$ reduction and the role of materials

The forecasts of global climate change are now generally accepted by the scientific community and by the population at large. The relative importance of anthropogenic sources of greenhouse gases and the predicted time scale and severity of their impact on the climate may still be debated, but there is a growing consensus that remedial efforts are urgently needed and are already late in being deployed.

Advanced tools for effective remediation have yet to be fully developed, aiming to find and test revolutionary technological solutions for which global synergies are needed to access the innovation we all seek. However, to fight traditional scenarios often involving many false starts, such as independent uncoordinated research efforts; reliance on slow dissemination of research results, among others, we must have a central global programme to reduce reliance on serendipity alone by providing the tools to align the manifold efforts of the diverse world-wide R&D community, thus delivering more rapid progress toward the common goal. This must be a global mission for which IUMRS must be ready to conduct and to harmonise the efforts taken worldwide.

For instance, the European Union (EU) has committed to achieve an economy-wide domestic target of at least 40% greenhouse gas (GHG) emission reductions for 2030 and at 80% GHG reductions by 2050. The need to reduce GHG emissions to avoid dangerous climate change was emphasized at the COP21 climate conference in Paris where an international agreement to limit global temperature rise since pre-industrial times to below 2 °C and preferably nearer 1.5 °C was agreed on, placing severe limitations on global carbon emissions.

There is by now ample scientific evidence,[1,2] that the emission of anthropogenic GHG is the main driver of climate change. If no measures are taken to reduce emissions, the consequences of climate change within the coming years are likely to be disastrous.

At European Union level, the commitment is to reach at 2030 40% cuts in GHG emissions; 27% share of renewable energy; 27% improvement in energy efficiency. This goal must be followed worldwide, otherwise the effective impact is not meaningfulness once climate does not have borders. For this type of advocacy, we believe that IUMRS as a

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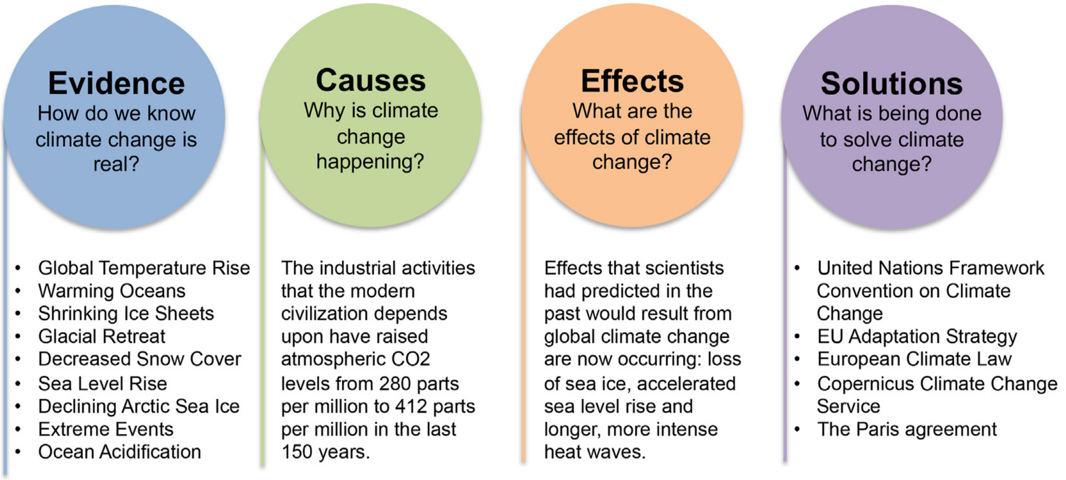
[1] https://ec.europa.eu/info/research-and-innovation/strategy/support-policy-making/scientific-support-eu-policies/group-chief-scientific-advisors/adaptation-climate-change-related-health-effects_en.

[2] https://easac.eu/publications/details/the-imperative-of-climate-action-to-protect-human-health-in-europe/.



