SUSNANOFAB
Grant Agreement No. 882506

Landscape of nanofabrication in new European high-value industrial ecosystem

Document Details

Deliverable Number:	D2.1
Due date of Deliverable:	July 2020 December 2020 (*integrated in D 2.5*)
Lead Beneficiary:	TECNALIA
Contributors:	TECNALIA, RINA-C, INL, CEA, IDONIAL, IPC, TYNDALL, TUW
Dissemination Level (*):	PUBLIC

Project Contractual Details

Project Title:	Integrated EU Strategy, Services and International Coordination Activities for the Promotion of Competitive and Sustainable Nanofabrication Industry
Project Acronym:	SUSNANOFAB
Contract No.:	882506
Project Start Date:	01-03-2020
Duration:	36 months

Document History

Version	Date	Description
V.0	July 2020	First draft
V.1	Sept 2020	Final version with comments from partners

Abbreviations and Acronyms

Acronym	Description
AI	Artificial Intelligence
EV	Electric Vehicle
GDP	Gross Domestic Product
ICT	Information and Communication Technologies
IPCEI	Important Projects of Common European Interest
KET	Key Enabling Technology
OEM	Original Equipment Manufacturer
SDG	Sustainable Development Goals
TRL	Technology Readiness Level
UN	United Nations

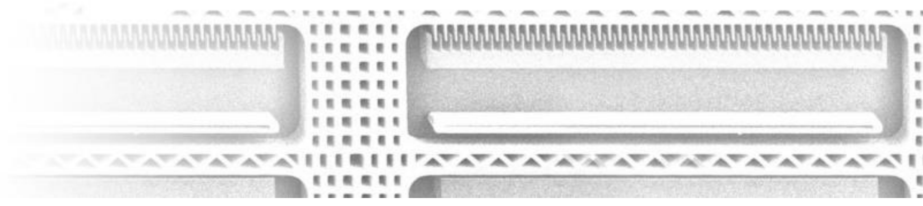
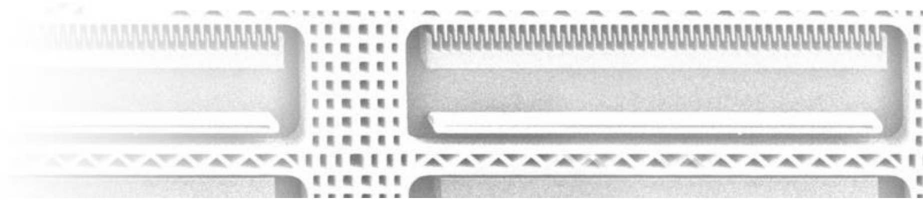


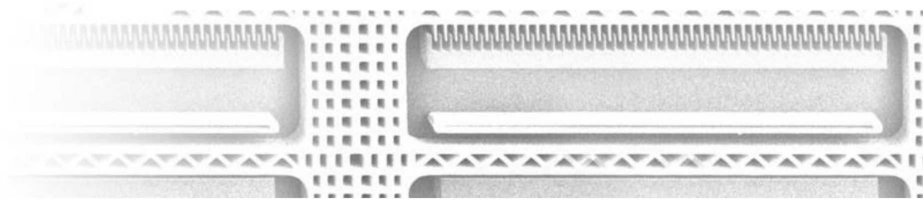
Table of Figures

Contents



Acknowledgements

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement no. 882506 (SUSNANOFAB). The content of publication is the sole responsibility of the author(s). The European Commission or its services cannot be held responsible for any use that may be made of the information it contains. Project website: http://susnanofab.eu/.

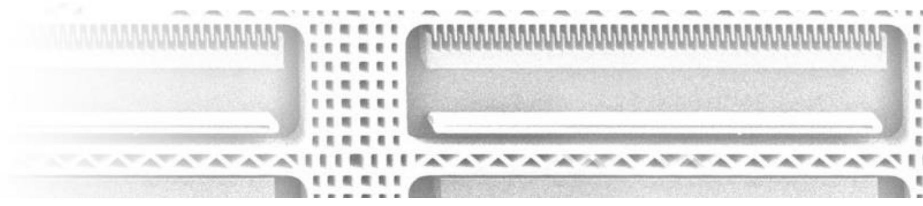


Executive Summary

The industry is recognised as one of the most important pillars to guarantee economic growth and social welfare in Europe. In last years, European Commission and Member States have been working to develop a roadmap towards a more efficient and competitive industry, but also a more environmentally sustainable and improved with new technologies. ICT and automatization have been crucial to digitalise European industry, and doors are open to introducing other key enabling technologies that allow the development of innovative products and solutions.

In this sense, nanofabrication shows an enormous potential to boost the European industrial ecosystem to higher levels of competitiveness. In this document, developed within the framework of SUSNANOFAB project, we explore the trends and needs of each studied sector (mobility, health, digital and industry, energy and climate change, food and natural resources, and inclusive and secure societies) as well as the main key nanotechnologies in each of them. Besides, we define the main drivers and challenges for the introduction of nanofabrication in the industrial ecosystem, classifying the factors into several groups: scientific and technological, environmental and societal, economic and policy, regulatory and legal issues.

Finally, the document offers some recommendations and measures that will be added to those obtained in the documents analysing international nanofabrication initiatives, networks and programmes, to complete the landscape of nanofabrication in the high value European industrial ecosystem.

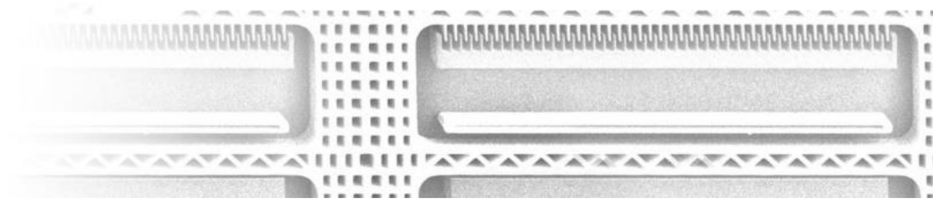


1 Introduction: the European Policy Strategy

Nanofabrication is defined as the design and manufacture of structures with dimensions measured in nanometers -nanostructures. In the words of (Ding, Yu, & Wang, 2019) "*nanofabrication is the future of technology and will soon be at the forefront of all manufacturing technologies by providing the design and fabrication of functional nanomaterials, which are potentially capable of responding to all major global challenges of the present and the future*".

The global target of SUSNANOFAB project is to put in place an integrated concerned action on nanofabrication, sustainable in the long term. The project establishes and promotes a robust network of European and international stakeholders and geographically distributed centers. These activities want to provide current missing links between policy, infrastructure, expertise and industry requirements, and contribute towards the improvement of the current EU positioning and performance in nanofabrication.

The first technical work package of this project (WP2) is focused on setting up the scene, studying the European nanofabrication ecosystem, and linking all relevant initiatives. There are four big objectives for this work package: provide a comprehensive landscape of nanofabrication ecosystems, including assessment of key drivers and challenges, and identification of exemplary target products in the target sectors; map the relevant public and private initiatives in the EU and international scale; identify and assess the existing relevant services and access to infrastructures; and provide an integrated map of the relevant stakeholders and their linkages to existing initiatives, infrastructures and services.



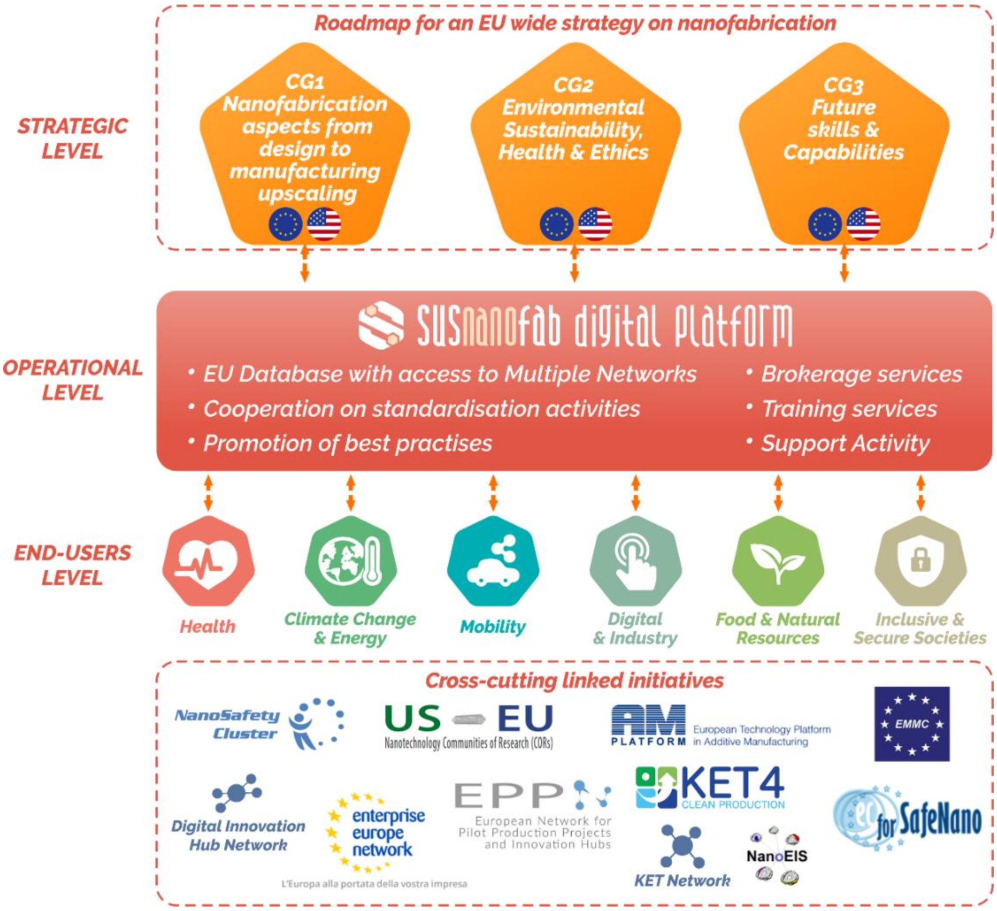


Figure 1. SUSNANOFAB Project.

This is the first document inside the second work package (D2.1) and its aim is **to identify and describe the most relevant opportunities for the integration of nanofabrication into the new European high-value industrial ecosystems** in the target sectors, contributing to the current EU policy strategies. For the purpose of this project, target sectors will be health, climate change and energy, mobility, digital and industry, food and natural resources, and inclusive and secure societies.

This document contains an analysis of the current technological development stage, market needs, future trends and role of industrial scale manufacturing of functional systems based on manufactures nanomaterials in different industrial ecosystems. The methodology to identify the opportunities for the integration of nanofabrication into the European high-value industrial ecosystem combines desk analysis performed on cross-cutting and sectorial strategic documents, and interviews to stakeholders all along the nanofabrication value chain.

European industry makes up more than 20% of GDP, accounts 80% of goods exports and employs more than 35 million people. European industry is the engine for productivity growth, high-value exports and quality jobs for European people. European Commission is very aware of this and also, of the changing environment for global markets. Environmental sustainability, pressure on natural resources, technological change, digitalisation and, unexpected event such as the crisis of the Covid-19 are some of the factors that affect worldwide and European industry.

Before the present crisis in December 2017, European Commission established an independent advisory group, the Industry **2030 High Level Industrial Roundtable**, to give recommendations about the future EU industrial policy action. The final document (Industry 2030 HLG, 2017) points five key drivers for the future European industry to manage a sustainable an inclusive transformation: leadership in technology, innovation and sustainability, social fairness and wellbeing, anticipating and developing skills, a fair competitive and agile business environment, and strategic value creation networks. To turn this vision into reality, the HLG articulates four proposals:

- Innovation and technology take-up: strengthen EU leadership in strategic value chains, link technology and innovation infrastructures to boost impact of regional smart specialisation, create a model city to test innovative technological solutions and promote open data for companies.
- Transition to climate-neutral industry: decarbonisation of traditional sectors, new measures to address carbon leakage risks, a green deal with industry to invest in sustainable technologies, global standardised carbon reporting for industry, targets for industry to become a global circular economy leader.
- Strengthening European global competitiveness: new cross-border networks of industrial clusters, new markets for innovative and sustainable products, testing of innovation outside actual regulatory

frameworks, open, fair and multilateral trading system, and sufficient energy and raw materials.

- Focus on people, skills and values: ensure faster reskilling and upskilling in European industry, improve general basic skills, integrate innovation and entrepreneurship into education, establish an EU digital online ID, measure the impact of companies on society and nature, and include value leadership in new areas and technologies of transformation.

After that, in June 2019, European Commission defined its main **political guidelines for the period 2019-2024** (von der Leyen, 2019) articulated around six great priorities:

- A European Green Deal, which main objectives are to make Europe be the first climate-neutral continent, be the world leader in circular economy and clean technologies, preserve rural areas, biodiversity and land changing the way we consume, produce and trade, and establish the necessary mechanisms to support these objectives.
- An economy that works for people, focused on social fairness and prosperity with a strong and resilient social market economy
- A Europe fit for the digital age, grasping the opportunities from the digital age within safe and ethical boundaries, fostering digital technologies (especially Artificial Intelligence) and Internet of Things among others.
- Protecting our European way of life, European citizens and values with new pacts about migration and borders.
- A stronger Europe in the world, as a brand of responsible global leadership guaranteeing free and fair trade and going forward a European Defence Union.
- A new push for European democracy at regional, national and European level.

Also, in 2019, the **Strategic Forum for Important Projects of Common European Interest – IPCEI** identified (Strategic Forum IPCEI, 2019) six key strategic value chain for European industry and member states:

- Connected, clean and autonomous vehicles
- Hydrogen technologies and systems
- Smart health
- Industrial internet of things
- Low-CO2 emission industry
- Cybersecurity

To support these value chains, the report points some actions such as joint investments, consolidation of Single Market, regulations to develop new skills, an agile governance process to monitor technological and industrial advances, and a monitoring process to evaluate the progress in the value chains.

At the same time, in November 2019, the **High-Level Group on Energy Intensive Industries** presented its recommendations to manage the industrial transition on Europe (HLG on Energy-Intensive Industries, 2019):

- Creation of markets: measure greenhouse gas footprint of products and materials, public procurement for sustainable products and services, and a framework to support the cost of climate-neutral circular economy products and services.
- Innovation: strategic pilots to showcase clean technologies, HE Partnerships on climate-neutral, circular industry and clean steel, and align eligibility criteria between different funds.
- Investment: pipeline of technology projects to be funded by public-private partnerships, private capital at affordable cost, Commission’s Action Plan on financing Sustainable Growth to support industrial competitiveness
- Energy and raw materials: access of climate-neutral energy at competitive prices, infrastructures for low emission feedstock sources (also hydrogen), infrastructure reflecting an integrated approach with energy, transport and digital networks, ensure access to sustainable raw materials.
- Circular economy: reduce greenhouse emissions through better material and resource efficiency, assess products based on life-cycle approach,

circular technological solutions and products, exploit potential for use of secondary raw materials, use of renewables and carbon-based recyclables.

- Social dimension: new skills for workers, more communication for consumers to make informed choices, transition of coal and carbon-intensive communities and regions.

Also, the document recommends setting up an observatory to monitor industry progress towards climate-neutrality and circularity.

The European Green Deal is Europe's new growth strategy.

At the heart of it is the goal of becoming the world's **first climate-neutral continent** by 2050.

The right conditions are needed for entrepreneurs to turn their ideas into products and services and for companies of all sizes to thrive and grow.

The EU must leverage the impact, the size and the integration of its single market to make its voice count in the world and **set global standards**.

Digital technologies are changing the face of industry and the way we do business.

They allow **economic players** to be more proactive, provide workers with new skills and support the decarbonisation of our economy.

Figure 2. A new industrial strategy for a globally competitive, green and digital Europe. Source: European Commission

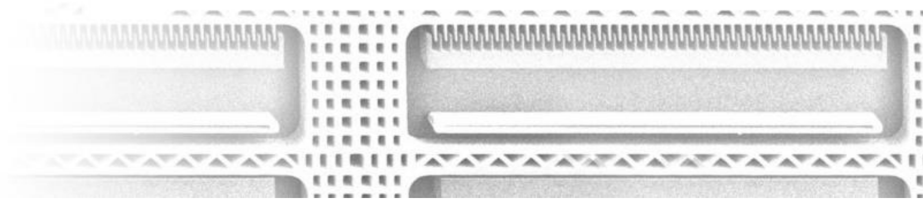
More recently, in March 2020, European Commission has presented a **new industrial strategy** to foster European industry, (COM(2020)102final), built on the following pillars for European industrial transformation:

- A deeper and more digital single market: new legislation, standardisation and certification to propel the European industry and adapt it to the digital era, new mechanisms to break actual barriers for businesses, support for SMEs and intellectual property, and a new competition framework.
- Upholding a global level playing field: secure beneficial trade inside and outside Europe and guarantee fair competition with competitors around the world with different standards and principles.

- Supporting industry towards climate neutrality: modernise and decarbonise energy-intensive industries, support clean breakthrough technologies, a more sustainable built environment, new financial mechanisms —Just Transition Fund—, low carbon technologies, capacities and infrastructures, clean hydrogen, and a comprehensive strategy for sustainable and smart mobility.
- Building a more circular economy: change the way of use, design and get rid of materials, a new sustainable product policy framework, empower consumers and foster green procurement.
- Embedding a spirit of industrial innovation: regulations and other mechanisms to incentivise SMEs to innovate with new ideas in the market, make the most of Europe’s research base to accelerate commercial applications, encourage place-based innovation and experimentation, and scale solutions to European and global markets.
- Skilling and reskilling: recruit and retain qualified people, reinforce higher and vocational education to provide more scientists, engineers and technicians, and support gender equality in industry.
- Investing and financing the transition: unlock private investment and public finance with existing and new mechanisms (e.g. IPCEIs), revise existing ones, such as State Aid rules, incentivise new investment towards competitive sustainability, and clear rules to guide investors to sustainable investments.

Also, the Strategy mentions its support to the development of key enabling technologies, including robotics, microelectronics, high-performance computing, data cloud infrastructure, blockchain, quantum technologies, photonics, industrial biotechnology, biomedicine, **nanotechnologies**, pharmaceuticals, and advanced materials and technologies.

The final aim of the European Industrial Strategy is to make European industry more competitive globally and enhance Europe’s strategic autonomy.



There are other interesting initiatives and mechanism related to European industry, such as Investment Plan for Europe[1] —with the European Fund for Strategic Investments and the European Investment Advisory Group— the Single Market Strategy[2] to unlock the full potential of Single Market, the Capital Markets Union[3], to mobilise capital in Europe, the European Skills Agenda[4] to take advantage of the green and digital transitions, and support a prompt recovery form the Covid-19 crisis, and the initiative Trade for All[5], a trade an investment strategy for the EU.

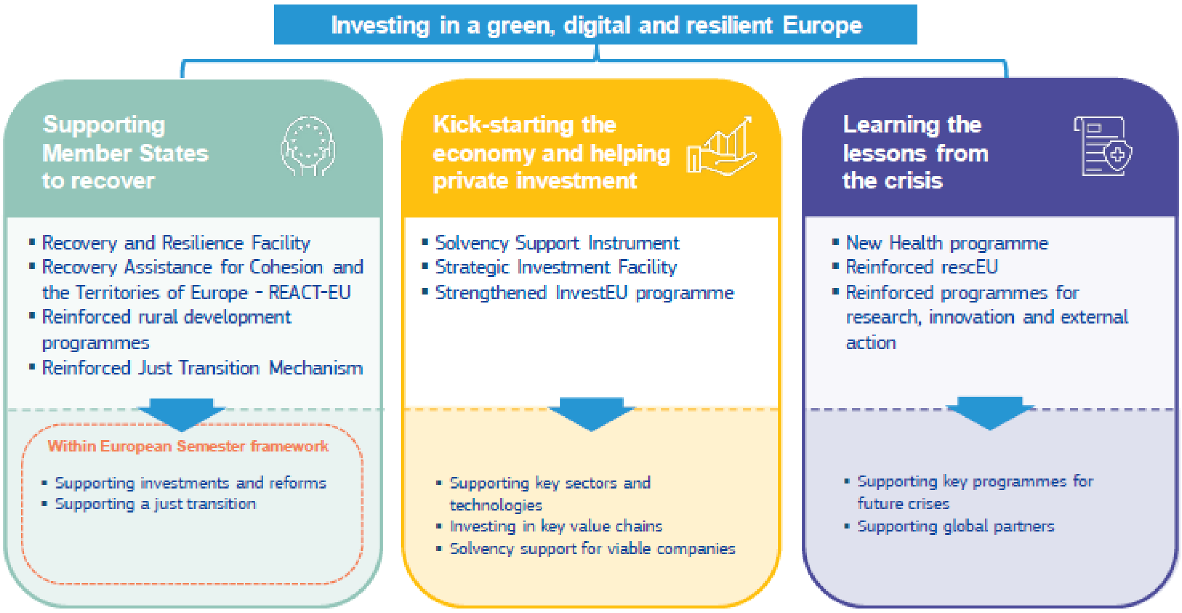


Figure 3. The EU budget powering the recovery plan for Europe. Source: European Commission

---

[1] More information about Investment Plan for Europe available at: https://ec.europa.eu/commission/priorities/jobs-growth-and-investment/investment-plan-europe-juncker-plan/what-investment-plan-europe_en

[2] More info about Single Market Strategy available at: https://ec.europa.eu/growth/single-market/strategy_en

[3] More information about Capital Markets Union available at; https://ec.europa.eu/info/business-economy-euro/growth-and-investment/capital-markets-union/capital-markets-union-action-plan_en

[4] More information about European Skills Agenda available at: https://ec.europa.eu/social/main.jsp?catId=1223

[5] More information about Trade for All available at: https://ec.europa.eu/trade/policy/in-focus/new-trade-strategy/

Finally, the **Recovery Plan for Europe** (COM(2020) 456 final) has been launched in 2020 "*to repair the economic and social damage brought by the Covid-19, kick-start European recovery, and protect and create jobs*".

To get the targets, the Recovery Plan mobilises two main sources of funds: Next Generation EU, with €750billion, and a reinforcer long term budget for 2021-2027 with €1,100billion.

For its part, **Next Generation EU** is rolled out across three main pillars: supporting member states to recover, kick-start the economy and helping private investments, and learning lessons from the crisis. All these pillars are supporting by new programs and financial mechanism such as grants and loans for companies, Member States, regions and municipalities.

Beyond individual programmes, Commission proposes an emergency budget for solidarity and emergence aid. Also, Commission has adjusted its Work Programme for 2020[6] to reinforce European resiliency facing this and future crisis.

One of the key points is the **European Green Deal, that** contemplates some pillars to foster sustainable growth in Europe, such as a modernisation of Europe's buildings and critical infrastructure, foster electric vehicles, create one million green jobs, support European farmers and sustainable agriculture, and protect natural ecosystems and forests, among others.

Also, the adjusted Work Programme for 2020 contemplates de renovation of the European Single Market and reinforces some of the more important European values such as inclusiveness, fairness and resiliency.