**Evidence**
How do we know climate change is real?

- Global Temperature Rise
- Warming Oceans
- Shrinking Ice Sheets
- Glacial Retreat
- Decreased Snow Cover
- Sea Level Rise
- Declining Arctic Sea Ice
- Extreme Events
- Ocean Acidification

**Causes**
Why is climate change happening?

The industrial activities that the modern civilization depends upon have raised atmospheric CO2 levels from 280 parts per million to 412 parts per million in the last 150 years.

**Effects**
What are the effects of climate change?

Effects that scientists had predicted in the past would result from global climate change are now occurring: loss of sea ice, accelerated sea level rise and longer, more intense heat waves.

**Solutions**
What is being done to solve climate change?

- United Nations Framework Convention on Climate Change
- EU Adaptation Strategy
- European Climate Law
- Copernicus Climate Change Service
- The Paris agreement

**Fig. 3.** Main cycle related to climate change effects. Source: NASA Global Climate Change.

global common house should be in the frontline.

Fig. 3 displays the main cycle related to climate change according to the problems identified and the possible solutions[4]. Responding to climate change involves a two-pronged approach, including reducing the emissions of greenhouse gases (**mitigation**) and planning and acting to address the consequences of climate change that cannot be avoided (**adaptation**). Both approaches should be followed carefully. Indeed, climate change is already having numerous negative consequences for example in health, which will get worse with the inevitable rise in temperature. For example, annual fatalities from extreme heat could rise from 2700 deaths/year today to ca. 30,000–50,000 by 2050 caused by global warming of 1.5 °C and 2 °C, respectively, assuming present vulnerability to heat and without additional adaptation measures. Therefore, health challenges need to be firmly integrated in climate change adaptation and so IUMRS should be definitively use its role inside the International Science Committee of UNESCO to pursue the objectives of the United Nations Framework Convention on Climate Change (UNFCCC), agreed in 1992, and share with its adherent bodies this concern (see Fig. 4).

Among main international commitments is the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs), adopted in 2015 by the UN General Assembly. A number of the SDGs are strongly linked to preventing adverse impacts of climate change, including most obviously climate action (SDG 13) and good health and well-being (SDG 3), but also e.g. clean water and sanitation (SDG 6), affordable and clean energy (SDG 7), sustainable cities and communities (SDG 11) and responsible consumption and production (SDG 12).

However, to get a sustainable impact, it is necessary to work together worldwide on these initiatives if we aim to reach the target ***to enshrine the 2050 climate-neutrality objective, for which, it is mandatory to engage citizens and all parts of society in climate action***.

Only a multinational, multidisciplinary effort can ultimately deliver globally effective mitigation technologies to address this major challenge. Realistic projections forewarn of a multi-decadal and therefore a multigenerational 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, until 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.

To this end, we propose the formation of a *Global Common House* centred in IUMRS, involving Research Universities; Corporate laboratories; Professional societies and associations and relevant program offices of governmental ministries and multinational entities, worldwide. For this end we purpose the establishment of a framework of international research that promotes synergy among currently disaggregated R&D efforts, shares resources and expertise and simultaneously brings the next generation of researchers into the field. IUMRS could be the promoter and the unifier of this Global Common house, making bridges with, Africa, Australia, Brazil, China, Europe, India, Indonesia, Japan, Korea, Mexico, Singapore, Thailand, Taiwan, Russia, through the Materials Research Societies, representing the Researchers of such countries. The objective is not only to promote discussions and brainstorms, through conferences organized in the front edge of the state-of-the-art matters but also in promoting global teams to target global projects to serve the science and technology needs for a better future for all.

In this context, IUMRS is well-positioned to be in the driving seat for $CO_2$ neutrality and the fight to minimise world climate change. Our Materials community broadly pursues sustainable development, responsible advancement of science and technology to the benefit of the society and environment. More than before, the strategic agendas from widely differing materials segments open avenues for materials solutions that minimize the $CO_2$ footprint. As far as materials for construction are concerned, the target should be a reduction in embodied energy and the enhancement of their eco-sustainability, which also implies to use and to develop new routes of production and/or low energy demand production technologies.

The same criteria are applied to exploit and to use materials for other purposes, such transportation, electronics, energy, energy storage and health, where additive manufacturing technologies must be foreseen, together with the use of eco-sustainable materials (so called, green materials see section 5).

Indeed, if our global target is to reach climate neutrality by 2050, a multinational and multidisciplinary effort is necessary, and it will go over more than one generation for getting the required advanced solutions to carbon-free technology and products sources. Although information and communication, energy and the environment are the direct beneficiaries, agriculture, water resources, and human health will also benefit.

### 3.2. *Future materials for efficient energy exploitation*

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,

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[3] http://www.globalcarbonproject.org/carbonbudget/17/files/GCP_CarbonBudget_2017.pdf.

[4] Adapted from https://climate.nasa.gov/.

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-based 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 pandemic times of 2019–2020 have seriously complicated the development of current strategies to face societal and social challenges and led to reflection on a new global economic model. In this regard we anticipate that the so-called “Circular economy” should play a crucial role.

So far, mostly of the decarbonisation strategies focused on improving **“energy efficiency”***(reduce the amount of energy required to provide products and services)* and promoting electricity from renewable energy sources, knowing that the major challenge associated with all renewable energy technologies is **storage**. There is a direct physical relationship between the quantity of raw materials used in industrial processes, the energy required and hence, GHG emissions. In this approach the notion of **“resource efficiency”***(means the Earth's limited resources in a sustainable manner while minimizing impacts on the environment),* greater recycling and re-use, as well as absolute reduction of raw materials use must become key elements of climate policy in the context of the **“circular economy”**. (Smaller the circle, the smaller the impact and the bigger the benefit for the environment and living bodies).

In the context of exploiting materials for efficiency energy use, we must focus on green materials and technologies, able to give welfare and comfort to citizens, without affecting negatively the environment nor the health of the human species. Therefore, the great commitment for sustainability of society and the planet is *to commit to a decarbonised society with only the use of renewable energy sources within the 21*st *century*. **Without abundant and sustainable energy to decarbonise society, all other societal challenges cannot be addressed and solved**.

Thus, the new energy paradigm requires important actions with 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 road map must cover:

a) Deployment of renewable energy sources where photovoltaic, wind and hydroelectric must be the essential contributions, together with its storage, not considered as isolated systems but integrated on global and complementary power units. Examples of solar energy conversion technologies are high vacuum tube for hot water, polypropylene collector for hot water, photovoltaic collector to produce electricity and solar streetlamps, among others. The future requires that we think on green power package sources, where we integrate eco-sustainable energy sources, exploiting different materials functionality, going from the ability to capture and transform light, mechanical pressure, pollutants on. In this respect, we should look for structural and functional materials for low carbon energy technologies, and lighter for construction of turbines; look for news designs and architectures of solar cell that may duplicate the present efficiency values (e.g., see how we can get more stable and efficient solar cells based on perovskite like material, but full based on eco-sustainable elements). As far storage is concerned, here we include new design and architectures for batteries that should be lighter and heave an extended storage capacity. In this respect, the has to be centred in selecting alternatives to lithium and what could be the best materials to be selected for cathode, anode, including the electrolyte.

b) We could expect that fuel cell based-transportations, power plants and electricity generators will become prominent in the coming decades! The price of the fuel cells will reduce when producing fuel cells in large quantities and commercializing them. Most experts believes that the future development of electrolysis technologies for hydrogen production will involve three main candidates [1]: Alkaline Electrolysis cells (AEC) [2]; Proton Exchange Membrane Electrolysis Cells (PEMFC) [3]; Solid Oxide Electrolysis Cells (SOEC). The first two for low temperature purposes while the second for high temperature purposes. To enhance this potential for the future, new materials have to be looked after, with novel designs, namely to what concerns electrodes, electrolytes and catalysts, for which carbon-based materials, such as graphene and their derivates should be looked carefully.