The European policy strategy maintains a coherent roadmap towards a more sustainable, fair and smart industry, and, in its different communications, reveals some areas that can be considered as key drivers for the transition: energy and climate change, health, sustainable mobility, food and natural resources, digitalisation and industry, and inclusive and secure societies. Besides that, European Commission also

---

[6] More information about WP2020 adjusts available at: https://ec.europa.eu/info/files/adjusted-commission-work-programme-2020-factsheet_en

points some key enabling technologies that are going to be crucial to develop innovative solutions to give answers to the main European societal challenges: ICT, photonics, biotechnology, advanced materials and micro and nanotechnology among others,

The next section explores the situation of the European industrial ecosystem in the cited areas and sectors: trends, technology development level and challenges to face in the next years, and also the situation of Europe versus other countries such as US or China.

2 European Industrial Ecosystem in target sectors

In 2015, United Nations designed a global agenda for people and planet to the prosper now and in the future: the 2030 Agenda for Sustainable Development (United Nations, 2015). In this agenda, UN defines 17 Sustainable Development Goals and 169 targets to end poverty, promote prosperity, ensure well-being for all and protect the planet.

Figure 4. Sustainable Development Goals. Source: United Nations

There are six target sectors defined in SUSNANOFAB and reflected also in the European policy for a sustainable transition for the industry, that have also a direct impact on the SDGs: health, mobility, energy and climate change, food and natural resources, digital and industry, and inclusive and secure societies.

At the same time, the market needs for each of these sectors, and also the future trends define the field to explore the role of nanofabrication to improve their industrial ecosystems. In next sub-sections, we explore the specific situation of each of them, as well as their relations with the SDGs and the main key nanofabrication technologies related to each of the sectors, so that we can define the role of nanofabrication to answer to their needs and to help them face the future trends.

2.1 European industrial ecosystem trends and needs for mobility

Mobility includes all the sustainable, safe, intelligent, connected and environmental-friendly solutions, products, materials, surfaces and services for the mobility of people and goods in urban and inter-urban ecosystems. This target sector is connected with, at least, the following SDGs:

- Affordable and clean energy (7)
- Industry, innovation and infrastructure (9)
- Sustainable cities and communities (11)
- Responsible consumption and production (12)
- Climate action (13)
- Partnerships for the goals (17)

According to (European Commission, 2018), the future directions of EU R&I policy in the strategy for smart and sustainable mobility should have into account the following fields: research in battery efficiency, energy storage and recovery technologies new mobility service solutions tested in pilot areas, research on new traffic management systems developments, research on methods, practices and policies for achieving behavioural change, agreements on interoperability standards for multi-modal transport systems, rules for autonomous transport, research on human-automated vehicles interfaces, research on smart grid management and on the opportunities for cross-domain solutions, regulation on data security and liability in the context of automated transport, research on automated transport applications in the freight sector, and investigation of the mobility needs in relation with personal freedom.

For its part, (Bernhart & Riederle, 2019) groups all future trends in mobility sector under the acronym MADE: **M**obility trends and behaviours developing around the world, the arrival of **A**utonomous technologies, the development and use of **D**igital features and the rise of powertrain **E**lectrification. According to the report, the main influencing factors for mobility can be grouped into five different categories: industry activity, infrastructure, technology, regulation and customer interest.

Regarding mobility trends, (Dressler, 2019) underlines the decreasing brand loyalty and design relevance in the mobility sector, and also the pressure from emission regulations. And not only the Original Equipment Manufacturers (OEMs) are going to be affected, but also Original Equipment Suppliers (OESs), because of the increasing financial pressure, the declining profitability and the change in business models.

Players along the value chain are repositioning themselves with new companies emerging (i.e. semiconductor companies) and an increasing pressure on others (i.e. TIER1 in automotive industry). However, the effects are not always negative for traditional car industry: the change from ownership to usership is expected to bring a growing demand for vehicles especially designed for mobility services with a global market volume up to 5 million a year by 2030 (Hasenberg, 2018). So, the new mobility does not only affect automotive industry, but also cities, drivers and passengers, transportation providers and alternative mobility offerings such as car sharing, air taxis or ride pooling among others.

As (Remane, Hildebrandt, Hanelt, & Kolbe, 2016) points, in last years, mobility sector is being affected by a new wave of digital transformation focused in ongoing improvements in processing power, miniaturization of hardware and ubiquitous wireless connectivity. According to (Meissner, Shirokinskiy, & Alexander, 2020), a quarter of the rise in electronics Bill of Materials in future cars will be attributable to digitalisation.

At the same time, all these changes are fostering new business models based in digital technologies viewed as combinations of information, computing, communication and connectivity technologies. Besides purpose-built ride-sharing vehicles, one of the most visible revolution in mobility business models is Mobility as a Service (MaaS) that relies on a digital platform that integrates all the services related to public and private transport, especially in the cities (Goodall, Fishman, Bornstein, &

Bonthron, 2017). These changes also imply the entry of new stakeholders and players like Uber and a great level of collaboration among the stakeholders.

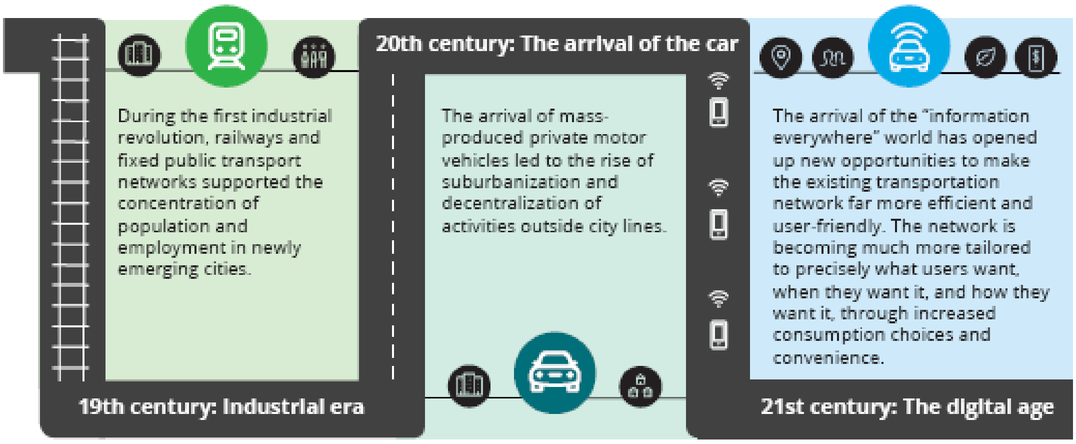


Figure 5. Mobility through the ages. Source: (Goodall, Fishman, Bornstein, & Bonthron, 2017)

Related to the autonomous vehicles, (Bernhart, HAsenberg, Karlberg, & Winterhoff, 2018) places mass production for 2025 with a fully development of automated driving systems (remote fleet management), driverless technologies, (sensors, radars, 3d projectors, computing core), ICT technologies (decision algorithms) and also new models of transport such as "last mile" transport systems, delivery robots or drone delivery.

In this sense, other of the main trends in mobility sector is the increase in the role of the automotive electronics, software and semiconductors, and the improving of reliability of electric drivetrains. Three factors will have a significant impact on the electronics of future vehicles: new Electrical Electronic Architectures, autonomous driving chips and new powertrain materials (Meissner, Shirokinskiy, & Alexander, 2020).

On the other side, the increased awareness for sustainability is reflected in the search for clean energy and electrification, but also in new forms for vehicle recycling and battery electric vehicles as energy storage systems. Due to regulations and to supply risks, the reduction of critical raw materials used for the manufacturing of several components for batteries is one of the trends for mobility sector. Also recycling strategies to recover critical raw materials and high value materials could be seen as a trend. According to (Meissner, Shirokinskiy, & Alexander, 2020), the demand of electric vehicles is increasing due to their specifications, lower operating cost and environmental concerns. Also, vehicles are being developed more and more with composites to improve the performance and reduce the weight, slash CO2 emissions and improve recyclability. Composites offer structural advantages over traditional materials, so it is expected a growth in the composite market for automobile industry. Other major consumer of composite material is the marine recreational craft industry (Kumar, 2018).

Relating to **mobility needs**, one of the most critical is to reduce vehicle weight, crucial to improving fuel economy and addressing range, performance, size, and cost challenges associated with fuel-cell and hybrid propulsion systems in mobility sector. The trend towards smaller and lighter, more environmentally friendly vehicles is accelerating, as the petrol price rises, and the CO2 reduction target becomes stricter. Dense metals are being replaced by lighter metals or by polymer composites to improve the performance of engines in extreme conditions, electric engines, surface technologies and materials for assembly systems among others. However, each one individually does not meet all requirements for mechanical, electrical and thermal abilities; moreover, providing multi-functional products expected by these markets at right cost is boosting the need for further integration of functional elements (materials, electronic components) in the structure and, at the same time, setting-up new processes to reduce cycle times and produce net-shape parts.

Nanotechnology, combined with other KETs such as advanced materials and advanced manufacturing, can lead to lighter and multifunctional structures. In aerospace industry, for example, throughout the last years there has been a growing demand of composites materials with integrated multifunctional capabilities in the manufacturing of structural components. The advantages of Carbon Fiber Reinforced Polymers (CFRP) over metallic materials in terms of specific stiffness and strength are clear. In this sense the integration of light modules for mobile application is also a market need.

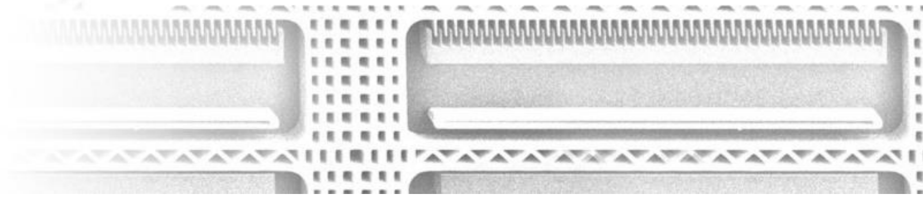
In addition, (Meissner, Shirokinskiy, & Alexander, 2020) point that more than half of the cost increase between Internal Combustion Engines (ICE) and Battery Electric

Vehicles is driven by powertrain electrification. (Dressler, 2019)quotes also the move from ICE to electric powertrains, as one of the main challenges, because it implies parallel and costly production structures. In fact, many of the business linked to e-mobility are going to be lower profit in the beginning, so players need financial muscle and public financial tools to ease the transition time.

The same author points as well the strong need for investments into automated driving and driverless technologies, artificial intelligence, and power train electrification. Relating to automating driving, one of the main needs pointed in (Bernhart, Olschewski, Burkard, & Yoon, 2018) is the infrastructure to test and validate automated vehicles. In this sense, legal framework continues to be one of the main critical success factors for automating driving.

Thus, (Alexander, 2017) points to the develop and improvement of smart sensors as one of the keys for driver assistance systems. Since their price is falling as a result of continuous competition, manufacturers may capture more value to make the industry more profitable. (Meissner, Shirokinskiy, & Alexander, 2020) also point other area that needs technological develop to foster autonomous driving, that is computing power and, more specifically, AI driven central computing, to receive and analyse pre-processed sensor data, and to determine the actions the machine must take. Since these central computers contain multiple chips, challenges remain to reduce power consumption on chip architectures.

According to the same authors, the semiconductor manufacturers need to expand from hardware drivers middleware to application-level software and have to move towards functional integration by SoC (System on Chip), SiP (System in Package) more complex boards. TIER1 providers need to reposition themselves in electronics and software integration. Software companies need to leverage differentiated software capabilities, platforms and service-oriented architectures, and OEMs need to expand their capabilities for module integration, and software development and integration. The same source estimates that the share of semiconductor components within the electronics will rise from 25% to 35%, driven by an increased complexity and higher integration of semiconductors. On the other side, traditional electronic manufacturing technologies are based on subtractive processing which involves numerous sequence

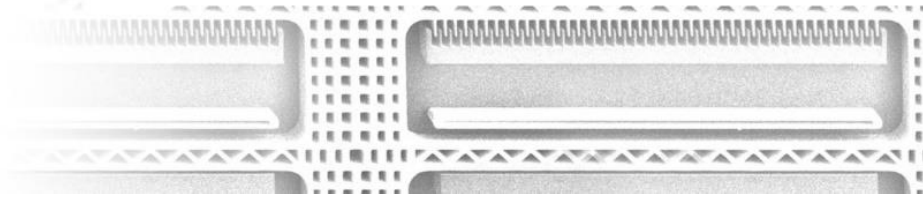


steps which are expensive, wasteful (produce chemical waste) and have high power consumption. Utilising these traditional processes means that manufacture in Europe has become unfeasible due to high labour costs and stringent environmental legislation.

Increasing battery safety is one of the general drivers for market uptake. Furthermore, (Meissner, Shirokinskiy, & Alexander, 2020) quotes the three main factors to foster electric mobility: simplification of recharging and maintenance, municipalities pushing for reduction of urban pollution, and regulatory requirements for average fleet fuel consumption. At the same time, (Bernhart & Riederle, 2019) underlines the importance of offering solutions to meet CO2 emission targets, focused on electrification and efficient battery development. (Bernhart, y otros, 2019) submit that the European automotive industry needs to improve in three areas to be the leader in electrical powertrains: improve the position in the battery value chain (currently, the battery cell market is led by Asian players); close the profitability gap between conventional and EV (with new business models such as Battery as a Service and technical requirements that allow modular designs), and develop complementary zero-emission technologies (fuel cell technology, hydrogen).

Finally, the entry of new players raises for the existing stakeholders the need to invest in innovative mobility strategies not to lose market share. New strategies are going to be necessary also to combine all the mobility offerings (private and public) in the urban context. Attached to the strategies are going to be necessary also business and environment regulation and policies to foster new models of mobility. Some of the main conditions to facilitate new strategies and new business models like Mobility as a Service are a widespread penetration of smart phones on 4G/5G networks, high level of connectivity, availability of secure and up-to date information and cashless payment systems.

NANOTECHNOLOGY	APPLICATIONS IN MOBILITY
MEMs, NEMs, and NANOSENSORS	In control emission systems, for example in exhaust gas recirculation (EGR), diesel particle filters, selective catalytic reduction systems and stop-start systems and gasoline particle filters. In accelerometers, gyroscopes, pressure sensors, chemical and gas sensors, thermal sensors, vibration sensors, radiation sensors, temperature sensors, magnetic sensors and microphone sensors among others. Accelerometers, for example, are used in airbags, stability systems, vehicle navigation, antitheft systems, identification of severe accidents and crash recorders. Gyroscopes are used for stability control, rollover detection and navigation systems, and also for vehicle dynamic control (VDC). Pressure sensors are used for manifold absolute pressure (MAP) sensors and tire pressure sensors. Nano chemical and gas sensors are used as exhaust sensors and cabin air quality monitors. Nano thermal sensors are used in stability control, rollover detection, night vision systems, navigation systems and engine environment monitoring. Magnetic sensors are used in steering angle, pedal position, battery current monitoring, charge level indication, hybrid battery control systems. In voice recognition and interpretation of emotions to improve the human-machine interaction
NES	For automotive sector the applications are focus on glass, paint and plastic product treatments, specifically with the following functionalities: water, dirt, insect repellence and antifrost, antifog and antireflective surface treatments, self-cleaning materials, summer heat reduction, body/aesthetic paint colours, paint protective coatings, textiles for interiors. For aviation, commercial development is focused on protective coatings: deicing and aerodynamic (fuel-saving metal protection coatings and optical pilot laser protection), metal erosion protection, reduction of metal abrasion. For marine: anti-biofouling and superhydrophobic drag reduction, durable fluid friction reduced coatings, superhydrodynamic coatings. For infrastructures: self-cleaning glass based on photo-oxidizable titanium dioxide nano-coatings, NES-modified aluminium and concrete, anti-corrosion coating. For electronics: waterproofing for cell phones, displays, hearing aids and, headsets, printed electronics, colour displays, flat panel displays, computer hard disk drive memory, wearables, memory chip packaging more electronic components.
NANOCOMPOSITES	There are several clay nanocomposites that can be used for automotive parts such as Nylon/Montmorillonite (for its high heat resistance used in timing belts), Thermoplastic Olefins/Montmorillonite (for increasing stiffness, low.-temperature ductility and mar resistance, used in minivan step assists, cargo beds and exterior trim parts), Polypropylene/Montmorillonite



NANOTECHNOLOGY	APPLICATIONS IN MOBILITY
	(among its properties are high flexural modulus, high impact resistance, low bulk density and scratch and mar resistance, and are used in sweat backs and center consoles), Polyethylene/Montmorillonite (used in automotive interior and exterior parts), Acetal, and Nylon/Micra Fluoride (used for injection molding, and in some engine covers for weight reduction), Nylon/NWNT for auto fuel lines and to paint exterior parts, PPE/MWNT for auto parts (e.g. painted bumpers) . Butyl/Vermiculite is being considered for use as air barrier films for tires. Nanotube-filled plastics are used to make door panels, fenders, bumpers, mirror housing and air bag covers. In aerospace, ceramic matrix nanocomposites improve optical, electrical, magnetic, tribological, corrosion resistant, and are used in the manufacture of lightweight jet engines. Carbon nanotube metal matrix are suited for turbo engines, wings, space shuttles and hypersonic aircrafts. Buckypaper: self-supporting sheet comprised of entangled carbon nanotubes. This type of nano-structured preforms enable and easier integration of CNTs into selective areas of a CFRP composite and can overcome the filtering issues arising when CNT are to be introduced by Liquid technologies (Liquid Resin Infusion, Resin Transfer Moulding, etc.) in composite laminates. CNT treated prepreg refers to the treatment of commercial pre-preg materials using tailored CNT-formulations towards specific performance by specific deposition techniques. CNT treated prepregs are developed to have minimum impact on processing and handling characteristics of commercial prepreg products and no (or minimal) impact on the composite manufacturing process parameters CNT doped non-woven veils: Non-woven veils are the structural materials composed of randomly distributed thin fibres. CNTs doped veils are the resulting product of the introduction of CNT in thermoplastic polymers. They exhibit conductive properties and improve mechanical performance of laminate. They possess a variety of applications as a lightweight alternative for shielding materials in aviation, automotive, military, medical and electronic industries. Nano-reinforced thermoplastic (based on master-batches) and Nanotextured surfaces in f B-pillar component for obtaining Anti-scratch and aesthetic properties for Automotive sector - ESTCRATCH (Injection moulding). (IZADI-NANO2INDUSTRY)[7]. Adding propylene nanoparticles to fuels to avoid compaction between particles (when stored mainly) and improve fuel homogenization.

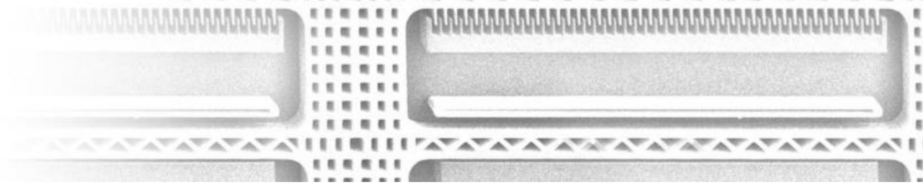
---

[7] IZADI-NANO2INDUSTRY Injection moulding casting and coating pilots for the production of improved components with nano materials for automotive, construction and agricultural machinery. H2020 EU.2.1.2.4/2.1.2.2/2.1.2.5

NANOTECHNOLOGY	APPLICATIONS IN MOBILITY
	Adding nanoparticle coating by deposition to reduce physical wear on the brake discs and increase their useful life. Reduction of friction in the pieces of aircraft flaps by coating with nanoparticles to avoid the use of bearings, thus increase the mechanical efficiency of the flaps mechanisms and reduce costs by eliminating bearings.
NANOCERAMICS	To improve energy efficiency in automotive, in reciprocation engines for wear components, turbochargers and a variety of diesel engine components, gas turbines for regenerators, recuperators and stationary elements. Ceramic catalysts in automobile engine exhaust to control pollution. To develop advanced batteries. Piezoelectric (PZT) ceramics in automotive for power seat controls, collision avoidance sensors and anti-knock sensors. Also, in aerospace for accelerometers and gyroscopes.
NANOFIBERS	In electronics: in sensors, in the manufacturing of integrated circuits, optoelectronic devices, magnetic devices, memory devices, electromagnetic interferences, shielding, printing imaging, and anti-static products. In transport: for manufacturing high-efficiency air and oil filters, in the fabrication of electrodes for lithium-ion batteries and micro batteries, in fuel cells (e.g., in 3D membranes for fuel cells), in manufacturing of lightweight and high-strength parts, anti-static components and conductive paints.
NANODEVICES	In electronics: semiconductors and component devices, data storage and MEMs. In industrial processes: nanodevice sensors for leak detection, monitoring and inspection.

Figure 6. Key nanofabrication technologies for mobility sector. Source: SUSNANOFAB

The table above shows some **key nanofabrication technologies** for mobility sector. Thus, Microelectromechanical Systems (MEMs) are main components in safety-critical and emission control applications in transport industry and combine sensors with electronics or other mechanical devices embedded in a semiconductor chip. The estimated global Market for MEMS Sensors is $11,154Millions for 2022 (BCC Research, 2018). The miniaturised version of MEMS are NEMs (Nanoelectromechanical Systems), an advanced class of devices that integrates electrical and mechanical functionalities on the nanoscopic scale. NEMS are considered as a disruptive technological advancement that extends miniaturization of devices to the next level, beyond MEMS. NEMS Market is segmented into graphene-based NEMS, silicon-based NEMS, silicon carbide-based NEMS, indium arsenide-based NEMS, gold and platinum based NEMS and gallium arsenide-based NEMS. The estimated market for NEMs is $55Millions for 2021 (Singh R. , 2017). the NEMS

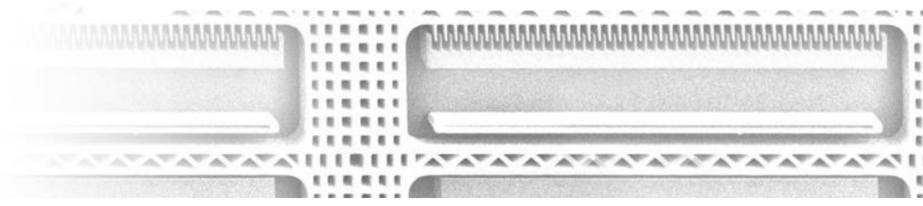


market for automotive industry is valued in $7.4Million by 2021, and for semiconductor industry is valued in $15.1Million by 2021.

Other key nanotechnology in mobility sector are nanosensors: tiny sensors with a size of 10 to 100 nanometres, that operates on the same scale as nanomaterials, atoms or molecules. Their estimated global market for 2022 is about $587Millions (BCC Research, 2018). In general, nanodevices and nanomachines (nanosensors, nanoscale computing devices, nanotools, nanorobots, nanomanipulators), have an estimated market of $2,670Millions for 2028, more than half, corresponding to nanosensors (Mc Williams, Nanodevices and nanomachines: the global market, 2018).