c) Hydrogen as an energy vector for a decarbonised society both in heavy transport and in industry. Hydrogen holds a decisive promise for the energy future of our planet. However, despite the abundance and great properties of hydrogen, challenges persist for its widespread application. Two major challenges are the efficiency of functional hierarchical materials for hydrogen production or conversion as well as the development of materials that behave favourably in contact with hydrogen, as it is more aggressive to 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 is demanded, for which proper design, supported by modelling tools are required. In this respect, we can refer to electrochemical membrane reactors (EMR) based on: (i) dense ceramic ion conducting electrolyte operating in the temperature range 500–700 °C; (ii) novel hybrid 3D structured metal organic-biosilica composites to synthesise biomimetic electrodes; (iii) 2D single/few layer heterostructure electrodes for water splitting electrolysers. The challenges involved in the development and operation of such membrane reactors are the harsh environments requiring sufficient stability of the materials and reactor performance. Of special importance is also the design of efficient catalysts and of the electrocatalytic electrode where the reactions take place and their interface with the selective membrane.

d) Fossil fuels play a large role in **agricultural** production. They are directly used in agricultural processes in the form of fuel and electricity, e.g., for heating, lighting, transport etc. They are also indirectly used for the manufacturing of production means, such as 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 the increase of population (∼10 billions in 2050) the intensification and industrialisation of agriculture will contribute to increasing carbon emissions. However, this might change with the development a **new generation of biofuels** [1][Solid (fuelwood, wood residues, wood pellets, animal waste, vegetal material, …); Liquid (biogasoline, biodiesel, bio jet kerosene, …); Biogases (from anaerobic fermentation and from thermal processes) …] **and fuels-cells** [Polymer Electrolyte Fuel Cell (PEFC), also known as Proton Exchange Membrane ((1) PEM) fuel cell; (2) Alkaline Fuel Cell (AFC); (3) Phosphoric Acid Fuel Cell (PAFC); (4) Molten Carbonate Fuel Cell (MCFC); and (5) Solid Oxide Fuel Cell (SOFC) …]. This is in addition to classical renewable energies as wind turbines, photovoltaics, batteries etc, as already mentioned.

e) Synthetic fuels and added value chemistry based on biogenic carbon, together with $CO_2$ capture and deployment of the circular $CO_2$ economy from its use to decrease $CO_2$ concentration in the atmosphere. For all of this, research and innovation should be centred in processes known as artificial photosynthesis in which solar energy is stored in the form of chemical bonds, is the most practical solution that can circumvent the daily and seasonal solar intermittency. The fact that it can supply a convenient fuel, compatible with existing infrastructures, eliminates most market barriers not only for space and water heating in buildings but generally to replace fossil fuels in all their other current uses (industry, mobility, etc.). Importantly, using captured $CO_2$ (e.g., from filtering of exhaust fumes) as the carbon source makes it an environmentally beneficial process enabling the reuse of emitted $CO_2$; thus, establishing a closed-loop $CO_{2,}$ cycle which turns conventional fuels into “green” energy vectors.

### 3.3. *Materials for food security*

Food security occurs when all people can access enough safe and nutritious food to meet their requirements for a healthy life. However, food security faces several challenges across production, consumption, packaging and preservation.

The United Nations Food and Agriculture organisations estimates that nearly 800 million people in the world suffer from chronic starvation. Global climate change will alter what can be grown and where, but the variability that makes up the average temperature and rainfall will lead to climate shocks (heatwaves, cold snaps, droughts, and floods), significantly reducing yields. Climate change can also alter the distribution and severity of pests and diseases in crops and livestock and has the potential for severe impacts on food production and animal welfare. Around a third of the food produced in the world for human consumption every year gets lost and wasted, whether early in the supply chain through and diseases and post-harvest losses, or late in the supply chain at retail and consumption!

A major challenge is understanding how we can re-design the food system to be healthy, sustainable, and more resilient to climate change. Here a better control on the way food is preserved, via eco-sustainable smart sensors as a key area for our development.

Although many **food preservation** methods have been developed over time, most current approaches try to target some medium/high-cost products, and/or intend to impact their attratibility by changing the cosmetic/packaging aspect. That is, there is no systematic activity that is re-recruited in the preservation and safety of food innovation control smart systems.

Recent studies on the field of food engineering and processing are focused on the development of alternative methods able to assure a prolonged and safe preservation to overcome the current inconvenience related with poor quality food. **Food nanotechnology** represents an emerging field that aims to revolutionize the global food system, with wide applications in food engineering, food nanosensing, development of nanostructured ingredients, food quality control, safety evaluation, food processing and food packaging and preservation. Today, the only bio-based food-packaging materials used commercially on a major scale are based on cellulose (paperboard and fiberboard; nanocellulose) and now, start using green plastics [2]. However, materials based on proteins, starch, polylactate and other renewable resources may be the food--packaging of tomorrow!