Also, nanoengineering surfaces (NES) represent an extension of biomimicry that replicates unique nanoscale as well as microscale features (Oliver, 2018). Some of the main techniques to fabricate NES are ionized gas plasma, chemical vapor deposition, laser ablation, layer-by-layer self-assembly, multilayer-film co-extrusion, nanoimprinting, rolling mask lithography or self-assembled monolayers of phosphonates. For automotive sector, aviation, marine and military, the NES applications are in early stage of commercial development and it is expected a significant revenue growth by 2022. The global market for automotive applications is calculated in $175Millions for 2022, for marine applications is calculated in more than $1,000Millions for 2027. The impact of NES electronic is calculate in $850Millions for 2027. In transport sector there are multitude of NES technologies: multi-layer nanocomposite film and laser-ablated superhydrophobic plastics, superhydrophobic coating, carbon nanotube-based paint with integrated ultrasound devices, acrylic polymer nano-emulsion coating, hydrophobic, oleophobic, non-stick coatings, CVD hydrophobic water repellent coatings, superhydrophobic plasma coatings, lotus leaf superhydrophobic fabric coating among others.

Besides, a nanocomposite is a special class of composite in which at least one of the components has a nanoscale dimension. Nanocomposites have applications in electro catalyst in fuel cells and light-weight materials for less fuel consumption among others. By 2022, automotive parts are expected to be almost the 8% of the global applications of nanocomposites. Global consumption of nanocomposites is expected



to be around 1.1 million metric tons, or $7.3billion by 2022 (Mc Williams, 2018). For automotive sector, this consumption is estimated in 374.7Million pounds for 2022. Among Nanocomposites are Nanoceramics and advanced ceramics, inorganic non-metallic granular materials fabricated from chemical processes with applications in energy storage and supply, and transportation systems. (Williams, 2019). Also, there are nanofibers, defined as cylindrical structures with a diameter below 1000 nm and as aspect ratio greater than 50, that have an expected market in 2023 of $4.3Billion.

In PLATFORM project,[8] three pilot plants are developed to incorporate CNTs into composite laminates to obtain three nano-enabled products (bucky papers (CNT sheets), CNT treated prepreg and CNT doped non-woven veils). Their technology readiness levels reached are TRL 6 or 7 as all three technologies have already demonstrated their effectiveness for introducing CNTs into traditional manufacturing processes for composite laminates.

2.2 European industrial ecosystem trends and needs for energy and climate change

For the purpose of this report, in **climate change and energy** we consider all the solutions and processes to give response to the effects of climate change and/or to give answer to the climate adaptation. Also, solutions and goods for sustainable energy production and energy consumption will be taken into consideration.

Energy forms the backbone of modern economies and is fundamental to economic development and prosperity. At the same time, the energy sector –still largely dominated by fossil fuel use in energy production, transformation and use– is responsible for two-thirds of global greenhouse gas (GHG) emissions and nearly 90% of CO2 emissions. Consequently, efforts need to be focused to reduce carbon dioxide emissions and tackle climate change. The world's energy supply is still almost as carbon intensive as it was two decades ago.

---

[8] PLATFORM Project. Open access pilot plants for sustainable industrial scale nanocomposites manufacturing based on buckypapers, doped veils and prepregs. H2020-EU.2.1.2.4

The energy-climate nexus is based on economy reliance on fossil fuels: in 2018 power sector was responsible for over 38% of energy-related CO2 emissions, transport sector accounted for 24% of direct emissions in 2017, industry sector´s emissions rose by 0.3% in 2016 from the previous year, and the buildings sector was responsible for almost a third of global final energy consumption in 2017, accounting for around 10% of total global energy-related to CO2 emissions. Moreover, buildings consume more than 55% of global electricity.

The European Green Deal (COM(2019) 640 final, 2019), aims to make Europe the world’s first climate-neutral continent with no net emissions of greenhouse gases in 2050, in part by developing cleaner sources of energy and green technologies.

Decarbonising the energy system is critical to reach those climate objectives in 2050. This drives innovations in the energy sector for the development of renewable energy sources all along the value chain, from the production of energy carriers from primary energy sources to the conversion, storage, distribution and utilisation of energy. In this sense, power sector has made significant progress in recent years in the use of renewable energy. On the other hand, industry, transport and the building sectors will need to use more renewable energy. On a global level, the latter sectors remain heavily reliant on fossil fuels, which are highly subsidized in many countries. In addition, the policy effort focused on these sectors has been insufficient compared to the power sector. Data of (REN21, 2020) clearly illustrates that ambitious policy and regulatory frameworks are needed to create favourable and competitive conditions, allowing renewable energy to grow and displace more expensive and carbon-emitting fuels .

To decarbonise Europe, clean renewable power production must become the main source of energy. According to (IRENA, 2019) energy demands are expected to continue increasing until 2030. Therefore, the energy system decarbonisation needs to be based on high energy efficiency and renewable energy.

Electricity accounts for 20% of the total final energy consumption for transport, heat and other energy services (broadly defined as the end-use sectors of building, industry and transport). Around 80% is obtained from other sources, notably fossil fuels and direct use of renewable thermal energy or fuels. The building sector consumes proportionately more electricity than other end-use sectors. Electricity use in buildings grew five-times faster than improvements in the carbon intensity of power generation since 2000, and rising demand for equipment such as air conditioners is putting pressure on electricity systems. Electricity demand in the building sector is projected to increase by 70% by 2050 (IEA, 2019). Up to three-quarters of energy consumption in buildings could be supplied by renewables.

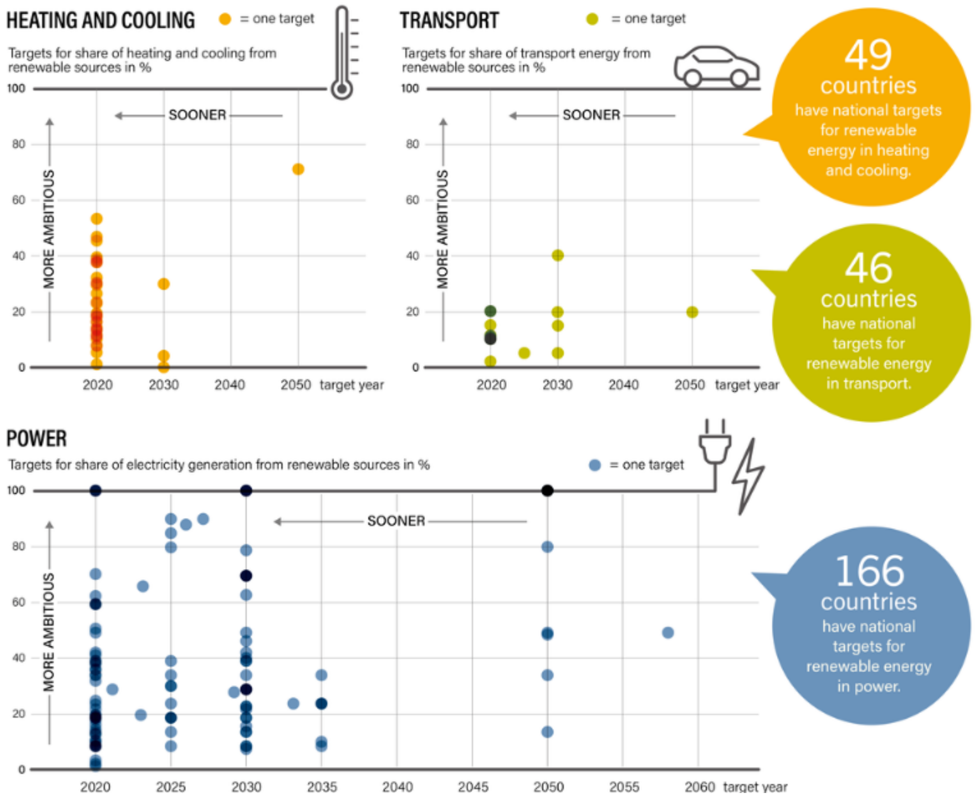


Figure 7. National sector-specific targets for share of renewable energy by a specific year, by sector, in place at end 2019. Source: REN21 Policy Database

The smart integration of renewables, energy efficiency and other sustainable technological solutions across sectors will help to achieve decarbonization at the lowest possible cost. In this context, it is necessary to develop innovative technologies, such as nanobased technology, in order to obtain a more effective and efficient process to produce energy and consequently, combat and stop climate change.

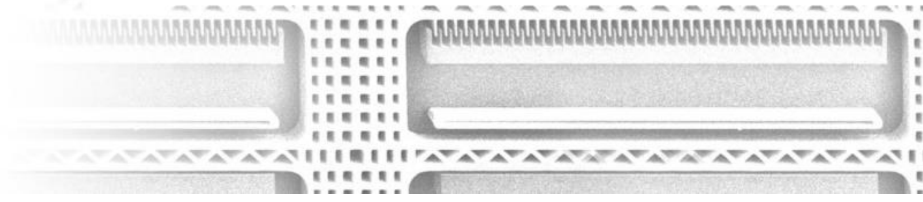
The application of nano technology or nano material in the field of energy is a hot topic in scientific research. Thanks to the development of improved materials and methods, nanotechnology can contribute to the development of cost-efficient and efficient renewable energy to foster their economic viability. Innovations driven by nanotechnology shall play a core role in all sections of the energy sector value chain, from the development of renewable energy sources to the conversion and storage of energy and on its utilization in industry and in private households. Nanotechnological solutions offer substantial energy-saving potentials across all branches of industry thanks to more efficient energy utilisation and optimised production technologies. In the long term, they raise hope for important contributions to sustainable energy supplies and the success of global climate protection policies. (Luther, 2008).

Nanofabrication of new structures at atomic scale has already produced novel materials and devices with great potential applications in a wide number of fields. Therefore, priority should be given to nano technology in the energy sector in order to obtain higher efficiency, lower production cost, and easier application. Some of the research areas are focused on lithium-ion battery, fuel cell, light emitting diode (LED), ultra-capacitor, and solar cell. Unfortunately, its current development is hampered by the expensive cost of production compared to conventional technologies.

Solar, hydrogen and new generation batteries and supercapacitors are the most significant examples of the contributions of nanotechnology and nanofabrication in the energy sector. The aim is to find solutions to one of the great challenges of our time, i.e., the production, storage and use of energy, without compromising our environment thanks to nanotechnology. In the following sections we will focus on three main axes dealing with the application of nanotechnology and nanofabrication on the Energy sector:

1. Utilising Renewable Energy Sources and Energy Conversion: Photovoltaic (PV) thin film, Thermoelectricity, Solar thermal Energy, Fuel Cells, Wind Energy, Marine Energy, are among the technologies where nanotechnology and nanomanufacturing are being used. In terms of carbon offset, thin-film solar panels will have a major edge over traditional panels. Two main families can be distinguished: 1) silicon-based thin films (amorphous [a-Si] and micromorph silicon [a-Si/c-Si]; and 2) non-silicon based (perovskites, cadmium telluride [CdTe] and copper-indium-galliumdiselenide [CIGS]). These technologies can be cheaper to produce, but they present lower efficiency levels.

2. Catalyst: the use of innovative catalyst materials is largely spread in renewable energy sector. We will focus on two relevant examples of potential application of novel catalyst: closing the carbon cycle in industry and catalyst for Hydrogen Fuel cells
    a. Closing the carbon cycle in industry. According to a model developed by International Energy Agency in order to limit the temperature increase within 2 °C by 2050, the CO2 levels should not exceed 15 giga tons annually. In this quest, increasing both the energy efficiency and the use of renewable sources is going to have the most profound effects. A range of different options that could help towards this target for mitigating climate change are considered worldwide, including carbon capture and storage (CCS). Recently an alternative option –carbon capture and utilisation (CCU)– has started to attract attention worldwide because it can turn waste CO2 emissions into valuable products such as chemicals and fuels, while at the same time contributing to climate change mitigation. CO2 will be a viable alternative to natural gas and oil as carbon resource for the chemical supply chain. Currently the developments of the latter alternative (CCU) are at different readiness levels (TRL): (i) existing mature technologies (such as urea production), (ii) emerging technologies (such as formic acid or other single carbon (C1) chemicals manufacture) and (iii) innovative explorations (such as electrocatalytic ethylene production).
    b. Hydrogen Fuel cells: Fuel cells represent an important component of the energy transition, as they supply electrical energy created directly from a reaction of hydrogen and oxygen to form water without first having to create heat and steam from fossil fuels. Catalyst layer is one of the most important compounds to drive Proton Exchange Membrane Fuel Cells (PEMFC) performance. Additionally, the MEA (membrane electrode Assembly) is responsible of 40% of the total stack cost, mostly due to the cost of materials (catalyst and ionomer) The development of novel catalyst



using nanotechnology will be crucial to foster this axis (Carlson, Kopf, Sinha, Sriramulu, & Yang, 2005).

3. Supercapacitors. Electrochemical double-layer capacitor, so called supercapacitors, enable electrical energy storage and have become the most significant energy conversion and storage system in recent renewable and sustainable nanotechnology. According to (Mordor Intelligence) these systems have the unique ability to temporarily store a large amount of energy provided by the cyclical nature of wind, solar, and wave systems. They usually have an energy density hundreds of times greater than that of a conventional capacitor and store energy between two high-surface-area electrodes separated by an ion-permeable membrane. Due to its large energy capacity and supply with relatively short time and long lifetime, supercapacitors are a breakthrough in advance energy applications. Recent progress on the development of supercapacitors is driven by nanomaterials design, structural/device engineering, and fundamental understanding of capacitive behaviour of materials at molecular and nano scale level to improve the device performance for a large variety of potential applications, including consumer electronics, wearable devices, hybrid electric vehicles, stationary and industrial systems, to name a few. New electrode and electrolyte materials for supercapacitors could be carbon-based nanomaterials including graphene, carbon nanotubes (CNT), organic and biomaterials, Inorganic nanomaterials including metal oxide nanoparticles, nanowires or nanosheets, and present different structures (e.g., 0D nanoparticles, 1D nanowires, 2D nanosheets, and 3D nanofoams) for efficient energy storage. Also, nanotechnology is delivering some of the latest developments in this field where advances in functional nanostructures are making progress towards the potential widespread use of supercapacitors as sustainable energy storage devices as an important part of the solution to store and recycle energy.

In this context, all the presented axes show a clear relation to the following Sustainable Development Goals and the related technologies for the Energy sector:

- SDG 7: Affordable and clean Energy,
- SDG 9: Industrial Innovation and Infrastructure
- SDG 11: Sustainable cities and communities
- SDG 12: Responsible consumption & production

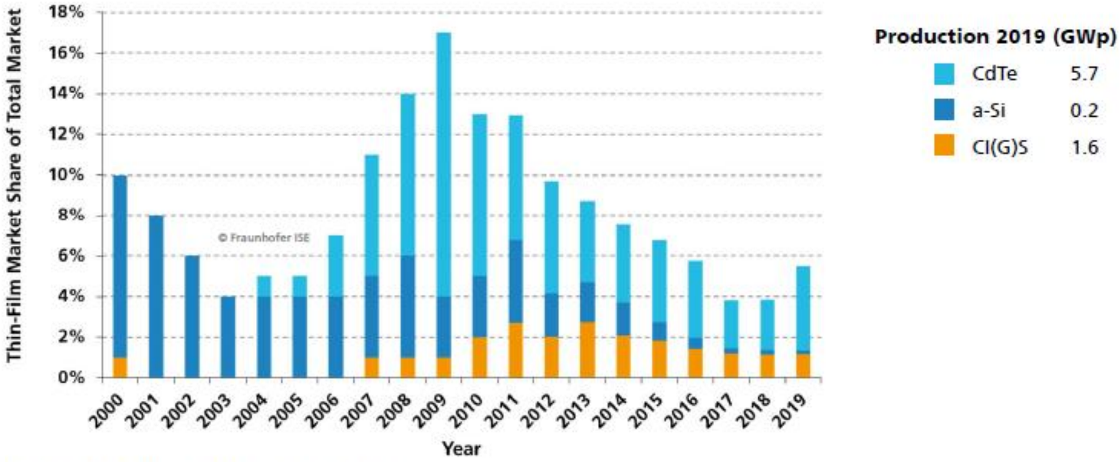
Related to the first axis, **Photovoltaics (PV)** is a fast-growing market: According to (Fraunhofer, 2020) the Compound Annual Growth Rate (CAGR) of cumulative PV installations has been 32% between year 2010 to 2019. The use of nanotechnology in thin film solar panels enables 'roll to roll' printing and easier manufacturing. Panels based on flexible steel and plastic also allow a greater range of applications, for example on portable objects and are quite demanded by the market. Currently Critical Raw Materials (CRM) as In, Ga, Si-metal, Sb, fluorspar are used to manufacture PV cells and modules; their scarcity and their high supply risk entails a constraint for the use and widespread development of some thin film solar technologies. The substitution of these CRM by other elements is becoming a technological and economical priority.

PV market by application can be structured in two main axes: mass installation at Gi Watts scale and technology driven modules (completely integrated in the site where the PV is installed) at KWatts scale. Considering this, the main market needs are the following:

- Bifacial PV. With market penetration exceeding expectations in 2018, bifacial technology is set to account for one third of global solar module production by 2022. Bifacial module technology is rapidly gaining ground within the PV industry, since it allows a significant boost of total module power output and is compatible with almost all types of cell technology, along with their low implementation barriers and minimal capex requirements.
- Bigger modules. For thin film PV a shift in wafer size that reduces overall production costs and bigger modules could imply a lower cost.
- Flexible modules. Thin-film solar panels are panels built from lightweight and often flexible material, but the market demands more flexible modules for their integration on buildings (Building integrated Photovoltaic).

- Recyclable modules. Recyclability for the modules and easy to set them up.
- Aesthetic features for the modules: shape and aesthetical modules as well as semi-transparent modules for easier integration on BIPV.

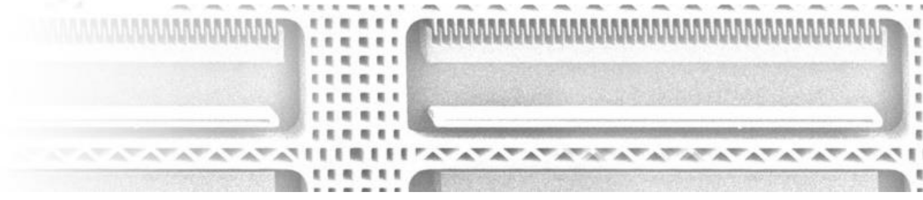
For PV market, the main trends are alternative ways to reduce material use and module degradation, and opportunities to reuse and recycle PV panels at the end of their lifetime. Other important trend is to adapt the modules to the climate conditions (desert, tropical climate, water, snow). It is also important the development of CRM free cells based on substitution of Ag by Cu or In by Zn. As example, there is work being carried out in the development of lead-free Perovskites based Tandem solar modules with improved performance.



Data: from 2000 to 2009: Navigant; from 2010: IHS Markit. Graph: PSE Projects GmbH 2020

Figure 8. Market share of thin film technologies. Percentage of total global PV production. Source: (Fraunhofer, 2020)

Other trend is related to recycling; cells recycling and second life of modules and cells in line with policy makers, and also the recycling and reuse of end-of-life waste and recycling of the residues from manufacturing and maintenance stages. It is important also the decentralisation of modules production: PV cell production and module productions is nowadays in China. It would be advisable to decentralise the modules production and manufacture them in the areas where the production of each type of module will be adapted to the climate and geographical conditions of the area.



In this sense, thin film modules, in particular transparent or double-glazed modules can cope much better with high temperatures build-up, even where no ventilation is possible.

Regarding the efficiency of PV, the market for thin-film solar PV is expected to grow at a CAGR of 23.02% during the forecast period of 2020 - 2025. Factors such as low PV module prices and technological advancements made to improve the efficiency of thin-film solar cells are the major drivers of the market studied. Manufacturing costs also need to be brought down in order to achieve competitive pricing. Improvement of efficiency from the current 7-14% to 9-17% in the next three to four years is the main area of interest in the industry (Research&Markets, 2020). Lately, PV industry looks at the developments for 3rd generation thin film PV: Perovskites, Organic Photovoltaic (OPV), Dye-sensitized solar cells (DSSC) and Quantum dot PV, that will foster in a near future the PV efficiency.

With respect to the second axis, one of the main needs in **catalyst** is to **close the carbon cycle in industry** with a renewable energy driven reduction of CO2 using innovative catalytic materials and technologies. In this sense, all member states of the European Union (plus Iceland, Liechtenstein, and Norway) are part of the EU Emissions Trading System (EU ETS), a market created to trade a capped number of greenhouse gas emission allowances (Alsen, 2019). Closing the CO2 cycle through CCU requires investments and supposes high costs for the industry. There is no direct market need but due to the current regulation and the carbon tax imposed by governments to the companies that burn fossil fuels producing greenhouse gases, the companies and thus the market, need to find Energy routes that do not transport Carbon but other Energy vectors (e.g. Hydrogen). Thus, carbon taxes make sure companies and consumers pay for the external costs they impose on society; returning the cost of global warming to their producers. The market requests the development of fuels from water and air in a closed loop powered by renewable electricity. One example could be the utilization of CO2 as a feedstock for synthetic applications in chemical and fuel industries –through carboxylation and reduction reactions. Finally, another market request consists on finding cheaper and more secure way of burying CO2 from fossil fuel burning underground.

Regarding to the trends in closing the CO2 cycle for industry, two are worth mentioning: carbon dioxide capture, utilization and storage (CCUS) including conversion to valuable chemicals (Taheri Najafabadi, 2013), and carbon bio-capture: microalgae growing for CO2 capture (Anguselvi, Masto, Mukherjee, & Singh, 2019). To achieve the first one, catalysts relevant to CO2 conversion are required to lower the energy barrier for converting CO2 to C1-building block chemicals and for example for the production of hydrogen-based fuels such as synthetic methane. On the other side (Anguselvi, Masto, Mukherjee, & Singh, 2019) show how algae strains that convert CO2 into other organic compounds were screened based on different parameters like fast growth rate, high rate of photosynthesis, strong tolerance to the trace constituents of other gases (gaseous hydrocarbons, NOx, SOx, etc.), high temperature tolerance, and possibility to produce high value products, etc. The study involves integrated methods for utilizing 90–99% CO2 from a natural gas processing industry (GAIL India, Ltd.) as well as 13–15% of CO2 from flue gas of thermal power plants (Chandrapura and Santaldih Thermal Power Station) as carbon nutrient source along with the additional nutritional supplements. A 400-ml and 25-l flat panel photo-bioreactor (PSI Photo-bioreactors) was used for CO2 capture. After CO2 capture, the algal biomass was used to extract value-added products such as amino acid rich feed, algal oil, algal and pellets among others.