## 4. Green technologies and products versus high technology electronic trash

Green technology refers to a type of technology that is considered environmentally friendly based on its production process or its supply chain, where clean energy production sources are used, as alternative fuels that are less harmful to the environment than fossil fuels. The aim here is the elimination of carbon-based emissions *(carbon dioxide and methane that arm the environment)* that we call decarbonization.

The green products are sustainable designed products, based on eco-sustainable materials aiming to minimize their environmental impacts during its whole life cycle and even after its of no use. The key targets here are reducing waste and maximizing resource efficiency. These products must be grown without the use of toxic chemicals and within hygienic conditions, can be recycled, reuse and is biodegradable in nature, uses the least resources, is eco-efficient has reduced or zero carbon footprint, has reduced or zero plastic footprint.

As far as comfort and welfare is concerned, more and more we are using electronics interfaces to interconnect with a huge number of commodities, including “the cloud” where information is stored. Nevertheless, the aggressive deployment of a tech-hungry society will affect the toxic legacy of disposable products, such as electronic gadgets since their short lifespans result in plenty of unwanted by-products of electronic waste (e-waste). This is becoming an enormous threat to our planet that must be resolved.

According to the United Nations (U.N.) the world produces 50 million tons of e-waste in each year, only 20% of which is formally recycled. However, in this rapidly progressing digital age, we cannot turn away from the exceptional growth in smart technology. With the burgeoning development in wireless technology and interconnected devices, we need to ensure access to affordable, sustainable and modern systems. The key element is that these systems will be smart, portable, flexible, conformable and are manufactured using eco-sustainable and fully recyclable components. The corresponding fabrication technologies should be in line with a sustainable property respecting the Green Deal concept. Conversely, we are living in a transition on electronics concepts, which migrate from conventional electronics to more eco-friendly manufacturing processes based on abundant, recyclable eco-materials with a much smaller environmental footprint, such as a plethora of organic and oxide materials for electronics purposes, easier to be fabricated and easier to be recycled and reused.

In this respect, our activity must be centred in **promoting the above-mentioned green technologies for multipurpose applications** by using industrially compatible processes, accompanied with in-line inspection tools and automatic systems for high throughput, driven by a novel Knowledge repository powered by Artificial Intelligence (AI) methods.

### 4.1. *Green materials for sustainable development*

Green materials offer unique properties including natural abundance, low toxicity, economically affordable and versatility in terms of physical and chemical properties. They are the activators of an eco-sustainable economy serving all innovation sectors. These 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, they can be developed as a source for energy harvesting tackling new outcome fields that will impact strongly in our development such as hydrogen, synthetic green fuels, or the future exploitation of integrated nanogenerators to backup smart recyclable and disposable platforms for a plethora of applications.

In this respect, biomass materials can be developed as a source for biodiesel and bioethanol production. They also can be transformed into advanced functionalized materials for applications such as the transformation of chitin into chitosan which can be further used for