Other interesting trends related to catalyst are:

- Hybrid CO2 capture via integrating two or more conventional technologies (Song, y otros, 2019): for example, the development of CO2 absorption and microalgae conversion hybrid processes, where the carbon could be more efficient utilized via microalgae in form of bicarbonate and converted into value-added ingredients without energy-intensive regeneration.
- In the long term, some form of electro- and/or photochemical reduction of CO2 will be an intelligent way of modifying/reducing it (Costentin, Robert, & Saveant, 2013). These processes have interesting analogies to the synthetic routes found in nature as photosynthesis.
- H2 storage in underwater cavities or geological cavities in order to absorb CO2 in big amounts. Man-made cavities and pore storage can be applied for projects

involving hydrogen. A pilot pore storage project-Geostock-, combining methane and hydrogen, is underway in Austria.[9]

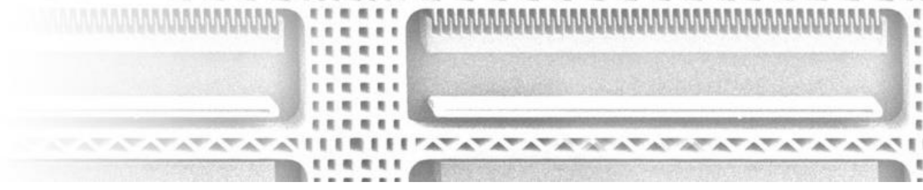
- Hydrogen can be stored and transported in pure form, blended with natural gas or bound in larger molecules such as ammonia or liquid organic hydrogen carriers (LOHCs).
- Replacement of Habber Bosch process to produce NH3: the next generation of Haber-Bosch chemistry should work at lower pressure and temperature, which can be achieved by using more active catalysts or a combination of catalysts with physical activation, and by continuous ammonia removal from the reaction zone thus shifting the equilibrium (Sooveichik, 2017)

On the other side, related to **Hydrogen Fuel Cells** (FC), to accelerate market integration of Hydrogen storage technologies these should integrate the fuel cell systems and hydrogen infrastructure in a way to decrease infrastructure complexity and cost. Lower infrastructure costs will expand the potential market beyond high count fleet sites. Fuel cells require costly platinum as a catalyst for this reaction, which restricts their more widespread use. The market requests materials that are less costly and more easily available than platinum. The next generation of PEMFC, opens great opportunity for FC market penetration. The MEA can be considered the core of the cell and is responsible for the whole performance of the PEMFC. A MEA is comprised of GDL (Gas diffusion layer), CL (Catalyst Layer) and proton exchange membrane (PEM). FC sector is looking at improving its characteristics (durability and power density) while reducing its manufacturing costs. The MEA manufacturing process involves the catalyst deposition supported by platinum (Pt) or Pt alloys (Gsteiger, Kocha, Sompali, & Wagner, 2005), PGM which are considered as CRM by Europe. Therefore, the majority of the known techniques for catalyst deposition seeks to reduce the utilisation of Pt to catalyse the oxidation (hydrogen) and reduction (oxygen) reactions, or to substitute the Pt for other less expensive and critical noble metals.

The main future trends in Hydrogen Fuel Cells are:

---

[9] More information available at: https://medium.com/@cH2ange/louis-londe-technical-director-at-geostock-hydrogen-caverns-are-a-proven-inexpensive-and-346dde79c460



- Nanocatalysis, is an emerging field of science due to its high activity, selectivity and productivity. The nanoscale size, shape and an exceptionally large surface area to volume ratio imparts unique properties to nanocatalysts because of the structural and electronic changes which differentiates them from the bulk materials (Singh & Tandon, 2014). There is an increasing number of nanocatalysis related patents, technologies and products in the market.
- Substitution of metallic catalysts by molecular catalysts: A team at the Max Planck Institute for Solid State Research in Stuttgart (Grumelli, Wurster, Stepanow, & Kern, 2013) has been inspired by nature to develop an alternative catalyst. It consists of organic molecules as well as iron or manganese on a metallic substrate. These materials are less costly and more easily available than platinum.
- Fuel cell recycling & materials recovery (Pt, Nafion (Nf)): using strategies to meet the WEEE (Waste Electrical and Electronic Equipment) directives for product end-of-life management while paying attention to recycling process design for recovering platinum from the MEA. It has been reported 95% Pt as well as almost all the Nafion can be recycled. The fuel cell performance of the recycled Nafion is close to that of the pristine Nafion (Pei, Yuan, Chao, & Wang, 2010)

Finally, the axes number three, **supercapacitors SC,** has a market valued at \$834.33 million in 2019, and it is expected to reach \$2663.7 million by 2025, registering a CAGR of 21.8%, during the period of 2020-2025. With the ability of quick charging and temperature stability, supercapacitors are replacing traditional electric car batteries. The driver of supercapacitors market is the increasing demand for renewable energy solutions. Solar PV panels and solar lighting are potential areas where supercapacitors are growing. In general, solar panels are used in both modes, online as well as offline, for which supercapacitors are reliable options. Another potential market need is the increasing production of supercapacitor-based vehicles due to environmental concerns. Nevertheless, the high costs associated with the products is restraining the market to grow. Some of the latest trends in electrochemical SC technology are 3D porous SCs, fiber-like SCs, and paper-like SCs.

Another trend is to use materials made of some form of readily biodegradable carbon. Supercapacitors are also gaining traction to protect Complementary metal oxide semi-conductor (CMOS) logic and power electronic toys. Security alarm systems, Uninterruptible Power Supply (UPS) systems, and solar power are other typical applications. In the future, the SC can be used either in conjunction with batteries or replace batteries in the storage system (continuous power supply, and load levelling). Recently electrochemical double layer capacitors (EDLCs) were used in emergency doors on an airbus A-380 with providing safety, good performance and reliability. For the future energy storage systems, both SC and batteries are given equivalent importance by US Department of Energy. Also, MIT researchers (Sheberla, y otros, 2017) have found that metal-organic frameworks (MOFs), extremely porous, sponge-like structures with an extraordinarily large surface area for their size, much greater than the carbon materials, can be a good alternative to carbon for supercapacitors.

Another important topic in addition to trends and needs are the **key nanofabrication technologies** for energy and climate change sector. **In photovoltaics market**, Perovskite thin films are compatible with sheet-to-sheet and roll-to-roll printing, which offers advantages such as low manufacturing cost, high throughput and continuous production. Perovskite solar cells can also be combined with other PV technologies, such as c-Si or copper indium gallium selenide (CIGS), into so-called two-junction (or tandem) solar cells to deliver efficiencies beyond the limit of single-junction devices. The combination of perovskite and silicon technologies is currently viewed as the most promising and fastest route to market for perovskites based thin films not only because of the large market share held by silicon, but also due to the high efficiencies obtained by the combination of silicon and perovskite. (Nature Energy, 2020)

As efficiency of the cells depends on the growth rate of the individual layers, roll-to-roll production is a clear advantage for increased manufacturing throughput, and flexible substrates offer this possibility as opposed to glass substrates (Reinhard, Chirila, Blosch, Pianezzi, & Nishiwak, 2013). Growing perovskite solar cells on flexible substrates can be seen as an exciting opportunity, allowing high throughput roll-to-roll manufacturing with a low embodied energy (Pisoni, et al., 2017). Perovskite PV technology has entered its industrialization phase and is beginning to explore the feasibility of various device architectures and manufacturing processes for different markets. Companies are setting up low-volume production lines, partnering with silicon and CIGS solar cell manufacturers and attracting the interest of investors and stakeholders. Nonetheless, the commercial success of perovskite solar cells still depends on the ability to avoid premature field failures. The upcoming years will be crucial for the future of perovskite PV technology.

According to (International Technology Roadmap for PV, 2019), Perovskite/silicon solar cells are expected to appear in mass production as early as 2021, with companies commencing their low-volume production lines, around the few hundreds of megawatts, by the end of this year .According to (IRENA, 2019), CIGS technology has already entered the market and CdTe presents a consistent market penetration.

In **Catalyst**, technology readiness level for classical catalyst materials (PGM: platinum group materials) is high (TRL 9) and commercial products already exist. Pt can be manufactured by electrodeposition, a very versatile technique for nanomaterials. By its part, Catalyst Enhanced Chemical Vapor Deposition (CECVD) and Catalytic chemical vapor deposition (CCVD) present lower TRLs (4-6). On one side, CECVD is an enhancement method, used for the synthesis of nanomaterials on thermally sensitive substrates in the presence of appropriate metal catalysts (Rashid, et al., 2015). On the other side, CCVD is an efficient and low-cost method for the mass production of nanomaterials as highly pure carbon nanotubes (CNTs). In this process, CNTs are produced by the catalytic decomposition of hydrocarbon vapours. Cobalt, Iron, Nickel and their alloys are the most widely used catalysts in CNTs production through CVD process chemical deposition in carbon.

Inks are deposited by induction or roller blade spray.

- CCUS: the world's first commercial CCS-equipped power station has started operation at the Boundary Dam facility in Saskatchewan, Canada, with a second project also in operation in Alberta, where Shell are capturing the CO2 arising/byproduct from H2 production. CCS is undoubtedly a well-understood, mature technology that is deployable at commercial scale today (MacDowell, Fennell, Shah, & Maitland, 2017).

- Electroreduction or Electrocatalytic CO2 reduction, enables CO2 reduction (CO2RR) to valuable fuels but controlling the reaction pathways and products remains challenging: TRL 5. Lately novel Cu2O nanoparticle film was synthesized by square-wave (SW) electrochemical redox cycling of high-purity Cu foils. The cathode afforded up to 98% Faradaic efficiency for electroreduction of CO2 to nearly pure formate anions under ≥45 atm of CO2 in bicarbonate catholytes (Li, et al., 2020)
- Direct air capture for CO2 recovery as Compressed Air (Climeworks): the air-captured carbon dioxide can either be recycled and used as a raw material, or completely removed from the air by safely storing it. TRL 6 but very high cost

Regarding **Supercapacitors SC**, it is worth to mention hybrid SC for the next generation of energy technology. For example, the fabrication of a supercapacitor employing hybrid metal oxides deposited over nanoporous gold electrode fabrication of Co–Mn oxides in a multi-layered and hybrid fashion through electrochemical deposition on nanoporous 18 k gold foil (Prabhin, Jeyasubramanian, Benitha, Veluswamy, & Cho, 2020)

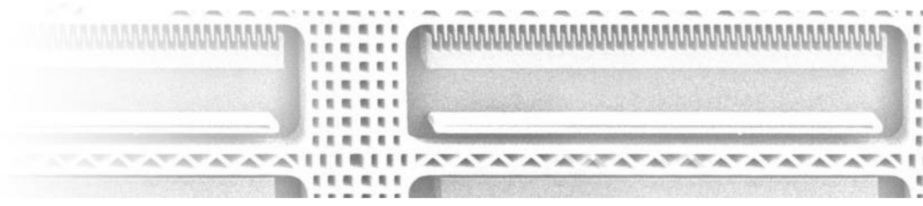
2.3 European industrial ecosystem trends and needs for health

The nanofabrication sector 'Health' encompasses nano-enabled medical technologies and nanomaterials applications in healthcare, including, nano biosensors, drug manufacturing and delivery, implantable and monitoring systems with focus on citizens' healthcare and wellbeing. The health industry follows a similar transformation seen in the automotive sector. Whereas automotive digitalised its products to the effect that the boundary between semiconductor companies and motor vehicles OEMs has blurred, the healthcare sector is moving from purely mechanical intervention to embrace both digitalisation and nanotechnologies.

The sector's primary Sustainable Development Goal is naturally "Good Health and Wellbeing". The controlled use of nanotechnologies has diverse applications in early detection and prevention of diseases, improved diagnostics/imaging and targeted therapeutics. There are already commercial products ranging from nano-delivery and pharmaceutical to medical imaging, diagnostics and biomaterials while hundreds of others are under clinical trials, covering all major diseases including cardiovascular, neurodegenerative, musculoskeletal and inflammatory. The latter include testing, diagnosing and monitoring applications in the combat against the COVID-19 pandemic. The sector also contributes to the ‘Industry, Innovation and Infrastructure’ SDG with an over 12% compound growth of the market and with its significant socioeconomic impact on providing relief to pain points of the already strained healthcare system.

The nanotechnology-based medical devices market has witnessed a healthy growth during the last decade primarily attributed to the rising aging population, rising prevalence of chronic diseases, neurologic diseases, bacterial infections, antibacterial resistance and cancer combined with increasing government support, globally. However, high costs and time-consuming product approval processes of the nanotechnology-based medical devices are inhibiting the growth of this market to a certain extent. In addition, technological advancements, evolving care models and the expansion of health care systems pose a risk to less developed countries which will impact the global community. Healthcare systems will need to work towards a future in which the collective focus shifts away from treatment (repair), to prevention and early intervention.

On the basis of applications, the nanotechnology-based medical devices market can be categorized into three major segments: therapeutic applications, diagnostics applications, and research applications. From a product point of view, the nanotechnology-based medical devices market can be categorized into the following products: nanobiosensors, smart drug delivery systems, implantable materials and wearables. These disruptive technologies can play a vital role in combating the above debilitating health conditions. For example, in 2014 the active implantable devices segment accounted for the largest share of the market, due to the rising incidence of lifestyle and age-related disorders, such as cardiovascular and hearing disorders (Markets and Markets, 2019).



In addition, availability of insurance coverage and reimbursement for medical procedures, presence of well-structured distribution channels, and growing out-of-pocket healthcare spending are further boosting the growth of the active implantable devices market. Mental health and neurological diseases have largely been treated outside of the mostly physical pathologies of primary health care. Yet, with dramatically increased technological enablement of human productivity, faster pace of life, information ubiquity and increased levels of stress, the incidence of mental health issues has also increased into what may be a much larger concern than anticipated. This may be ascribed in part by a much slower physiological adaptation than the pace at which people have been enabled to function. Health systems are working to achieve financial sustainability by reducing the cost to deliver and finance high-quality and effective patient care. New strategies, capabilities and technologies are shifting health systems to focus from providing episodic, acute care to keeping people healthy. Patient engagement is also seen as of value-based care.

It is foreseen that future innovation into the health care sector will be enabled by collaboration with key building blocks in (ABCD) – Academic, Business, Clinical and Design Thinking. It will become increasingly important to develop, design and innovate for humans, as they will drive the move to preventative healthcare and wellbeing through the adoption of wearable and information-based technology.

The healthcare industry is going through massive disruptive transformation with consumers now bearing more cost for their care. Therefore, customers expect new tools for comparison shopping and for finding 'value' as they shop for healthcare. The value-based care model ties medical payments to the quality of care provided. There is a movement towards the model where healthcare providers are incentivized and rewarded on lower spending and better outcomes instead of the traditional fee-for-service reimbursement models, which are pushing providers to innovate their care delivery processes and infrastructure.

Precision medicine and genomics will play a critical role in the understanding of human disease. The collection and analysis of genetic and clinical data will allow further expansion of genomic medicine, towards development of personalised health and medicine for patients. Despite the progress the industry has made in genomic medicine, there are still several barriers to overcome, including deeply entrenched disparities and limited genomic knowledge. Progress will be critically dependent on platforms and governance that lower barriers to the integration of genetic and phenotypic data across studies and countries, along with technical standards that are reliable, secure and compatible with the international regulatory landscape

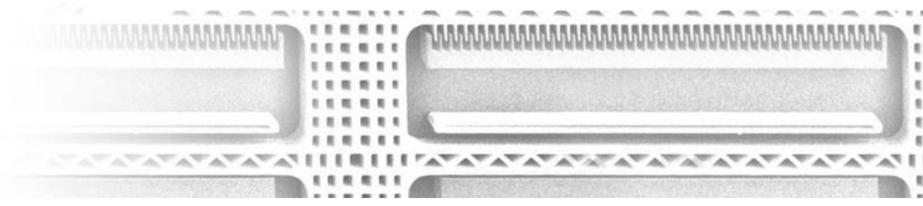
There is a need to increase the quality of patient care at a lower cost to address the disparities and inequities within country’s health systems. Involving more pharmaceutical companies and hospitals focusing more towards value-based care models, care delivery, operational efficiency, chronic disease management, specific therapeutic areas moving from hospital to home care it is a current and future trend. Moving from measuring illness to measuring prevention and wellness is a need which is being driven by consumer. The focus on these platform technologies will and is leading to patient empowerment. This is manifested generally at the systemic level through peer-to-peer health and the new wearables that allow direct personalised health information - the quantitative self.

There is a growing need for biosensors for health-related applications. Currently biosensors are lab based. There is a need for more commercial outputs. Researchers are working towards to their goals. Medtech and pharma companies associated with this research, need to work closer to drive and commercialise these devices, where there is a clear path forward to scaling.

There are few nanofabrication technologies associated to the market needs and future trends of health sector:

Nanobiosensors

A sensor (also called a detector) is a converter that measures a physical quantity and converts it into a signal. This can be read by an observer or by an instrument (today mostly electronic). Sensors may be direct, i.e. measuring the temperature as temperature, or indirect, measuring the resistance of an element that has been calibrated against temperature prior to use. All automated equipment, and this includes all machinery used in manufacturing, work on the basis of sensing some aspect of the local environment. This sensing is then used as information to activate



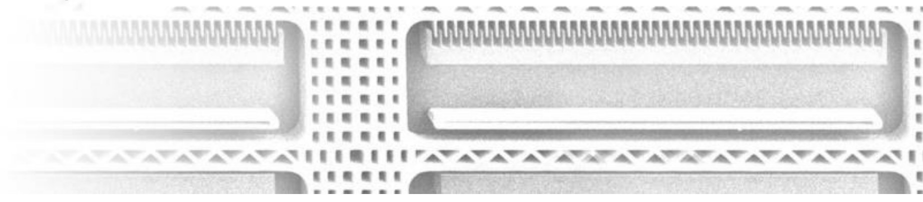
(actuate in technical parlance) a response to a piece of equipment. To that extent sensing is pervasive and is reaching into ever more sophisticated realms of everyday life. A life support system can operate without a person being present all the time because the breathing, heartbeat, temperature, blood pressure and as well as other key parameters are being sensed, recorded and used to modify the system if necessary, the life support systems.

Requirements: Therefore, there is a need for some current sensors to get smaller, to move to the realm of micro to nano which leads to further miniaturisation of the device system. Typically, nanofabrication continues to be led by the semiconductor industry.

Nanofabrication techniques play a crucial role when differentiating the transducer and signal processing method in a biosensor. When nanobiosensors are considered at their highest level of integration nanofluidic technologies can also be added, giving birth lab-on-a-chip systems. In these applications the sensors have to be small. They also have to be able to react to the small changes that occur when nano-systems operate and actuate a response on the timescale of the system. This is important because of its small scale which is intrinsically fast. For that reason, nano-electro-mechanical systems are now being developed for sensing and controlling very small systems.

There is a general need to address the valley of death moving from TRL4 (validation in a laboratory) to TRL 7 or above (prototypes in industrial environments). For this, the ability of engineering to scale up will be a key requirement. Technological facilities which incorporate the science and knowledge such as RPOs, pilot lines (demonstration) to scale from TRL 4/5 to 7/8 to ensure the avoidance of the valley of death will be important to ensure that more innovation makes it to the market. To overcome this challenge, the implementation of nanotechnology and advanced materials will play an important role.

A growing use of nanobiosensors occurs in catheters. Catheters have and are moving from mechanically structured and assembled devices to highly sophisticated surgical equipment which are becoming more and more sensorised. Many of the new catheters today or that are in development are theranostic toolsets. This trend will



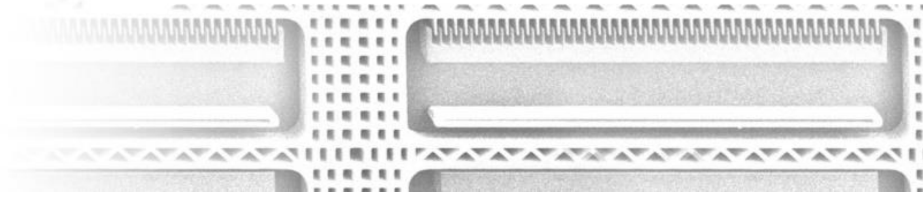
continue. Nano enabled lubricious coatings with imaging, nano-enabled sensors, are facilitating catheters and guidewires to travel to further regions of the vascular, neuro system within the human body, thus opening up new areas of treatment. The global catheters market is projected to reach USD 24.2 billion by 2025 from USD 15.9 billion in 2020, at a CAGR of 8.7%. The demand for catheters is majorly driven by the growth in the target patient population and the rising focus on minimally invasive surgical procedures over conventional surgery. However, product failures and recalls, unfavourable taxation policies, and trade barriers are expected to restrain the growth of this market during the forecast period.The global catheters market is segmented broadly into cardiovascular, urological, intravenous, neurovascular and specialty catheters.

In 2019, cardiovascular catheters commanded the largest share of the catheters market. This is attributed primarily to factors such as the high incidence of CVD, the growing geriatric population, and increasing awareness regarding early diagnosis among people. These factors have increased in cardiovascular surgeries, which positively impacts the cardiovascular catheters market. The primary end-users of the catheters market can be segmented into hospitals, long-term care facilities, diagnostic imaging centers, and other end users.

In 2019, hospitals accounted for the largest share of the catheter market. The large share of this segment is attributed to factors such as the rising prevalence of CVD, urinary incontinence and other chronic diseases along with the subsequent increase in the number of patients across the globe, leading to a growing demand for hospital treatment.

Smart drug delivery.

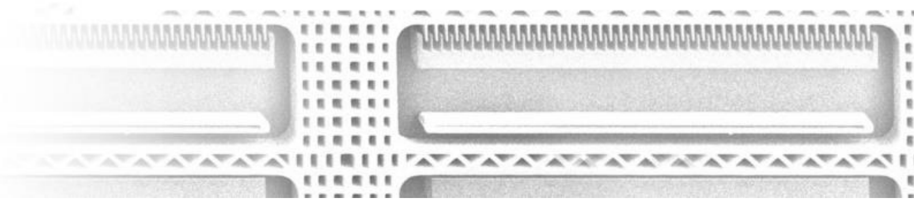
Smart drug delivery devices - which utilise delivery routes such as oral, transdermal, pulmonary, ocular and implantable - are poised to significantly facilitate increased public health arising from better patient adherence. Poor adherence, i.e. the failure of the patient to take medication as prescribed, is linked to demographic factors, incorrect patient beliefs about costs and benefits, and perceived patient burden regarding obtaining and using medication. It is estimated that up to 50% of patients fail to medicate as planned, and for chronic diseases this can lead to further



hospitalisation, patient distress and financial burden. Ultimately, non-adherence contributes to the premature deaths of nearly 200,000 Europeans annually. Conversely, the potential societal impact of improved adherence is huge – in one study, patients who showed improved adherence had a 13% reduction in the risk of hospitalization or emergency room visits. Recent years have seen also significant increases in the prevalence of chronic diseases such as diabetes and autoimmune conditions, and the very high cost of the drugs (>€10k/yr) and treatment regimens associated with these conditions has intensified the pressure to shift medication administration from traditional settings to cost-effective alternatives. – and emerging drug delivery technologies will further accelerate this trend.

Nanotechnologies will play a significant role in all aspects of the revolution in connected health that is required to make this a reality, by either making it easier to take medication as intended, or by facilitating unobtrusive monitoring and reporting of adherence. A key objective is to utilise nanotechnology in the transdermal technology devices that are being developed to conquer the skin barrier by means of (1) minimally invasive, painless delivery routes, (2) improved drug pharmacokinetics, and (3) targeted drug delivery. In this field, nanomaterials will enable biodegradable transdermal delivery systems such as thermally stable microneedle patches, removing the requirement for cold chain storage from the vaccine distribution network and potentially self-administered, mass vaccination programmes in developing countries. Topical formulations such a creams and ointments typically do not pass the outermost skin layer known as the stratum corneum, and will therefore incorporate various particulate nanocarriers (nanoemulsions, liposomes, nanoparticles…) that are being developed in an attempt to reversibly modulate this skin barrier and/or to provide novel delivery systems for the target active ingredient.

Nanotechnologies will also be essential for use in aerosol-generating nebulisers and pulmonary drug delivery. These nanoparticle-mediated drug delivery systems will modify the physical properties of the active ingredient, such as increasing the drug solubility, encapsulation efficacy and surface alterations to enhance the drug release profiles and to obtain a maximum therapeutic benefit.



In order to develop closed-loop delivery devices that are also capable of monitoring patient adherence, miniaturisation and integration of the hardware associated with these delivery systems is also critical, in order to provide patient-friendly devices that are high performance, yet comfortable and unobtrusive to use and wear. Nanotechnology will play an essential and high-profile role in the development of this next generation of wearable and implantable delivery systems. Among a huge range, examples include nanofabricated meshes for nebulisers, nanolithography for application-specific integrated circuits (ASICS), nanomaterials for new bespoke antenna designs, biodegradable and epidermal electronics, high-power and incinerable battery materials, as well as nanofabricated and biocompatible structures such as microneedles, fluidic systems, membranes, and sensors.

Implantable devices

Many implantables already exist, from cochlear, neural brain stimulation, pacemakers, defibrillation, hip, knee, ankle implants, GERD (Gastro-Esophageal Reflux) and smart pill camera/electrochemical technology (TRL > 8). Other more radical devices are on the way such as smart contact lenses, eye implantations, prosthetics, high performing blood brain barrier nano technology as well as bone growth technology for spinal implants. The market for human implantables continues to grow. The Medical Implants Market is estimated to grow €107 billion by 2022.

Medical implants are made up of medical devices or tissues that are surgically transplanted inside the body. These implants are used to replace or support any damaged body organs, to enhance/replace function of a body organ. It should also be able detect errors in normal body functioning. Implants can either be surgically placed in humans as permanent or temporary devices. Therefore, they can be replaced or remove when they are no longer required or need to be replaced further. Some implants are made up of bone, tissue, skin, ceramics, metals, plastics, and other natural materials.

It is a complex area as implants are made up of key submarkets typically as follows: pacing devices, stents, structural cardiac implants, neurostimulators, spinal implants, ophthalmic, cochlear, orthopaedic, dental, breast and facial implants.

In the case of implantable devices where a microreservoir of drugs is implanted in a body for subsequent controlled release of different drugs in varied doses, the use of nanofabrication techniques, materials, and formulations are essential. The implantable will be deposited just under the skin, generally using minor surgical procedures or even simply by injection through a standard hypodermic needle. The device itself may contain nanoelectronics and a series of nanoreservoirs that contain a therapeutic agent, both fabricated by applying nano-scale photolithographic techniques at extremely high volumes and correspondingly low cost. If required, power is provided by wireless transfer through the body, or else delivery is triggered via one of a number of actuation mechanisms such as electrolytic, pressure, magnetic or thermal actuation of the nanoreservoir closure mechanism. Both routes require development of nanotechnologies and structures such as nanoporous membranes, meshes, materials and for use in reservoir closure, power transfer, biocompatibility and avoidance of biofouling, system integration and dissolution.

The target active pharmaceutical ingredient (API) itself will also require reformulation on order to meet the pharmacokinetic requirements posed by slow release within the subcutaneous tissue. With this, as the market continues to evolve with more technology integration, more functionality, smaller footprint (in some cases), more efficient powered and powering of devices, there is a strong need for the continued investment in nanotechnology to realise this future growth and healthcare needs.

The technology development for pace making, smart pills, neuro, cochlear, ophthalmic, urinary and GERD (gastroesophageal reflux disease) requires key building technology building blocks as they shrink in size: ASIC, System level integration, (System on a chip (SoC)), Smaller sensing modalities (Electrochemical, Biochemical, Mechanical), Actuation sensing (Optical, Mechanical), Power)PMIC, Energy/power harvesting, Types of remote powering), Communications(Wireless, Bespoke antenna design for its environment and body area, Purpose or functionalist), Packaging (Nano packaging, Biocompatible materials, Inert stable materials., System backing integration), Software (AI, ML, NN, Edge of the cloud, Cyber secured networks).

Wearables

The global wearable healthcare/medical devices market is expected to reach USD 27.49 billion by 2026, according to a new report by Reports and Data.[10] Connected devices and wearable technologies are transforming the healthcare industry by enhancing patient care and impacting the efficiency and quality of care providers. The changing ecosystem will have significant impacts on the industry. Similar to Implantable, similar requirements are expected to make these devices less intrusive on the human/patient.

These will be devices/wearables/IoT or medtech that will be worn on the body, able to connect to the internet either directly or indirectly via a smart device (phone). Such devices will/are empowering humans to move to healthier more sustainable healthy living. Development of nanomaterials with enhanced sensing capabilities as well as bending and stretching capabilities will be key to enable development of future skin compatible wearable sensors for continuous monitoring of biomarkers. These sensors are currently at TRL 5 and will find applications in monitoring of chronic diseases for hospital and home patients as well as monitoring of wellbeing in the professional and leisure sport fields.

Patients with medical conditions are also benefiting and being empowered to take control of their disease and this is evident in the use and development of smart inhalers, insulin patches, respiratory devices and many more. They do come with risks such as cyber, privacy, power, environmental impact, disposal and their need to integrate to the circular economy.

Whereas there are several Health wearables in the market, they are largely classified as wellbeing products. Similar to nanobiosensors, there is significant need to take proof-of-concept devices and laboratory demonstrators of wearables (TRL3/TRL4) and develop to medical grade Healthcare solutions.

---

[10] Markets and markets. More information available at: https://www.marketsandmarkets.com/PressReleases/nanotechnology-medical-device.asp

2.4 European industrial ecosystem trends and needs for food and natural resources

The application of nanotechnologies is showing an increase in the food and drink industry and natural resources for sustainable exploitation and preservation.

Regarding the food industry, nanotechnologies are used in various fields of food science and food microbiology, including food processing, food packaging, functional food development, nutraceuticals, detection of foodborne pathogens, and shelf-life extension of food products. With a turnover of around €1 trillion (Food Drink Europe, 2019) counting direct, indirect and induced, the European food and drink industry is one of the strategic industries for the EU future in terms of revenue, employment and circular economy.

In recent years, the depletion and the sustainable use of natural resources, such as petroleum, have become a major focus of governments and organizations. For this reason, the implementation of nanotechnologies in this field is now opening to a series of bio-based environmentally friendly nano- with micro-structured polymeric materials such as chitin, starch, polycaprolactone and nanocellulose. Bio-based products can make the economy more sustainable and lower their dependence on fossil fuels. For this reason, the EU has declared the bio-based products sector to be a priority area with high potential for future growth, reindustrialization, and addressing societal challenges.[11] In addition to this, innovation and changes linked to natural resources and nanotechnologies also include smart sensors for air, water and soil monitoring, water treatment and desalination, nano-engineered enzymes for biowaste recovery and nanotechnologies for precision agriculture and breeding.

In the end, the sector of Food and Natural Resources nanofabrication is in line with the Sustainable Development Goals sets by the United Nations:

- End hunger, achieve food security and improved nutrition and promote sustainable agriculture
- Ensure availability and sustainable management of water and sanitation for all

---

[11] More information about bio-based products available at: https://ec.europa.eu/growth/sectors/biotechnology/bio-based-products_en

- Ensure sustainable consumption
- Conserve and sustainably use the oceans, seas and marine resources for sustainable development
- Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably

Nanotechnology for the food and natural resources industries represents a new emerging sector, which is strongly linked to human, animal and earth health aspects. To receive the green light from the market and the consumers, the above-mentioned sectors must take into account ethical principles to be adherent to health, safety or environmental risks scientifically studied, also in order to prepare international regulation and certification for nanomaterials acceptance. In this context, societal and market impacts of the nanotechnologies need to be examined and considered, then it is important to ensure that the knowledge generated in research laboratories will be exploited and disseminated for the benefit of society to avoid friction between science and society perception.

Food nanotechnology is a sector where primarily R&D activities and purposes are focused on food packaging, food with functional properties and food processing. Regarding the “natural resources” segment, nanotechnologies are mainly in a development stage and adherent to the agriculture (agrochemicals, nanosensors and water treatments) and bio-based sector. For both industries nanotechnogies include nanomaterials growth, processing and encapsulation; design and fabrication of nanoscale features; nanostructuring; nanoparticle dynamics and reactions.

Nowadays, nanotechnologies application could play an important role against viruses and bacteria thanks to the possibility to develop products with integrated functional features such as antimicrobial (Rhim & Whan, 2014) or antibacterial properties (Nakazato, Kobayashi, Seabra, & Duran, 2017) for food packaging or to advance nanoparticle-based sensors for pathogenic bacterial detection in food or management of natural resources such as the water treatment. (Stephen & Inbaraj, 2016), (Moca, Matea, & Pop, 2017).

Application and Nanotechnology	Development stage	TRL (1 to 9)
Food Processing: texture, taste, and appearance of food, nutritional values, preservation and nanocarrier system.	Currently, the food processing with nanotechnologies is in an advanced stage of development with a number of nanostructured food ingredients and additives (organic and inorganic) understood. Only nanocarrier systems for delivery of nutrients and supplements represent a solution commercially available in some countries and over the internet.	7-9
Food packaging: polymers containing or coated with nanomaterials for improved mechanical strength, barrier and functional properties (antimicrobial/antibacterial films in packaging sensing)	The application of nanotechnologies in this area represents, currently, the largest share of the market with a high TRL value and technology solutions already available on the market. (e.g. plastic polymers with nanoclay as gas barrier; nanosilver and nanozinc oxide for antimicrobial/antibacterial action; nanotitanium nitride for strength).	7-9
Nanosensors for food labelling: edible or not sensors to monitor food safety	Low level of development with a high potential in future industrialization. To be evaluated the safety issues correlated to the edible sensor integration.	4
Food health monitoring and food traceability	nanofunctionalised RFID tags optimized to monitor temperature, humidity, and light exposure.	4
Nanosized agrochemicals: nanocapsules for delivery of pesticides, fertilizer and other agrochemicals.	Nanotechnology research in agriculture is still at an early stage and evolving quickly. Before nanofertilizers can be used on farms, it is necessary to better understand how they work and regulations to ensure they will be used safely.	4
Nanosensors for natural resources: monitoring of soil conditions, water and air quality.	Nanosensors for water and soil monitoring are on high level of development. However, they require further development into consumer- and operator-friendly tools or to operate in inaccessible locations. Nanosensors for air quality require development for more widespread, local and reliable data acquisition.	4-6
Water management: wastewater treatments, decontamination, desalination and purification.	Nano metals are already available in industrial-scale quantities. Despite the high potential, these products exhibit certain limitations, especially when considering the potential uptake of these materials into wildlife.	5-7
Animal feed supplement	Nanosized additives for livestock food, which have the aim to remove toxins or pathogens, are under development to define the effects and the safety aspects.	4
Nano-engineered enzymes	Development stage of specific enzymes for biowaste recovery and application in bio-fuel production	4
Bio-based sector: applications of environmentally friendly nano- with micro-structured polymeric materials to improve intrinsic properties.	Biopolymers based on nanotechnologies are currently in R&D stage, they represent a potential green solution for the future of the plastic.	5
Nanotechnologies for portable real-time viral disease diagnostics in crop production	Nanosensors can be integrated in strategies to alleviate the impact and prevent the establishment of viral diseases whose spread/emergence presents a new/emerging threat to sustainable crop production in European organic and conventional agricultural and horticultural systems.	4

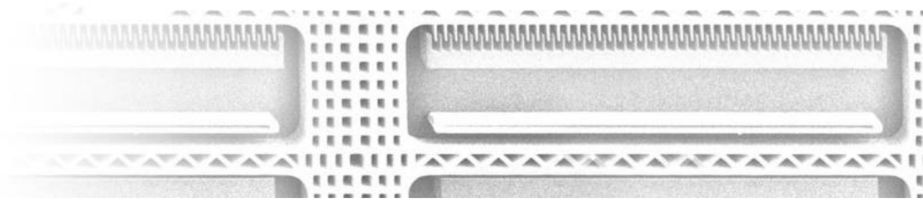
Application and Nanotechnology	**Development stage**	**TRL (1 to 9)**
Animal health monitoring	Nanobiosensors for disease diagnostics and monitoring, enabling accurate prognosis and timely intervention	4

Figure 9. Key nanofabrication technologies for food and natural resources sector. Source: SUSNANOFAB

As a result of the application of new concepts and engineering approaches to the food industry and to the natural resources sector, nanotechnologies represent a growing point of interest for research and development.

Concerning the food sector, nanomaterials allow better encapsulation and release efficiency of active food ingredients compared to traditional encapsulating agents, and the development of nano-emulsions has led to improved properties for bioactive compounds protection, controlled delivery systems, and masking undesired flavours. Nanotechnology also has the potential to improve food processes that use enzymes to confer nutrition and health benefits. The food packaging science is experiencing a significant change thanks to the adoption of nanomaterials to improve mechanical or functional properties. (Sekhon, 2010), (Trepti, y otros, 2017), (Hernandez-Sánchez, 2015)

By analysing the natural resource sector, nanotechnologies are now emerging as promising knowhow to promote plant growth and resources management. This idea is part of the evolving science of precision agriculture and breeding, in which farmers use technology to target their use of water, fertilizer, animal feed and other inputs. Precision farming makes agriculture and breeding more sustainable because it reduces wastes, it improves the monitoring production and the amount of the output. (Frewer, Norde, Fisher, & Kampers, 2011). Nanosensors can be used to improve pest management and to reduce the use of antibiotics in animals. Nanotechnologies also have the prospective application on biopolymers synthesis with a significant reduction in terms production of petroleum-based products and an improved biodegradability and bio-compatibly. (Mishra & Hussain, Nanotechnology for sustainabkle water resources, 2018), (Mishra, Kyu Ha, & Verma, 2018), (Vikesland, 2018).



2.5 European industrial ecosystem trends and needs for digital and industry

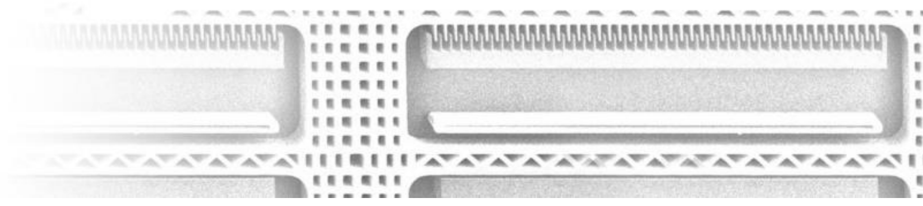
Nanomanufacturing in the "Digital and Industry" sector is mainly composed of the semiconductor and the chemical and processing industries.

The semiconductor industry is now mainly focused on "nanoelectronics" which have been developed at high-volume for many years. A wide range of components are already using the nanoelectronics technologies: transistors, memory/data storage, integrated circuits (IC), thin film transistors (TFT), electromagnetic shielding (EMS), etc.

Simultaneously, the chemical and processing industry developed new processes over the years to industrialize the production of nanoparticles, nanocomposites and nanostructures. The production, control and characterization tools have been adapted towards nanomanufacturing of a large range of semi-products and products: nanocarbons (Graphene, Mxene, nanotubes, nano diamond...), nanocomposites, metal-organic frameworks (MOF), catalysis, sensors, coatings and functional surfaces, etc

The following table illustrates the contributions of the “Digital & Industry” sector to the Sustainable Development Goals:

SDG	NANOELECTRONICS	CHEMICAL AND PROCESSING INDUSTRY
Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture	Miniaturized, portable and affordable biosensors for food safety authenticity and traceability based of molecular biology. Integration of food value chain sensors with AI and blockchain, Embedded sensors for smart packaging. *Development of sensors and food sensors for quality control. Anticounterfeiting stamps and labels	Nano encapsulated substances to provide protective barriers for food packaging Nano emulsions to avoid utilization of excessive fat and emulsifyers Nanocoatings for “Active” packaging Materials Nanosensors for monitoring food spoilage in packaging
Goal 3. Ensure healthy lives and promote well-being for all at all ages	Nanoelectronics-blood-based diagnostic biomarkers *Lab-on-Chip devices and Sensors	Nanoparticles, nanomembrane and nano powder for detection and removal of chemical and biological substances



Goal 6. Ensure availability and sustainable management of water and sanitation for all	Sensors for water monitoring and quality: detection of water contaminants, toxins.	Holey Graphene nanosheet for water desalination MOF to purify water or air Nanowire-based LED for Water Purification
Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all	e-skin for energy harvester in wearable systems Nanomaterials as metal replacement in Electronics	Nanoimprinted Polymer Solar Cell Self-cleaning coating (Nanosized Silica) for production of Solar Panels
Goal 13. Take urgent action to combat climate change and its impacts	-	Gas sensors for detecting air pollution or gas leak monitoring

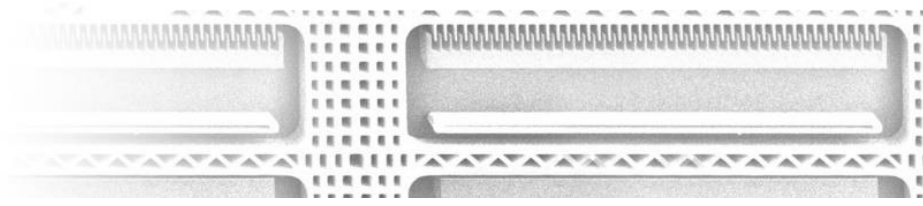
Figure 10. Contributions of the Digital and Industry sector to the SDGs. Source: SUSNANOFAB

The main needs of Digital and industry sector in **nanoelectronics** are expected to be the following ones:

- Sensing and mobility, especially with the uptake of the IoT and AI applications.
- Post-classical computations and communications that paves the way for new generations of existing infrastructures with ever-faster processors at a constant price: 5G, new generation of memories, low orbit satellites (LEO), 3D nanoimprinting, etc.
- Digital ecosystems: interconnections via digital platforms (based on emerging technologies such as Knowledge Graphs, Blockchain, DigitalOps, Decentralized Web, smart contracts, etc.).
- Advanced AI and Analytics: automatic or semi-automatic data or content analysis, from new classes of algorithms and data science, which will play a key role in Transfer Learning, adaptive machine learning, Edge AI (use of embedded artificial intelligence in IoT), AI PaaS (platform as a service, AI platforms in the cloud).

In addition, the complexity and volume of global digital data is increasing, creating challenges to store and provide access to this data in a secure, fast and reliable way. For example, facial recognition at the era of smart sensors and artificial intelligence requires a whole new level of data analysis to identify and interpret not only physical data, but also psychological data.

In order to meet these market demands, power and functionalities need to be strongly improved, driving demand for nanoelectronics that will allow for innovative design, architectures and manufacturing processes.



The nanoelectronics market is expected to show a significant growth in the next few years. For example, the global semiconductor market was valued at USD 488.07 billion in 2018 and is projected to reach USD 730.29 billion by 2026, exhibiting a CAGR of 5,2% during this period (Fortune Business Insights, 2018)

As described in the (ECS, 2019), the nanoelectronics sector will be fostered by various opportunities:

- Need for alternative performance approaches besides miniaturization
- Advances in AI and Human-Computer Interfaces creating new solutions and market opportunities
- Ubiquitous connectivity/ 5G deployment
- Internet of Things
- New energy paradigm
- Solutions for zero fatalities in road transport
- Disruption in design, manufacturing and business models
- Societal changes requiring nanoelectronics based solutions

Besides, several markets will support the growth of the nanoelectronics industry such as Industry 4.0 and safety and security among others. On one hand, Industry 4.0 can be seen as an interoperable, integrated, adaptive, optimized, service-oriented manufacturing process that is correlated with algorithms, Big Data (BD) and high technologies such as Internet of Things (IoT) and Services (IoS), industrial automation, cyber security (CS), Cloud Computing (CC) or intelligent robotics. Industry 4.0 will thus drive demand for nanoelectronics. On the other hand, following (Gouvernement République Français, 2020), Cryptography is a new market that is set to expand rapidly due to the increased number of cyber-attacks (+61% per year between 2014 and 2018), regulatory obligations in terms of cybersecurity (DPR, NIS directive in 2018), and the development of new technologies leading to new threats (IoT, data storage, AI). This market is creating the need for reliable nanoelectronics components.

KEY NANOELECTRONICS TECHNOLOGIES	KEY TECHNOLOGIES FOR NANO-ENABLED CHEMICAL AND PROCESSING INDUSTRY
Photolithography EUV (Extreme Ultra-Violet) lithography Electron beam lithography Epitaxy Atomic Layer Deposition Printing technologies Spin coating Atmospheric pressure plasma deposition Supercritical CO2 surface modification	Self-assembly of block copolymers Nano Imprint Lithography (NIL) and derivative techniques: • Thermal Nanoimprint Lithography (TNIL) • Ultraviolet Nano Imprint Lithography (UVNIL) • Roll-to-Plate printing (R2P) UV replication Hot embossing Injection moulding Roll to roll embossing Grafting on polymeric substrates Application of (multi)functional micro- and nano-enabled coatings by spray coating Direct laser processing on plastic products Atmospheric pressure plasma deposition Supercritical CO2 surface modification Multi-nanolayering

Figure 11. Key manufacturing technologies in Digital & Industry sector. Source: SUSNANOFAB

For its part, following the priorities defined in (SusChem SIRA, 2019), the **nano-enabled chemical and processing industry** should answer three overarching and interconnected challenge areas:

- Circular Economy and resource efficiency,
- Low-carbon economy towards mitigation climate change,
- Protecting environmental and human health.

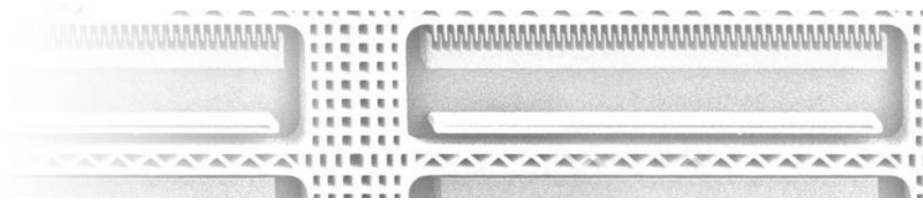
The nano-enabled chemical and processing industry should play a key role in answering these main challenges by developing a wide range of innovative solutions (e.g. sustainable chemistry making use of nano-enabled bio-based raw materials, innovative recycling process such as enzymatic recycling, thin film solar cells, etc. The nano-enabled chemical and processing industry is expected to continuously gain market share. As an example, the nanomaterial market is projected to reach 3,210.0 million USD by 2025, actuating at an estimated CAGR of 67.3% from 2019 to 2025 (Patel, Nanda, & Sahoo, 2015). There are some markets that will support this growth such as those already mentioned of mobility, health and food, climate change and smart cities. In this sense, transforming Europe into a more Circular Economy will drive demands for safe-be-design, recyclable, compostable and/or bio-based materials. Nano-enabled chemical and processing industry has a key role to play to answer these challenges. Besides, more than 60% of the population lives in cities and this figure is expected to reach 80% by 2050. In this context, smart cities are key enablers to drive sustainable growth while tackling environmental issues. Nanotechnologies will make it possible to manufacture the necessary materials like fluoropolymer films used for batteries or organic photovoltaics, graphene supercapacitors for electricity production and energy storage among others, as well as intelligent traffic management systems.