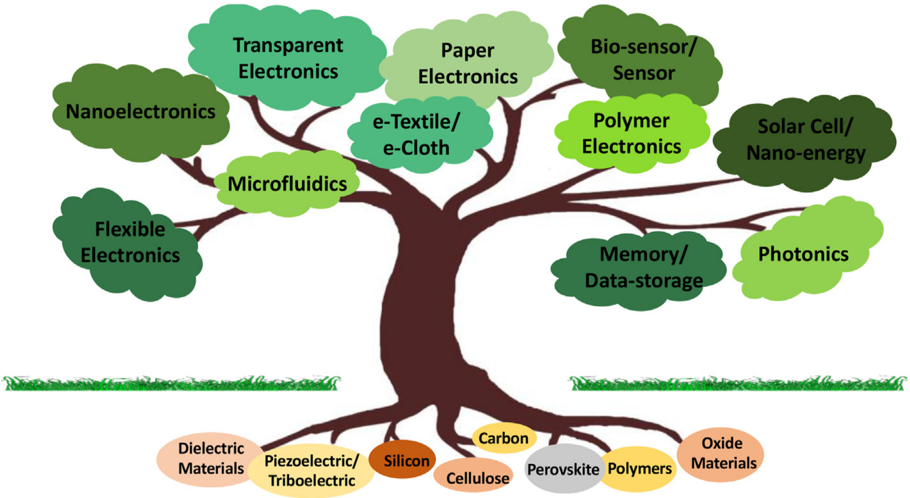

**Fig. 4.** Sketch of the materials' tree, Materials for a better future, going from the roots (materials with different functionalities/properties) to the fruits and leaves (applications/products).

biomedicine, biomaterials, and tissue engineering applications.

Recently, cellulose-based, and lignocellulose-based materials as a source for the developing functional materials attracted the potential prospect for biomaterials, reinforcing materials and nanotechnology, besides allowing the building up of products satisfying fully to green prosperity. Furthermore, the development of pigment materials has gaining interest by using the green materials as a source due to their unique properties.

As said before, materials for electronics, are a key vector of our comfort and welfare, impacting directly in the so-called Internet of Things (IoT) that aims to serve a plethora of applications in the so-called information ad communication technologies. In this respect, the integration of novel devices on conformable, flexible substrates with free-of-form surfaces for innovative product development is a key area of future development, for which green materials and technologies must be looked after. Here we highlight the exploitation of easy to recycle materials, for which a different mindset, away from silicon (requires high process recycling temperatures and some materials selection problems concerning the other materials used to process the electronic chips) must be developed, targeting large consumable applications, where response speed is not the master specification of the envisaged applications. This opens the door for the application, at a micro and nanoscales the other organic (biopolymers, cellulose, nanocellulose) and metal oxide materials, exploited as passive and active components in electronics, to be used in a plethora of emerging applications such as flexible large-area printed electronics and photonics field which includes among others, thin film transistors (TFTs), CMOS devices, printed electronics and circuitry, (bio-)sensors, in-vitro diagnostic platforms, photovoltaics (PV), nanogenerators and energy storage media.

By doing so, we are promoting new sustainable industries, mainly Small Medium Enterprises, encouraging the adoption of green technologies, which will have a strong impact on the global economy. To support the consolidation of this technological revolution, the establishment of new communities is a prerequisite, to address this strong demand towards global prosperity.

## 5. Artificial intelligence/machine learning as a tool to better exploit data base

Today, materials science and technologies see a new development with Artificial Intelligence (AI) and specifically with Machine/Active Learning, to better exploit data base to backup all expected developments concerning materials selection, architecture and design and its integration on devices, products, and systems. For instance, it can support the realization of materials by design, which can provide multiple functionalities. These "**stem**" materials,[5] [3] will embed a concept of "internet in things", 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 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 our mother nature and giving the comfort people deserve. Indeed, it is a tool, which can guide researchers and engineers in an unbiased way towards the best materials and the best synthetic strategies, hence saving time and money. However, adopting a new paradigm requires overcoming an energy barrier. Not only new concepts and techniques need to be learned, but also good new practices (such as data and metadata sharing) need to be accepted.

## 6. The materials as activator for a plethora of applications and the metro station concept

Overall, we saw that materials are the activators to back up the challenges of the future, able to generate an industry grounded by the principles of eco-sustainability. For all of this, we need to exploit materials functionalities, at a macro and nanoscale, such as oxide metals, biopolymers, perovskite, carbon, silicon, piezoelectric/triboelectric materials, dielectric materials, organic semiconductors, cellulose, ferroelectrics materials, among others, which are the roots of the tree that bears fruits and leaves for a plethora of applications, foreseen circularity. This opens new routes of our development centred in novel commodities, where the surface will be the key factor to build up the interfaces that will sustain our development, as far as functional and structural materials are concerned.

As far as electronics are concerned, we foresee the exploitation of these materials to build up the new generation of eco-sustainable flexible electronics, full self-powered; nanoelectronics to produce the electronics of the future, for very ultra-high-fast response devices; smart microfluidics, using low-cost eco-sustainable platforms, like paper; transparent electronics, for display, security and sensing purposes; e-textiles; paper electronics; smart-biosensor (not only able to detect but also to communicate and to process the results); green polymer/organics

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[5] 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.