2.6 European industrial ecosystem trends and needs for inclusive and secure societies

The Inclusive and Secure Societies sector has a transversal impact in most of the Sustainable Development Goals. But the developments made through research and innovation in the nanofabrication area will impact directly the following SDGs:

- Goal 1. End poverty in all its forms everywhere.
- Goal 3. Ensure healthy lives and promote well-being for all at all ages.
- Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
- Goal 5. Achieve gender equality and empower of all women and girls.
- Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive.
- Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
- Goal 10. Reduce inequality within and among countries.
- Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable.
- Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.

In the first approach for defining the clusters within Pilar II “Global Challenges and Industrial Competitiveness” of the Horizon Europe programme, the European Parliament and the Council have adopted five clusters: Health; Inclusive and Secure Society; Digital and Industry; Climate, Energy and Mobility; and Food and Natural Resources. Later on, in April 2019, the European Parliament and the Council have



adopted slight modifications on the definition of the clusters, creating a separated cluster for security. The Pillar II now comprehends the following clusters: Health; Culture, Creativity and Inclusive Society; Civil Security for Society; Digital, Industry and Space; Climate, Energy and Mobility; and Food, Bioeconomy, Natural Resources, Agriculture and Environment.

This sector addresses the needs of both Culture, Creativity and Inclusive Society and Civil Security for Society clusters, adopting the intervention areas proposed to structure the work programmes:

- Democracy and Governance
- Cultural Heritage
- Social and Economic Transformation
- Disaster-Resilient Societies
- Protection and Security
- Cybersecurity

The needs in the **Democracy and Governance** area that could benefit from innovative solutions from the nanofabrication sector are:

- Rapid technological and scientific advancements, including big data, online social networks and artificial intelligence on democracy.
- Innovative approaches to support the transparency, accessibility, and effectiveness of democratic governance.

Also, the future trends identified in the Democracy and Governance area that could be addressed by the nanofabrication solutions are related to Artificial Intelligence (AI), big data and the Internet of Things (IoT).

The needs of the **Cultural Heritage** intervention area that could benefit from innovative solutions from the nanofabrication sector are:

- Conservation and restoration of cultural heritage with the use of cutting-edge technologies (e.g.: nano-coatings for conservation of historical monuments in churches, museums, historical buildings, and others).

For the Cultural Heritage area, the future trends that could be tackled by nanofabrication lays down in the field of new technologies applied to the conservation of cultural heritage goods; digitalization of the cultural heritage sector through cutting edge technologies related to data science, such as big data, AI and IoT.

The needs in the **Social and Economic Transformation** intervention area that the nanofabrication could provide innovative solutions are:

- New solutions for knowledge-based advice on investments forward-looking policies to boost productivity and human capital. Education and training systems are also needed for a more equitable and prosperous future.
- Inclusive and sustainable development and growth models for urban, semi-urban and rural environments.

The future trends in the Social and Economic Transformation area are related to global digitalization, information and communication technologies and transformation of the socio-economic systems. The nanofabrication innovation ecosystem could address these trends though new technologies applied to AI, automation and industrial processes, and other applications aiming at smart and sustainable growth, social transformation and social innovation

Needs in the **Disaster-Resilient Societies** intervention area that could be addressed by nanofabrication solutions:

- Technologies to prevent, manage and reduce disaster risk (e.g. wearable electronics for critical environments).

The trends in the Disaster-Resilient Societies area are aligned with technological advances in new materials and miniaturization of wireless systems and sensors in the key areas of protective equipment, communication and navigation systems.

The needs in the **Protection and Security** area that could benefit from innovative solution from the nanofabrication sector:

- Innovative approaches and technologies for security practitioners, such as police forces, fire brigades, medical services, border and coast guards, customs offices.

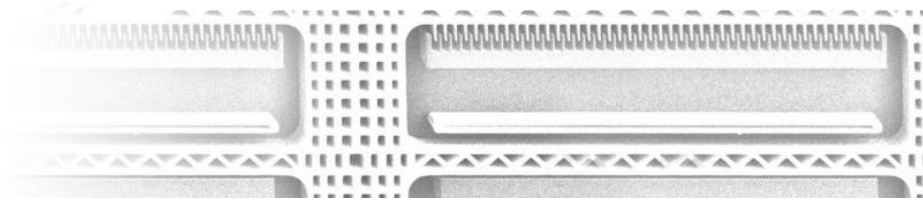
- Analysis of security aspects of new technologies such as DNA-sequencing, genome editing, nanomaterials and functional materials, Artificial Intelligence, autonomous systems, drones, robotics, quantum computing, cryptocurrencies, 3D printing and wearables and blockchain.
- Developing techniques and solutions for identifying counterfeit products, for enhancing protection of original parts and goods and for controlling transported products.

Needs in the Cybersecurity intervention area that could be addressed by nanofabrication solutions:

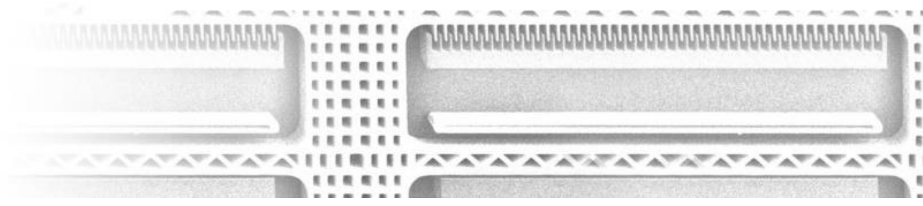
- Technologies across the digital value chain, from secure components and quantum-resistant cryptography to self-healing software and networks.
- Technologies, methods, standards and best practices to address cybersecurity threats, anticipating future needs, and sustaining a competitive European industry, including tools for electronic identification and threat detection.

In the Protection and Security and in the Cybersecurity areas, the trends that could be addressed by nanofabrication are also related to AI, big data and IoT. Developments in the electronic components, systems and sensors in the hardware sector; and machine learning (deep learning algorithms) and blockchain in the software sector can be impacted by nanofabrication solutions.

The **key nanofabrication technologies** associated to the Inclusive and Secure Societies sector covers a multitude of disciplines and are transversal to several different sectors. From the nanochemistry and nanomaterials approach, the highlights are bottom-up catalysis, synthesis and research of materials – catalytic, adsorption, thermoelectric and electronic, applications such as electrodes for water electrolysis, novel magnetic nanoparticles for biomedical area, more efficient thermoelectric for cooling, effective water treatment and monitoring technologies and inexpensive photovoltaic (PV) modules for clean energy, to name a few. Additionally, nano-coatings and thin films applied to surfaces to create or improve the material´s functionalities could also be applied to a multitude of areas that would have great impact in the Inclusive and Secure Societies Sector.



From the nanofabrication path, the main technologies are associated with MEMS and NEMS, spintronics, microfluidics, graphene and thin film semiconductors, energy storage, conversion and optical devices, lithography and advanced packaging. Still, in the nanofabrication for electronic components and systems, examples of key technologies are wearable and flexible electronics, that includes nanosensors applied to biomedical monitoring; graphene-based nanosensors; devices embedded in textile substrates for new generation of garments with distributed sensors and electronic functions. In the optoelectronics, the key nanofabrication technologies that deserves to be highlighted are optoelectronic devices for high energy efficiency; and optical and thermal properties in carbon nanotubes and graphene to establish a new class of electronic materials. Still, the manipulation of the magnetic and spintronic properties of matter at the nanoscale would allow applications in the computation and data storage area, as well as new technologies to exploit quantum behaviour for computing.



3 Estimated COVID-19 impact on target sectors

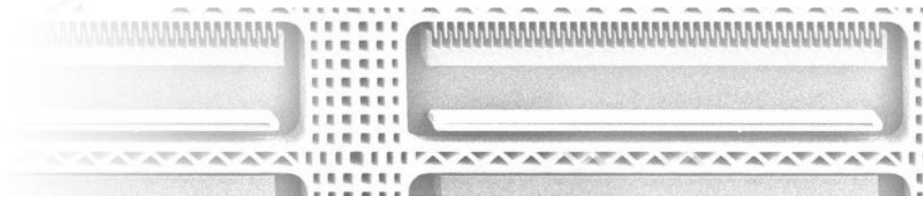
The COVID-19 crisis is expected to impact almost all industries and sectors around the world. However, according to Statista[12], the most impacted sectors will be manufacturing and travel and transportation, both of which are closely related to mobility sector. Besides, various nanotechnology products are available to equip people for combating COVID-19. For example, nano-fibres can be used to create filters for respirators or masks. Graphene, nanodiamond, polymer nanofibers (e.g., polyacrylonitrile), and nanoparticles such as silver, titanium dioxide, and copper oxide are commonly incorporated into these products to improve their efficiency. Other much-needed goods like air filtration systems containing high-efficiency particulate air (HEPA) filters play a crucial role in capturing bacteria, mold spores, and viruses in order to prevent airborne contamination in hospitals. Such systems are based on nanostructured absorbers.

Following (Baumgartner, Heid, Fleishman, & Freund, 2020), one of the main expected impacts on advanced industries is related to complex supply chains and their impact on the production and availability of certain models, as in the case of transport industry. The report points the importance of having a close relationship with suppliers to get information, monitor lead times and identify potential and future problems, and also to define recovery plans in case some critical supplier disappears. The less transparent the value chain is, the more difficult will be to anticipate disruptions. Anyway, (Hausler, et al., 2020) estimates that the standstill in OEM and supplier factories will reduce the production of vehicles in 7.5 million in 2020. And not only for private transport, public transport will also experience declines of up to 70%, and many other mobility players (carpooling and so) have already suspended their services.

According to the same authors, this crisis will make people to change their financial habits, postponing purchases and increasing their savings to anticipate harder times. Since the Covid-19 has also impact on the consumer behaviour limiting

---

[12] Projected coronavirus (COVID-19) impact index by industry and dimension-minor (1) to severe (5) in 2020. Available at: https://www.statista.com/statistics/1106302/coronavirus-impact-index-by-industry-2020/



personal contact, some industrial companies in mobility sector should reinforce their marketing online and sales channels to negotiate remotely. Anyway, dealership visits and test drives (frequent in automotive sector) may be challenging or even impossible with limiting personal contact. On one side, the changes in consumer behaviour are expected to increase private vehicles purchase to avoid public transportation in some countries (this seems to be the tendency in China during the first weeks after the Covid-19). On the other side, the new forms of work, such as remote work, could produce a reduction in commutes and a long-term decrease in vehicle miles travelled.

The expending cuts in companies may limit investments in new technologies (such as nanotechnologies) and processes, and the launch of costly new products. This could affect the autonomous vehicle testing or the advances in micromobility and shared mobility. Anyway, some authors such as (Hausler, et al., 2020) point the long-term consolidation of these forms of mobility since they support physical distance and will have an increasing attractiveness to investors. The authors also consider that the impact of Covid-19 on electric vehicles will differ across regions, increasing sales in China and Europe but with a stagnation in United States due to federal regulations about emissions and low oil prices.

In fact, the impact of regulation will depend on each country. Some countries could regulate to foster the sustainability of transport (increasing the use of electric vehicle or giving more space to pedestrians and cyclists), while others may relax the current environmental regulation to support OEMs. Europe is expected to lean towards the first option with a strict CO2 regulation, diesel ban in some cities and public incentives to purchase EVs.

COVID-19 has highlighted where our economic systems fall short and the weaknesses of our society; from the fragility of international supply chains, to the economic, environmental and health risks Europe suffers because of our dependence on fossil fuels and on critical raw materials.

An example of how the coronavirus pandemic is affecting the renewable energy sector is the wind turbine firm Siemens Gamesa Renewable Energy (SGRE). As announced in (Frangoul, 2020), the company has withdrawn financial guidance for the 2020 financial year. The company said "COVID-19 disruptions" in its supply chain, manufacturing operations, project execution and commercial activity had “primarily affected and adversely impacted the situation” in its onshore business.

The research and consultancy firm (Wood Mackenzie, 2020) points that as much as 150 gigawatts of solar and wind projects in the Asia-Pacific region could be either delayed or cancelled between 2020 and 2024 if the “coronavirus-led recession” continued past this year.

For PV thin film and catalyst systems fabrication strongly depends on materials supply chains as almost every critical material needed for their manufacturing come from different geographical sites: Si comes from China, Cu (Chili). The world sanitary crisis is fully affecting all supply chains; If modules manufacturing is delocalised on different regions, the PV fabrication will be less dependent on certain supply chains.

In general, more autonomy for European Energy production and in particular for renewable energy chain shall mitigate in the future the adverse effects linked to European dependence on Energy coming from fossil fuels.

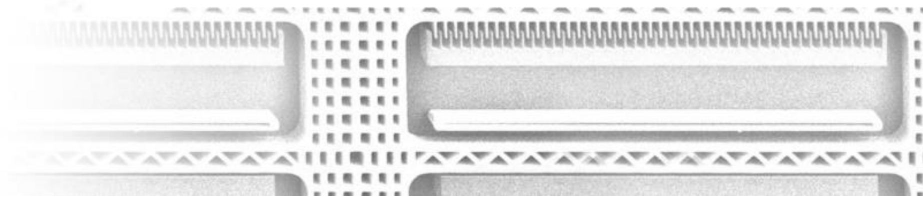
With the current pandemic of COVID-19, the need for sensor-based technology in health sector is of critical importance. The research around the technology pathways is there, but the technology has not been scaled or implemented into hospital supply chains. PCR takes too long and faster diagnosis is required. Days to minutes is a fundamental requirement to stop the infectious nature of the virus through contact tracing. This can only be achieved though the implementation of nanobiosensors, more robust, small integrated instrumentation tools and point of care diagnostics. It is expected that drug delivery systems will experience a growth due to the pandemic effect.

The COVID-19 virus outbreak, mainly, has been influencing food consumption and disrupted the supply chain. While at-home consumption showed a spike over the last months (to be highlighted an increase in e-commerce sales and grocery delivery), out-of-home food consumption showed an important drop. As out-of-home has historically generated the highest margin, this will have an immediate impact on the revenues of the food and agriculture sector. The supply chain changed drastically due to rapidly changing consumer behaviour and demand. Once the situation begins to normalize, and a series of rules in terms of safety will be defined, out-of-home consumptions will pick up again, but it is unlikely to be enough to cover lost sales in the coming months (Deloitte, 2020).   With countries going into lockdowns one by one, electricity demand around the world has been dropping. In particular, the industries involved in the exploitation of natural resources, such as oil gas and power generation from renewable, are suffering significant losses in revenues. The economic impact of COVID-19 in the natural resources sector will likely depend on the different countries' lockdown duration. As a result, new technologies may have a harder time getting financed, potentially delaying new projects that had planned to come online in the next years.

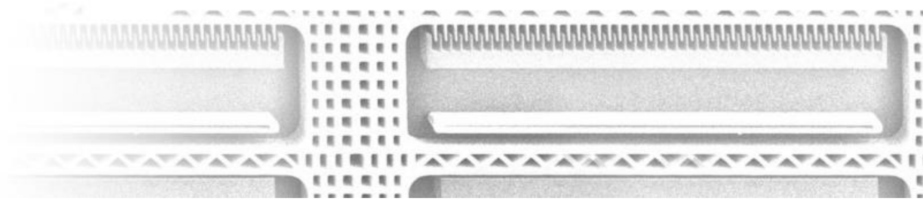
In Digital & Industry sector, the main effect of the COVID-19 crisis will be an acceleration of automation for industries that had already initiated a 4.0 transition. The nanoelectronics industry already operates in clean rooms, which has reduced the risk of virus transmission and maintained activity through a high level of automation. Many organizations will consider robotic process automation as an attractive response to the challenges posed by COVID-19 pandemic. In all sectors, investments in automation are expected to rise after the crisis.

With personnel and employees security being at the forefront of organizations’ concerns, security of goods and data has also been hitting headlines. For example, Zoom, one of the leaders in video communication, has been struggling with security issues as demand for videoconferencing dramatically increased during the COVID-19 pandemic. Many organizations compromised security over rapid response to the crisis, thus exposing themselves to potential security breaches. Should those temporary solutions become permanent, security protocols and associated hardware would need to be improved.

Finally, the estimated COVID-19 impact that nanofabrication could have in the Inclusive and Secure Societies Sector is aligned with the Disaster-Resilient Societies and the emergency response and protective equipment. It can be characterized in two approaches: Detection and rapid diagnostic technologies; and nanomaterials and technologies to enable a fast pandemic response. Potential nanofabrication solutions for the protective equipment are innovative face shields and goggles fabrication,



innovative filters for breathing masks, nanoenabled applications to provide new functionality for textile, and nanocoatings with long-term efficiency. Regarding detection and diagnostics, potential nanofabrication solutions identified are innovative devices for fast diagnostics, new optical instrumentation, microfluidic devices and biosensors.

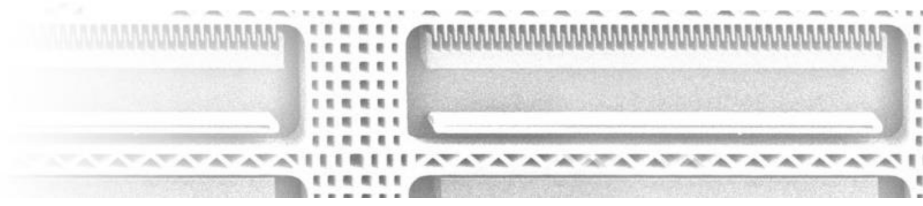


4 Drivers for the integration of nanofabrication in the European industrial ecosystem

The main drivers to foster nanofabrication in the European industrial ecosystem are classified in four different categories: scientific and technological, societal and environmental, economic and policy, regulatory and legal. In the first place, scientific and technological drivers are related to the increasing interest for new properties and functionalities, and for improving product and processes performance. Societal and environmental drivers point to reduce the environmental impact in manufacturing processes thanks to the incorporation of nanofabrication techniques, and also to reduce material consumption and to promote a sustainable use of the resources. For their part, economic drivers are focused in the cost reduction and substantial savings of using nanofabrication over other alternatives. And, finally, policy, regulatory and legal drivers see the regulation of sustainable production and consumption, and the environmental regulation as an opportunity to foster nanofabrication in the industrial ecosystem.

4.1 Scientific and technological drivers

The **increasing demand** for precision microscopes, electronics with higher functionality, and miniaturisation in general, is expected to push the commercialization of NEMs and MEMs sensors over the following years, especially in transport sector. The small mass and size of NEMS gives them many **unique attributes** offering immense potential for new applications and fundamental measurements. NEMS-based devices can now have fundamental frequencies in microwave range (approximately 100 GHz); mechanical quality factors in the tens of thousands, meaning low-energy dissipation; active mass in the femtogram range; force sensitivity at the attonewton level; and mass sensitivity up to attogram and subattogram levels (Singh R. , 2017). A key application of NEMS is atomic force microscope (AFM) tips which constitutes a huge driver for the development of NEMS for next years. Also, NEMS offers a solution to obtain **electronic devices with higher functionality** (closely linked with semiconductor market), which constitutes a driver for NEMS demand.



There are several technological trends that are expected to contribute to market growth for nanofibers (electrospinning roll-to-toll processes, portable nanofiber fabrication equipment, increasing interest for wearable electronics). Since 2000 to 2017 the **increasing number of patents** in nanofibers shows a raising interest in the development of this nanomaterial closely linked to electronics, sensors and transport sector in general.

Also, there is an **increasing number of publications** concerning nanotechnology for fuel cells between 2000 and 2016, which reveals a growing interest, specially led by Asian countries (more than 50% by China).

Total commercial **consumption of nanomaterials for battery** and other energy storage devices is expected to growth in next years to reach 4,916MT in 2023 (Pleutin, 2019). Rechargeable lithium batteries (Gen3, liquid electrolyte) are currently the main battery technology for mobility applications, while Gen4 (solid electrolyte) is considered to be the future technology. Lithium batteries are the major subject of industry investment, but performances such as energy density, power density and cycle life should be improved while cost should be reduced. Design and development of nanostructures materials-based electrodes and nano-enabled battery packaging are interesting approach to overcome the current limitations of li-ion batteries. In this sense, the low durability and high cost of fuel cell systems are the mains obstacles for large scale industrialisation. The develop of new nanomaterials with better performances is a critical part of an emerging fuel cell market.

In automotive sector, the use of nano-additives may ensure the requested **functionalities maintaining the high level of performance**. Nano-additives show higher interfacial interaction with the matrix polymer comparative to the micro contra-parts, enhanced nucleation capability determining changes in matrix crystallinity, all contributing to restricted mobility of the polymer chains and increased rigidity. With particular nano-additives balanced stiffness-toughness properties could be reached. Moreover, the nano-additives have similar size to the segments of the surrounding polymer chains, if properly dispersed, and enhanced adhesion to the polymer matrix, especially when surface treated, which contribute to less material removal in case of damage. The technique is known from many years but smart master-batches which can ensure the desired degree of additives dispersion at nano level, exploiting the synergy between additives in a very stable and reproducible manner is a trend of the last years and with really positive results as demonstrated in recent research projects.

For its part, printed electronics (PE) is set to revolutionise the electronics industry over the next decade and can offer Europe the opportunity to regain lost market share. Printed electronics allows for the direct printing of a range of functional (conductive, resistive, capacitive and semi-conducting) nanomaterials formulations. Nanoenabled materials fit with printed electronics to enable a simpler, more cost-effective, high performance and high-volume processing in comparison to traditional printed circuit board and semiconductor manufacturing techniques.

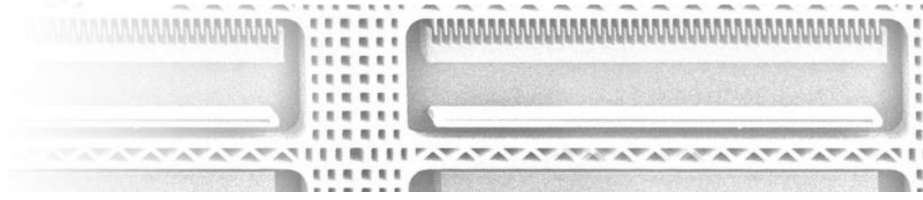
In energy sector, the main technological drivers related to **PV** are:

- Glass/glass thin-film technology, able to reach very high efficiencies and varying the glass substrate thickness and size on the same manufacturing line. The flexibility of the manufacturing process will allow the European photovoltaic industry to quickly adapt to the market needs, notably by proposing high-added-value and tailor-made products.
- CRM free thin film PV devices with acceptable manufacturing costs.
- CdTe solar cells are made through low temperature processes, which makes their production very flexible and affordable. CdTe currently has the largest market share of all thin-film technologies.

In relation to **Catalyst,** the main technological drivers to foster nanofabrication into energy industrial ecosystem are:

- Better understanding of size and shape effects of the nanoparticles and their interactions with support materials or stabilizing agent, could foster the upscaling of heterogeneous catalytic reactions.
- Homogeneity control: Catalyst dispersion and integration at local scale and into the 3D structure.

And finally, with **supercapacitors,** discovery of electrically conductive and high-performance MOFs could foster the upscaling of supercapacitors technology. Carbon based supercapacitors manufacturing is relatively low cost, compared to the MOFs



based one since the materials used to make it are more expensive than conventional carbon-based materials. Nevertheless, their performance is significantly better than that of carbon-based materials, and thus they could be useful for many applications: electrochromic windows, which can be darkened with the flip of a switch, and chemo resistive sensors, which could be useful for detecting trace amounts of chemicals for medical or security applications.

In health sector, there are several technological and scientific drivers to foster nanofabrication: the development of new nanonoparticles and encapsulation techniques for drug formulation, controlled release and targeted delivery, recyclable or incinerable materials for high-performance batteries and power sources, biodegradable and dissolvable materials for epidermal and implantable electronics, and ultraminiature and highly integrated sensors, substrates and systems for the future health and well-being technology integration.

4.2 Societal and environmental drivers

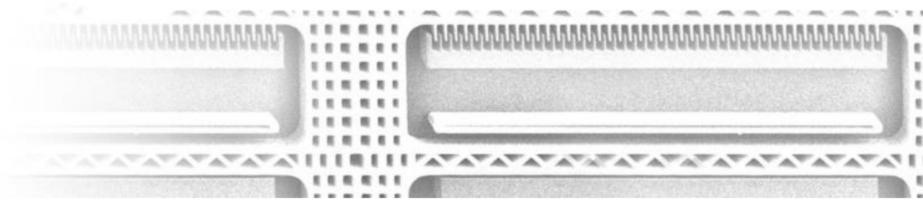
It is possible to **reduce the environmental impact** in the manufacturing processes of nano-enabled products for automotive and aeronautic industries, due to the reduction of raw material use, materials waste and energy consumption[13]. In this case, the introduction of nanofabrication techniques has a clear impact on SGD12: responsible consumption and production.

What is more, Open Innovation Test Beds act as a **catalyst for innovation** because the success of innovation in deep-tech innovation businesses like the ones involving nanotechnologies, requires the confluence of three dimensions –3Ms-: technology expertise (minds), management and smart capital from investors (money).

In energy sector, the main environmental driver is to **lightweight and to reduce material consumption**. In this sense, thin film PVs present efficient manufacturing processes and fast energy payback times. Thin film PV technologies contribute to a circular economy by providing a secondary use for mining by-products that would

---

[13] Source: Platform Project



otherwise be disposed of. Cadmium, gallium, germanium, indium, selenium, and tellurium are sourced as by-products from the production of aluminium, zinc, lead, copper and coal. Also, in catalyst, are the activities to foster hydrogen deployment as the ones foreseen in the Strategic Roadmap for Hydrogen and Fuel Cells as expansion of hydrogen mobility applications and deployment of stationary fuel cells, or demonstration project will increase **societal acceptance** of hydrogen with the final aim of achieving a global "hydrogen society". Regarding Supercapacitors, these are **safer** than Li-ion batteries as they have negligible risk of causing fire or explosion under impact. The active materials of present supercapacitors are based on porous carbon or carbon compounds, which are more abundant and are obtained with *lower environmental impact* when compared to lithium (Horn, MacLeod, Liu, Webb, & Motta, 2019).

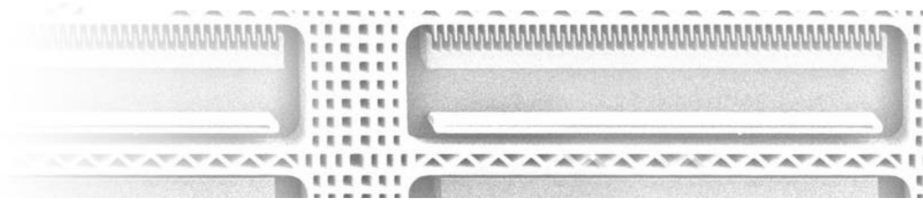
In health, there are significant benefits arising from increased patient adherence and better efficacy, also in the reduced usage of biopharma interventions through the use of closed loop systems. Also, personalised medicine empowers patients to be in more control of their health and wellbeing.

Finally, focusing the attention on food and natural resources, nanotechnologies could potentially drive a reduction of hunger and promote sustainable use of marine and terrestrial ecosystems.

4.3 Economic drivers

There are **multiple suppliers of semiconductors** materials for NEMS manufacturers, so their bargaining power is low, and it is expected to remain low during the next years guaranteeing competitive prices for manufacturers. At the same time, the increasing demand for NEMs is expected to improve the manufacturing process, leading to a **decrease in price** and the entrance of new players.

In mobility sector, the processes needed to coat the parts in an automobile with skins (PVC, TPO, etc) or to paint them are expensive. This implies an increase in energy consumption, special health and safety measures to be adopted and generates a lot of scraps. Replacing these coatings by nano-patterned surfaces guarantees a



significant weight reduction and an important **cost reduction** that would have a positive effect in the final price of the part.

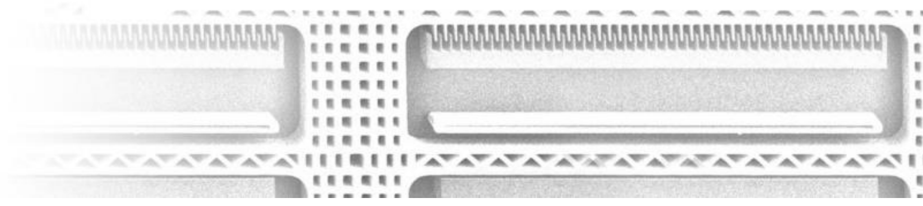
In energy, thin film PV are ideal for large scale solar farms, as well as Building Integrated Photovoltaic applications (BIPV) due to lower production costs of certain technologies (kesterites, perovskites …) Also, Perovskites cells have the potential to change the dynamics and economics of solar power because they are cheaper to produce than solar cells and can be produced at relatively low temperatures, unlike silicon. Thin film PV technologies provide the **greatest return on energy** invested as they require less energy during manufacturing (Bhandari, Collier, Ellingson, & Apul, 2015).

On the other side, novel and better performance catalysts will support the hydrogen development and deployment which can greatly help on climate mitigation and other environmental goals, energy supply diversification, and technological leadership.

Finally, greater market share for EVs, and increasing the economy of scale for their production, and the growth in the demand for electronic products including laptops and smartphones globally will drive the supercapacitors/ultracapacitors market during this historic period.

Application of nanotechnologies is at an early stage of development and this represents a driver for all future technologies and new industries including the food and natural resources. An added incentive to researchers and entrepreneurs developing applications is the curiosity shown in this field by medium and big companies with the aim to explore this growing market and to gain advantage against market competitors. The drive behind all these activities is the continued development of nanomaterials and the constant flow of new properties and capabilities that are intrinsic in nanomaterials and nanostructures. (Pitkethly, 2004)

These innovations appear to make possible an increasing number of applications for which nanomaterials can provide improved performance, competitive advantage and value creation (Matteuci, et al., 2017) For this reason, the food and natural resources nanotechnology sector shows a wide range of potential products and



applications with a low level of Technology Readiness Level. At this stage, the technology progress plays a crucial role by driving nanomaterials development for specific purposes thanks to the advances in computing power, modelling and design and characterization methodologies, in order to bring nanomaterials and nanoenabled solutions into commercial products.

Nanofabrication also offers economic advantages in health sector: for instance, the reduction on current hospital infrastructure and moving health from a reactive service system to a preventative proactive informing system. Also, substantial savings in national health budgets through better adherence, leading to remote healthcare delivery tools, reduced drug wastage, stable dosage regimes, fewer hospital visits and decreased incidences of secondary complications. There is also increased economic activity in fields of P4 patient care, artificial intelligence, personalised medicine, and high-value, low dose drug formulations.

4.4 Policy, regulatory and legal drivers

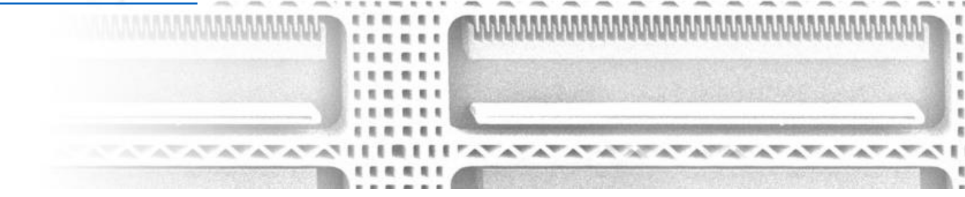
Due to the **environmental regulations**, the recycling of Metalworking Fluids (MWF) used in automotive sectors is being increasingly important, which constitutes an opportunity for nanofiltration techniques.

The directive for **sustainable production and consumption** for the prevention of Waste Electrical Electronic Equipment[14] is an opportunity to reduce the disposal of waste and to contribute to the efficient use of resources and the retrieval of valuable secondary raw materials.

In energy sector, **public financial support** for the PV sector, and incentives for consumers are expected to increase market penetration, although they are not mandatory to ensure the market feasibility of thin film technology. Policymakers have begun to incorporate PV LCA results in energy tendering systems. The French Environment and Energy Management Agency (ADEME) included carbon footprint

---

[14] Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE). Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02012L0019-20180704



assessment as a component in recent French PV tenders in order to stir up technologies with the lowest environmental impact. As a result, the carbon footprint advantage of thin film PV technologies is translated into increased business opportunities. An EU Ecolabel tool is currently being developed to help professionals and consumers assess PV technologies based on reliability as well as technical and environmental performance[15]

In addition, additional government regulation and policy support is important to incentivize an adequate market development for green/clean hydrogen production (Jensterle, et al., 2019). Hydrogen fuel cell deployment will come also by the identification of a range of legal and administrative barriers in the EU for the commercialisation of hydrogen and fuel cells. In this sense, JTI FCH projects as HyLaw,[16] will help to identify legal and regulatory barriers for hydrogen market deployment and provide recommendations for adjustments in the EU regulatory framework.

On a separate issue, supercapacitors are common today in solar panels and hydrogen fuel cells, car batteries, and all policies and regulation applied in the former will impact them.

Besides that, modern governmental policy is driving devolved **healthcare**, for example in remote medicine, self-administration, and smart medtech driven by artificial intelligence. This requires development of new drug formulations as well as highly miniaturised, closed-loop delivery devices. On the other health, commercial health insurers are increasingly moving to 'evidence-based' reimbursement strategies, i.e. where proof of patient adherence and/or associated health benefits are required before reimbursement is provided.

---

[15] More information available at: http://pvthin.org/life-cycle-analysis
[16] More information available at: https://www.hylaw.eu/

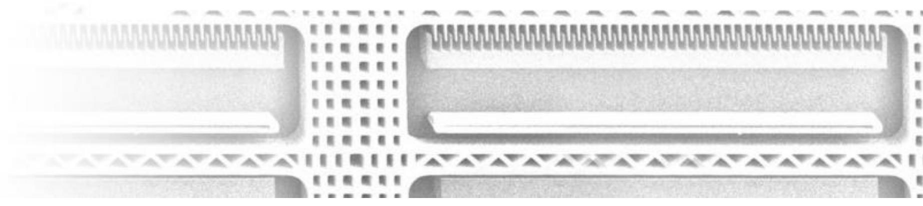
5 Main challenges for the integration of nanofabrication in the European industrial ecosystem

Even though la majority of technological challenges depend on the sector, there is a consensus about the lack of mass production techniques, the lack of nanoscale manufacturing capacity for some industries (e.g. electronic), and also about the difficulty to get a balance among precision, performance and throughput in other areas such as nanoenabled chemical and processing industry. Sometimes there is also a problem of inconsistency between results obtained in a laboratory level and the ones obtained when these materials are scaled to industrial levels. For their part, societal and environmental challenges for the introduction of nanofabrication are in the worries about the disposal and recycling of nanomaterials and in the lack of knowledge about the real effects of the use of nano techniques on human health and environment. In this sense, the public perception of nano still needs to be managed, and it is necessary to furnish citizens with more information.

Besides, from the economic and legal point of view, there is still room for improvement in the attraction of private capital and venture capital to nanotechnology investments, among other things, because it is necessary to bring the gap between research and markets in nano. Also, increasingly complex regulation is an important barrier to foster nanofabrication, especially in some sectors such as human health.

5.1 Scientific and technological challenges

The electronics sector has a critical leverage effect on other industrial and service sectors. In particular, the electronics industry plays a key role in Industry 4.0 and the energy transition. The future production of reliable, high performance and/or low power Integrated Circuits and systems will be made possible using nanoelectronics (NEREID PROJECT, 2014). Based on the SWOT analysis carried out by the Electronic Components and Systems European Industry in 2019, the major weakness of the electronics industry is the **lack of nanoscale manufacturing capacity.**



As defined in the framework of the IPCEI (Important Project of Common European Interest) to support research and innovation in micro-/nano-electronics[17], the nano-electronics main technical challenges are the following:

- Energy efficient chips: developing new solutions to improve the energy efficiency of chips. These will, for example, reduce the overall energy consumption of electronic devices;
- Power semiconductors: developing new technologies of components for smart appliances, to increase the reliability of final semiconductor devices.
- Smart sensors: working on the development of new optical, motion or magnetic field sensors with improved performance and enhanced accuracy. Smart sensors will help improve car safety through more reliable and timely reaction to allow a car to change lanes or avoid an obstacle:
- Advanced optical equipment: developing more effective technologies for future high-end chips; and
- Compound materials: developing new compound materials (instead of silicon) and devices suitable for more advanced chips.

Similarly, the nano-enabled chemical and processing industry has the potential to answer global challenges in various applications. For example, self-assembly of block copolymers could be used to produce thin photovoltaic films, self-assembly of nanoparticles in monolayers to make nanoporous membranes and light-emitting diodes, nano surface structuring to provide antimicrobial properties, etc.

Finding the best compromise between high-precision, high throughput and high performance is one of the main challenges to be overcome by the nano-enabled chemical and processing industry. Other of the main challenges related to nano-enabled chemical and processing industry is associated to metrology[18], especially for quality control. Handling, measurement and control at the nanoscale are even more challenging that each nanoscale process is unique.

To bring these technologies to higher TRL, there is a need to:

---

[17] More information available at: https://ec.europa.eu/commission/presscorner/detail/en/IP_18_6862

[18] More information about metrology available at: https://www.lne.fr/fr/LNE-Nanotech

- Characterize the key parameters of nanomaterials (size, shape, charge, concentration, specific surface area, porosity, surface condition, etc.).
- Develop an appropriate metrology to contribute to the assessment of the risks associated with nanomaterials (exposure and toxicity) at different stages of their life cycle (production, use, end of life).
- Develop tools to characterize the properties of nano-devices (dimensional, electrical and thermal).
- Develop metrology for 2D and 3D material characterization.

From its part, NEMs must be **designed to perform** in short durations. Their expected life ranges from a few hundred thousand to many billions of cycles, thus putting heavy requirements on materials. On the other side, the surface-area-to-volume ratio in NEMS is large, and surface forces and viscous forces become very large compared with inertial and electromagnetic forces. There is a need for fundamental understanding of adhesion, friction, stiction, lubrication and surface contamination and environment on the nanoscale level. Besides, silicon is not optimal for all NEMs, and they will require new materials that can function in conjunction with silicon or alone (e.g quartz, graphene or ceramic). This is especially true for microfluidics and devices in harsh environments, and also for mechanical devices.

Furthermore, there is a **lack of mass production techniques** of NEMS. There are still some technological challenges to optimise NEMs production. This market is still a niche market and relatively new. NEMS can be manufactured in two ways: by traditional microfabrication (that lacks the quality to form very small structures),and a second process (that relies on the self-organising chemical property of single molecules to arrange themselves into a patter, in which the manufacturer loses control over the manufacturing process as it depends on the chemical property of the molecule used). The last option is a combination of both. The same problem, lack of mass production techniques, affects to nanofibers: production speeds need improvements and there are still high initial manufacturing costs.

Since 2008 there is a high increase of the number of publication patents in fuel cells, but the **technologies in fuel cells have still important progress to be made** (durability, cost, or reduction of critical raw material content such as Platinum Group Metal).

In automotive sector, regarding the nano additives, the main drawback the industry has faced so far is the **inconsistency between results obtained in a laboratory level and the ones obtained when these materials are scaled** to industrial levels because of the poor dispersion of these nano-additives in the thermoplastic matrix. The **lack of scalability** of available fabrication methods such as lithography and the **high cost of equipment** is a major hurdle for the true commercial exploitation of advanced nano-patterned surfaces for automotive sector.

In energy sector, Perovskites still face some significant challenges before achieving market maturity. One of the main ones is durability. Because the crystals dissolve easily in water, they are not able to handle humid conditions and need to be protected by moisture through encapsulation, for instance through an aluminium oxide layer or sealed glass plates.

Another challenge for scientists is that, whilst they have been able to achieve high efficiency levels with small perovskites, they have not been able to replicate such effect with larger cell areas.

The use of less expensive raw materials is another challenge for the upscaling of PV thin film systems that will enable reduced production cost to thrive their suitability for market applications requiring flexible and/or light substrates.

In fuel cell catalyst, there are three main technological barriers:

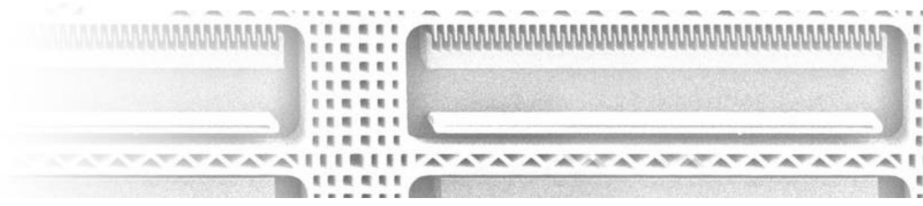
- The use of non-precious metal at the cathode for the Catalyst Development and Electrode Structure design is foreseen to provide the requisite activity and minimise losses (Othman, Dicks, & Zhu, 2012). So far, the precious metal catalysts (containing CRM as Pt) continue to be used for the cathode catalyst. The newer catalysts, iron-based nanostructures on nitrogen-functionalised mesoporous carbons are emerging as possible contenders for future commercial PEMFC systems thanks to improved performance and durability and reasonable electrocatalytic activity.

- Impurity, pollutants (e.g. SO_2 and NOx) in the flue gas that deactivates the catalyst.
- Stability and durability of the catalyst: Novel nanostructure supports may help to understand how to tailor catalyst support and active site structures to enhance its catalytic activity as well as stability.

Finally, in energy sector, as they charge and discharge very fast, high capacity supercapacitors could be a vital component in charging electric cars. MOFs have a major drawback for such applications: They are not very electrically conductive, which is also an essential property for a material used in a capacitor.

In health sector, the main tehnological challenges to introduce nanofabrication into the industrial ecosystem are in the scaling of volume production (MedTech requires small to medium volume manufacturing), testing, packaging and deployment from research-grade to mass market levels, and also in achieving sustainable, environmentally-friendly power sources for wearable devices powering and sustaining.

Finally, there is a big challenge for nanomaterials companies to provide the materials in volume to meet market demands, with the desired quality, economically and safely. One of the main barriers to be overcome for food and natural resources, and in general, for all nanofabrication sectors, is the development of large-scale production methods of products to mitigate the initial investment and to produce materials with nano-features in volume commercially at viable prices. The main challenge is to develop integration of materials and processing technologies for using nanomaterials in industrial production with an evaluation of the supply chain and the business model. For this reason, few companies in Europe are working exclusively on the nanotechnologies sector. At a European level, nanomaterials’ manufacturing does not reflect the global emphasis on this field, in particular, from the point of view of food and natural resources, it comes clear comparing the US with Europe. Another major issue is that the production site needs to be equipped with in situ monitoring (tolerances, characterization etc..) of the whole process in order to deliver high quality products with consequential higher costs in production (Chaditidis, Georgiou, Koklioti, TRompeta, & Markakis, 2014).



5.2 Societal and environmental challenges.

In energy, and more specifically in thin film PV, one of the main challenges is mitigating environmental effects by reducing waste: in this sense, Projects as the SPIRE EU project CABRISS[19] aims to develop a circular economy strategy mainly for the photovoltaic, but also for electronic and glass industry.

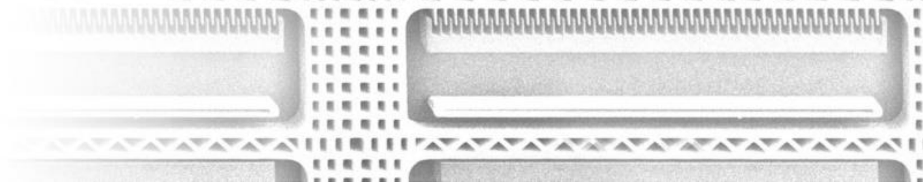
Nanotechnology may also have **negative impacts on human health and the environment.** Some nanomaterials such as nanofibers may pose health risks similar to asbestos Such effects are not yet understood, since the quantum mechanics regulating nanomaterials’ interactions with other substances also makes their toxicological behaviour difficult to predict. Further research is needed concerning the toxicological and ecotoxicological properties of nanoparticles, their uptake in the body, accumulation in tissues and organs, transport characteristics, exposure and dose/response data, their distribution and persistence in the environment Although food nanotechnology has immense benefits and potential, public perceptions, are generally negative signifying that there is much to be done to change mindsets (He & Hwang, 2016).

Nanoparticles or nanotechnology procedures may be used to make food products, food additives, and food packaging materials and agriculture nanomaterials to produce new and novel nanofood. While a lot has been written about the benefits of nanotechnology and nanomaterials in the food system, there is little research into the toxicological and possible hazards of nanofood.

From the aspect of the food industry, the inhalation and skin penetration are almost exclusively related to workers in the nanomaterials producing factories, but the main exposure of concern for final consumers occurs by ingestion. The presence of nanoparticles in food mainly occurs from direct contact of nanopackaging and food and migration of nanoparticles from nanopackaging materials

---

[19] More information available at: https://www.spire2030.eu/cabriss



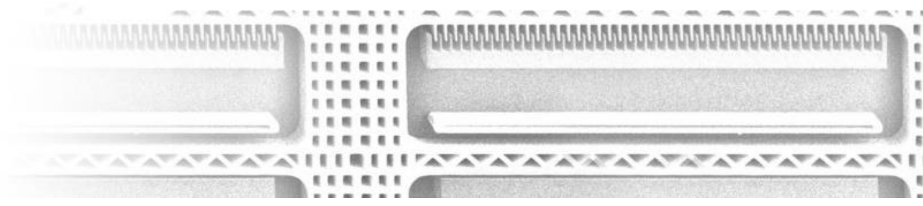
The environmental impact, **disposal and recycling of new materials** is also an important challenge for health sector, as well as the management of public perception of harmful nanoparticles in personal healthcare.