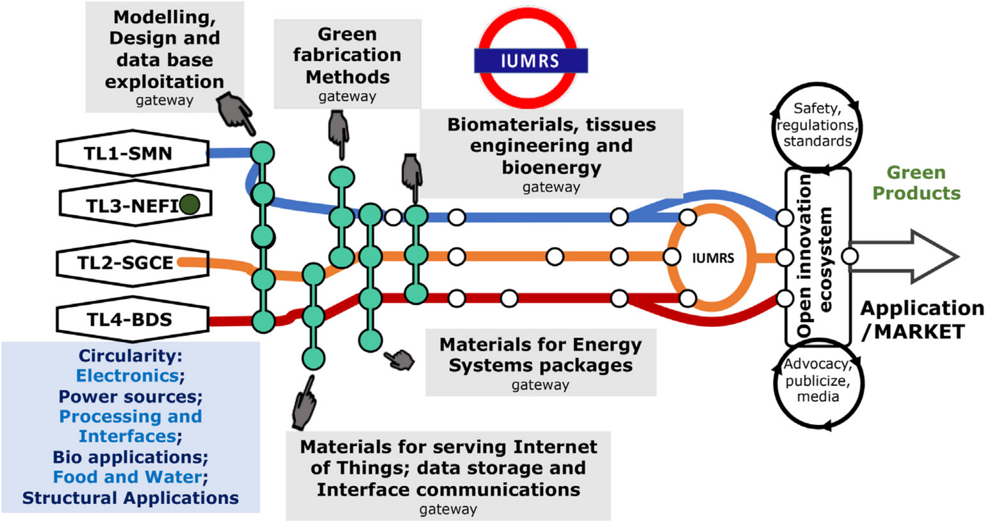

**Fig. 5.** The metro station concept that includes products to be developed, considering the circularity of materials; materials for electronics; materials for power sources; processing technologies and interfaces for communication; materials for bio-applications, materials for food and water control; structural materials for avionics, space and building construction. This is followed by proper gateway to evaluate them and to exploit the best pathway for their applications, supporting by proper Artificial Intelligence tools. At the end, we have an open innovation eco-system centred in IUMRS actions to advocacy and to publicise in the media the scientific and technical achievements of researchers, besides identifying the future prospects.

electronics; memory data storage; solar cells/nano-energy; photonics; integrated green power units, where supercapacitors and batteries do play a relevant role; besides all relevant area connected to space, car-industry and smart building constructions.

All these goals can be faster achieved when materials scientists and engineers collaborate closely with computer and data scientists, statisticians, materials chemists, solid-state physicists, electronics experts, and other experts across various fields to further incorporate data science tools into established workflows for solving problems raised concerning the use of materials in different sectors. This means that great advances can be achieved if we can properly exploit the field of materials' applications and this can be facilitated if we have a multidisciplinary platform/network, involving Academics, Research Technical Organizations, and Industry, such as a global common house, that contains different lines of action, crossing in different points and so, researchers can move from one line to another, to exploit novel concepts, for which, some identified materials specificities are better exploited. This vision of the future research works like a METRO line where we have crossroads and travellers can move from one line to the other. Of course, new fields can be even though, as shown in Fig. 5 (examples of gateways identifying possible exploitations of the materials applications, away from the one's initial thoughts). In all this pathway we must better understand the set of analysis to be performed, to back up modelling and simulation activity to design materials and devices, according to their expected performances and where the convergence to all for an open innovation eco-system, it is made via the Global common house, represented by IUMRS, the heart of the action. This is the way I foresee IUMRS.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgments

I would like to thanks to Elvira Fortunato, from the executive committee of E-MRS and my colleague at CENIMAT/I3N (https://www.cenimat.fct.unl.pt/), institution that I thanks for the support given, as well as to SYNERGY H2020-WIDESPREAD-2020-5, CSA, 2020-INFRAIA-2020-1, EMERGE, Reference 101008701.

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