5.3 Economic challenges

The profit margins of MEMS sensor are declining due to increasing market competition and increasing applications. The declining cost has led to the consumer choosing the suppliers based on **costs rather than quality**. Also, the entry in NEMS market requires significant capital investment so small players are expected to enter through partnerships. Thus, for NEMS manufacturers, the best business strategy is to create partnerships with leading equipment manufacturers.

In energy sector, manufacturing CIGS cells can be difficult due to the scarcity of indium, as well as to the complex stoichiometry and multiple phases to produce them, hampering large-scale production in the near future (Cherradi, 2019). Also, for full-scale introduction of a commercial hydrogen supply chain in the future, a **feasibility study and assessment** should be conducted around 2025 with respect to the initial plan to reduce the cost of a hydrogen supply chain to a level comparable with the cost of fossil fuels. Finally, Improvements in efficient, scalable, and economical syntheses are needed to drive supercapacitor applications and their up scaling (Crane, Lim, Zhou, & Pauzauskie, 2017). In relation to cost reductions biomass waste could play a key role. According to Andrew Burke's investigation, in carbon/carbon SCs, the carbon is responsible for about 60% of the total materials cost, with the total electrode material cost around 0.1cent/F, whereas biochar-derived electrode material costs only around 0.001cent/F. Therefore, the use of biochar has the potential to create large profits as carbon materials cost reductions will increase SC applications. Using waste materials to fabricate electrodes is attractive because it does not only offer a solution for waste disposal, but it also provides a way to increase the economic viability of SC technology (Raza, Ali, Raza, & Kim, 2018)

Venture capitalist investment in nanotechnology companies has declined in recent years (Mc Williams, 2018). Some of the main reasons could be the generally



low level of interest among VC in material companies, the highly technical nature of nano business that make it difficult for some VC to understand it, or the unfavourable market realities of some of the sectors that nano business are targeting (e.g. memory).

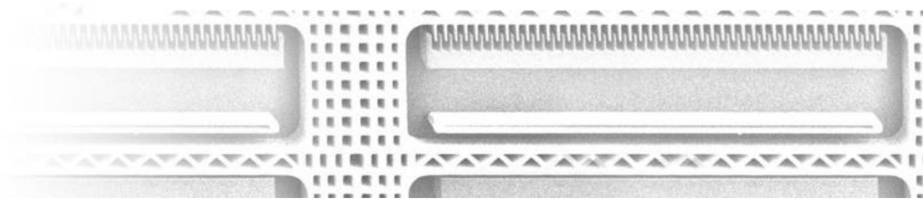
5.4 Policy, regulatory and legal challenges

In general, there is a big challenge into bringing the **gap between nanotech research and markets.** It is necessary to develop seamless integration of technologies and processing for using nanomaterials in production, to improve the control and monitoring of the conditions required for the use of nanomaterials in industrial processes, to increase the level of robustness and repeatability of such industrial processes; to optimise and evaluate the increased performance and functionality of the product as well as that of the production line in terms of productivity in actual operational environment. SMEs are particularly affected and are invited to participate, in order to develop and make use of the needed economic and knowledge and infrastructure capacity to carry out the required developments of process control, metrology and lifecycle analysis in-house, which represent critical steps before committing to pilot production.

Furthermore, all the devices with nanotechnology must comply with an **increasingly complex regulation**. For example, functional safety standards for electronic market, and for automobile industry. Since nanomaterials are regulated by the same health and safety regulations as macroscale products, it is important to maintain special care in design and manufacturing of products with nanoparticles that could be released into the human body. In same concrete cases, such as nanofibers, they are prohibited by **safety regulations** for certain uses.

Specifically, in energy sector, current political-legal barriers are preventing investment in the majority of European PV markets namely: lack of political commitment and effective incentive schemes; insufficient and disparate monitoring systems and lack of co-operation between key actors in the definition of political action, especially on the trans-national level. Eight national energy agencies of key “solar nations” (DE, FR, NL, AT, SL, PT, EL, ES) formed the "PV Policy Core Group" to define common actions for the improvement and alignment of national support systems for PV. Also, regarding to fuel cells, regulators and industry should jointly set out clear, long-term, realistic, and holistic decarbonization pathways for all sectors and segments. (Grand View Research, 2020). Also, in energy sector barriers can be found in catalysts since CCS is not politically accepted and leads to societal discussion as CO2 is still produced, but not emitted anymore. In this sense, too strict sustainability standards might slow down the development of a global clean hydrogen supply chain and hinder the development of nanocatalyst materials and systems.

Regulatory and legal barriers are especially intense in **health sector**: extensive clinical safety testing is required, particularly where nanoparticle-based drug formulations, both liquid and aerosol-based, are used. Besides, smart delivery systems will be viewed as combination devices and will require the full regulatory approval process before being approved for market. On the other hand, European regulatory bodies are gaining a reputation for becoming over burdensome with regulation.



6 Exemplary target products

Examples of target products of **high social and industrial impact** where nanofabrication could lead to major technological advancements and commercial competitiveness related to Inclusive and secure Societies sector includes the following:

- Nanostructured integrated circuits for sensors (e.g. health monitoring systems; miniaturized, portable and affordable biosensors for food safety authenticity and traceability of molecular biology; integration of sensors in the food value-chain with AI and blockchain technologies; sensors for air quality control; lab-on-chip devices);
- Wearable electronics for critical environments; (e.g. sensors embedded in clothes able to detect movements of the body in disaster events, such as earthquakes, floods, or fire).
- Unmanned vehicles;
- Monitoring systems for cyber security and disaster resilience approaches;
- Nano-enabled imaging systems for security applications (e.g. advanced X ray);
- Nanoscale 3D printing (e.g. to "build" materials for atomically precise sensors to the semiconductor and consumer electronic sectors);
- Nano-coatings to create and/or improve the material´s functionalities (e.g. antibacterial nanocoatings, anti-corrosion applications nanocoating with superconducting properties);
- Smart devices for impair or elderly population (e.g. sensors for smart home devices, motion sensors, wearable devices to control heart rate, respiration, restlessness)

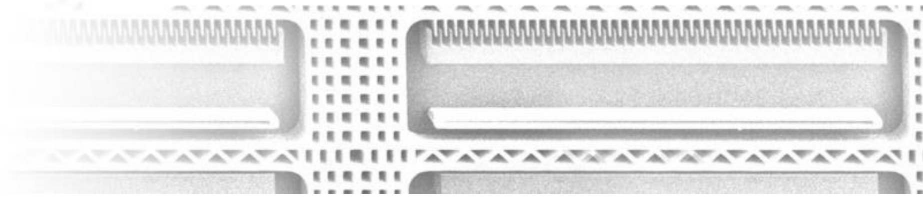
The information and communications technologies industry is one of the most relevant sector applying nanoenabled systems and technologies nowadays. Their applications could have a huge impact in the inclusive and secure societies sector, leading to faster, smaller, and more portable systems that can manage and store larger and larger amounts of information. Transistors, magnetic random-access memory (MRAM), ultra-high definition displays using quantum dots and flexible electronics illustrate some of the nano-applications in the ICT industries.

Specifically, in **mobility** sector there are numerous examples of products that contains nanotechnology: nanomanufactured engine components and batteries, embedded electronics and micro-sensors, carbon fibre moulds, chassis or hull components, composites for aircraft fuselage and wings, turbine parts, etc. Some of the most representative examples are:

- Nylon/Montmorillonite nanocomposite (Nylon 6-Clay Hybrid (NCH)), developed by Toyota in 1980, it is considered to be the first commercial nanocomposite (in the form of a timing belt cover for Toyota Camry in 1993). Now it has applications to reduce the rolling resistance of tyres, to provide ultra-hard protective coatings for paintwork, windscreen glass and headlamps
- ENVE composites, uses Zyvex Inc's Arovex carbon nanotube prepreg system to make high-strength wheels for its mountain bikes.
- Showa Denko's carbon nanofibers (SDK), used in the fabrication of lithium-ion batteries, manufacturing of supercapacitors[20] and fuel cells, electrically conductive paints and adhesives, and thermally conductive resin pastes.
- A123 Systems (USA) has introduced a line of lithium-ion batteries whose electrodes are fabricated from iron phosphate nanoparticles, using technology developed at, and exclusively licensed from the MIT..
- Kuraray and Ube have developed a multilayer tubing system for fuel lines with the commercial name Ecobesta-9T, that combines PA12 with polyamide PA 9T which is a fuel barrier material. Some of the features of the product include excellent cold impact and chemical resistance, superior adhesive strength with PA9T which has low permeability to gasoline and low monomer and oligomer elution.
- Bombardier C Series, Airbus A380 and Boeing B767 are equipped with carbon nanotubes composites to increase adhesive bonding.
- Structural nanoreinforced Al castings by HPDC process (Ford)

---

[20] Supercapacitors are used to protect electric vehicle batteries, to enhance vehicle performance and to harvest the energy generated from braking. The application of nanomaterials is to increase the energy density of the supercapacitors.



- Energy storage in prefabricated walls (Airbus)

In **energy sector**, a whole range of products only made possible by nanotechnology are already in the prototype stage or available on the market. For example, nanoporous antireflection coated solar glass, nanostructured LEDs, nano-additives for engine lubricants, nanoelectrodes for lithium-ion batteries, nanocrystalline magnetic materials for power electronics and nanoporous hydrogen storage materials, as well as nanocatalysts in fuel cells and industrial chemical production processes.

These can be high social and industrial impact products where nanofabrication can lead to major technological advancements and commercial competitiveness.

- Fuel cells: proton Exchange Membrane Fuel Cell (PEMFC) accounted for over 67.7% units shipped in 2019. PEMFC is widely used in applications, such as forklifts, automobiles, telecommunications, primary systems, and backup power systems. Versatility is a major factor slated to bolster their demand in the forecast period. Molten Carbonate Fuel Cells (MCFC) (Grand View Research, 2020)
- 3rd generation Thin film PV: perovskites, OPV, DSSC and Quantum dots PV
- Nanocatalyst

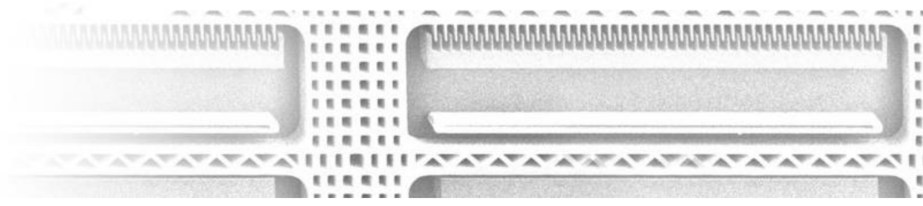
There are some interesting examples of nanofabrication in energy sector. The manufacturing process of thin film PV starts by depositing the thin photoactive film on the substrate, which could be either glass or a transparent film. Afterwards, the film is structured into cells similarly to the crystalline module. Unlike crystalline modules, the manufacturing process of thin-film modules is a single process that cannot be split up.

- The company Oxford PV presents the first manufacturing line for perovskite-on-silicon tandem solar cells.
- Together with leading photovoltaic equipment supplier - Meyer Burger, Oxford PV has installed a silicon heterojunction solar cell line, enhanced with production equipment for the perovskite top cell. The fully integrated line will be built at their industrial site in Germany and will commence production at the end of 2020.

In Catalyst, a MEA can be manufactured by the following three main methods: (1) catalyst coated membrane (CCM) in which catalyst layer (CL) are deposited onto a membrane directly; (2) decal transfer CCM in which coating CL is deposited on a substrate and then transferred onto a membrane; and (3) catalyst coated substrate (CCS) which deposits CL on a GDL. Depending on the type CCM or CCS, the deposition of the catalyst layer can be done by screen printing, doctor blade, inkjet, ultrasonic spraying, sputtering, dual ion beam assisted deposition. When dealing with ink-based technique, the first step is to prepare the catalyst ink. It consists of mixing a carbon-supported Pt catalyst, isopropyl alcohol and an ionomer solution in H+ form, and thereafter the catalyst ink is deposited. One of the objectives is to obtain a MEA with a low Pt content without sacrificing the cell performance. Therefore, it is very important to decrease the Pt catalyst loading to reduce the cost of the anode and cathode electrodes. The objective is hence to reach a microstructure: a nanocomposite material consisting of carbon nanoparticles (30-50 nm) supporting Pt or Pt alloy nanoparticles (2-10 nm) and covered by a thin layer (5-15 nm) of ionomer binder, but it is also a porous material with some pores larger than a hundred nanometers

Finally, to decrease ionic impedance of supercapacitors the use of nanostructuring is promoted, with for example arrays of pores. Production of naturally porous graphene with high surface area from silicon carbide thin films for energy storage at the wafer-level is used by several organisations. Griffith and Queensland in Australia, South Florida University (US) and The Plasma-Therm LLC and Air Force Research Laboratory in the US demonstrated an approach for producing naturally porous graphene in ‘the first attempt to produce graphene with high surface area from silicon carbide thin films for energy storage at the wafer-level. (Ahmed, et al., 2015) suggest the method may open numerous opportunities for on-chip integrated energy storage applications.

Other nanostructures besides pores and arrays have also been exploited as nanowire structures to maximise the surface area (Ren, et al., 2015) .Surface area tends to be directly related to an increased capacitance or energy density, and in graphene all atoms are surface atoms. Researchers at the Beijing Institute of



Technology in China and the Helmholtz-Zentrum Dresden-Rossendorf in Germany review some of the advantages posed by what they describe as a 'fascinating material'—graphene fibres. The benefits they list include a 'unique and tuneable nanostructure, high electrical conductivity, excellent mechanical flexibility, light weight, and ease of functionalization (Chen, Liu, Zhao, Chen, & Qu, 2016).

The environmental motivation for supercapacitor research has also encouraged an impressive resourcefulness for sustainable synthesis of supercapacitor materials. Promising supercapacitor properties are freeze drying nitrogen-doped porous carbon cryogel (Ling, y otros, 2015), as well as the production of activated carbon—the most common material for electrochemical double layer capacitors—from bark and coffee grounds (Luo, y otros, 2015).

In health there are important target products such as medical implants, bioprinted living tissues, new formulations for transdermal drug delivery, including transdermal patches, cosmetics and topically applied medications, ultraminiature batteries for high-performance, wearable systems, new drugs for nebuliser-based drug delivery, biodegradable materials for tattoo-like ‘personal electronics, and nanoscale sensors and actuators for closed-loop, wearable health devices, among others.

BIOSENSORS	RubyNanoMed
	Cellix Bio
	Patsule
SMART DRUG DELIVERY	West Pharma Onedose
	BD Libertas Autoinjector
IMPLANTABLE	Radiation/Radfet Implantable Sensor
	Endotronics blood pressure
	Boston Scientific Pacemaker
	Medtronic GERD
WEARABLES	PMD respiratory patch
	TevaPharma Smart Inhaler
	Aerogen Nebulisation Technology

Figure 12. Examples of nanoproducts in health sectorSource: SUSNANOFAB.

In food and natural resources, these could be some of the main target products:

- Food packaging with added functionalities
- Monitoring of food and natural resources by smart sensors
- Water decontamination
- Precision agriculture and breeding
- Plant and animal health

- Bio-based materials and bio-fuel production
- Food processing to improve nutritional values

In the food industry some of the nanoenabled applications are in smart packaging to improve quality and safety and prolong shelf-life of products; nanofilters for beverage and drink filtrations, wastewater management and cleaning processes; novel ingredients with specific functionalities and properties aiming an improved nutrition. Recently, food packages produced with nanoparticles, "nano-food packaging," have become more available in the current market; for this reason, several industries are working on the development of products that -thanks to the addition of nanoparticles- can supply improved performances. For example, Durethan® polymers (available from Lanxess Deutschland GmbH), a combination of engineered plastic polyamide 6 (nylon 6) and nanoclay, are transparent composites for the barrier film and coating in packaging (Bumbudsanpharoke, 2015). They can be applied in various areas of packaging, from ordinary foodstuff to the medical field since the clay nanoparticles are dispersed throughout in a polymer matrix, providing excellent properties of gas and moisture barrier, strength, toughness, and abrasion and chemical resistance.

The nanotechnologies application shows a potential in the development of smart sensors that can be directly integrated in the item that it's necessary to monitor, it is the case of the chemical sensors based on carbon nanotube. An example of this application comes from PROTEUS[21], a project started in 2015 and funded under the H2020 framework program for research of the European Commission. The project delivered an autonomous, highly multifunctional MEMS- and nano-enabled sensor node for adaptive and cognitive drink and water quality monitoring.

---

[21] More information available at: http://www.proteus-sensor.eu/

Figure 13. Commercial adoption examples of the quantum dot technology Source: (Ghaffarzadeh, 2020)

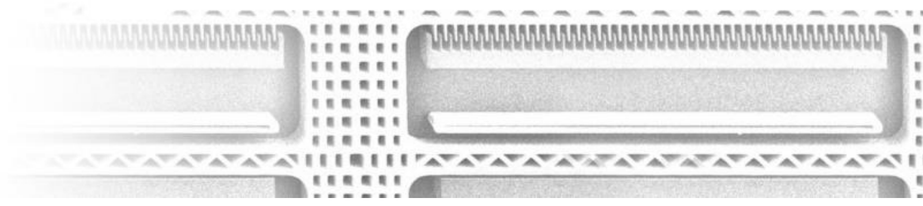
There are interesting examples of nanofabrication in Digital and Industry sector:

- Tyndall FlexiFab. Tyndall National Institute is home to a high-tech national research infrastructure unique in Ireland and is a national research asset. Hosting the only full CMOS, Micro-Electronic-Mechanical Systems (MEMS) and III-V Wafer Semiconductor fabrication facilities and services in Ireland.
- NanoMat Nano-Enabled Printed Electronics Pilot Line. Nano-Enabled Printed Electronics offer a wide range of functionalities (smart tags and sensors, transistor, etc.) on flexible surfaces. NanoMat (KIT, Germany) is equipped with an advanced Nano-Enabled Printed Electronics Pilot Line.
- Avantama nanofabrication of quantum dots through nanoparticle engineering
- INL Micro and Nanofabrication Facilities. The INL cleanroom facility offers micro- and nanofabrication solutions on substrates from 200-mm-diameter wafers down to samples below 10 mm in size, some of which are performed in multi-project wafer (MPW) formats. This facility provides support throughout all the development chain in cleanroom processes: device modeling and design, process integration and device fabrication, packaging and testing. Technologies available include: Advanced Si micromachining, MEMS and NEMS, processes for spintronics, sensors, and hybrid devices, microfluidics;

thin-film silicon electronics, nanostructuring methods for solar cells and other devices, fabrication of flexible substrate systems, laser microstructuring, interconnects and packaging.

- TECNALIA buckypapers continuous manufacturing line. The first European buckypapers continuous manufacturing plant, sheets made up of carbon, based on a safe-by-design concept.
- IPC pilot line for multi-nanolayering. The multi-nanolayering process produces films with specific properties (optical, barrier properties, etc.)

The Digital and Industry market sees, for example, the fabrication of nanostructured semiconductors, flexible electronics, flat panel displays, MEMS, Micro-Opto-Electro-Mechanical Systems (MOEMS), inkjet print heads, smart manufacturing machines and advanced sensoring units, nanocomputing (i.e.), internet of things devices for manufacturing environment and consumer applications, lightweight and multi-functional components for space industries and other high demanding manufacturing sectors among others.



7 The view of the nanotechnology experts

To contrast the desktop research made to elaborate this document, 22 interviews have been done between May and August 2020. 27% of the answer came from RTOs, 45% from companies, 23% from universities of basic research centers, and 5% from public agencies. There is a list of detailed profiles with job title, country, gender and type of stakeholder in Annex "*Information about interviews*".

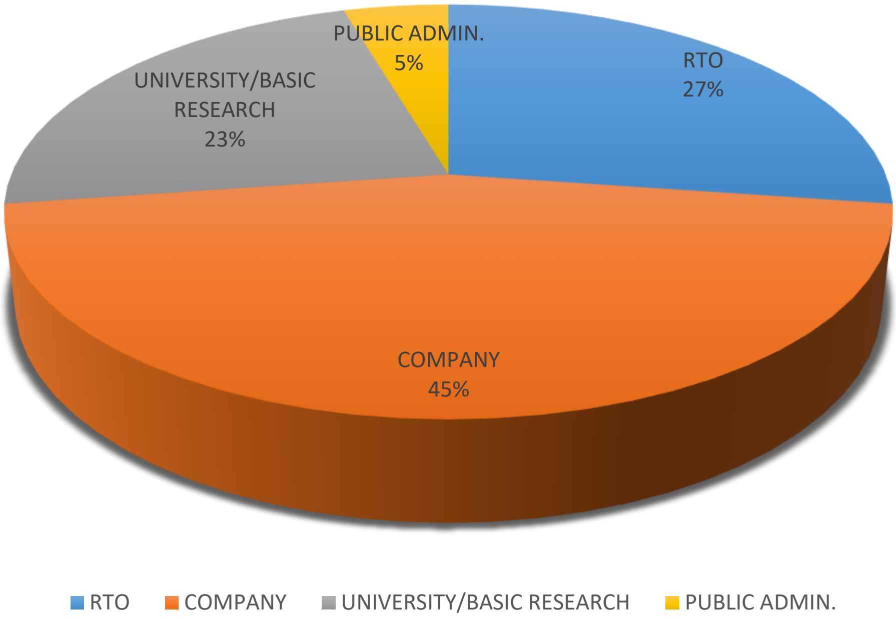


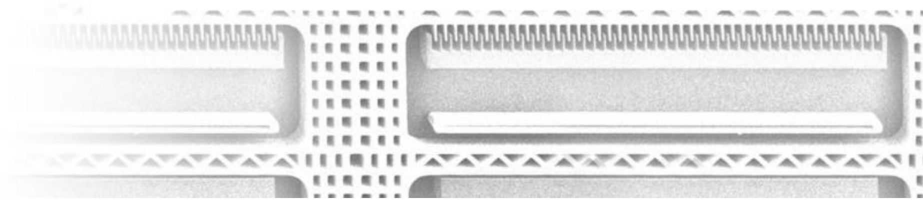
Figure 14. Type of stakeholders consulted in the interviews. Source: SUSNANOFAB

Barriers

The majority of nanotechnology experts consulted (60%) points the **lack of information and communication** as the main barrier to introducing nanofabrication in the European industrial ecosystem. In their opinion, there is still a very high level of reluctancy and ignorance both in industry and in society about what nanotechnology is and which are its potential applications. On one hand, there is a complex terminology that overwhelms and makes society dizzy; on the other hand, it seems to be a lot of information but little concrete, which creates the feeling of difficult application of nanotechnology in the industrial processes. Besides, industry, the potential user of nanotechnology, has an important lack of knowledge about the safety and guarantees of implementation, which produces fear and rejection. In this sense, some experts affirm that the social reluctancy is one of the main problems for nanotechnology upscaling. Also, the lack of safety regulations affects the confidence of industry and society in nanotechnology, and this is even more relevant in some areas such as medical and automotive sector where safety is a critical aspect and the manufacturing processes are highly structured and regulated. In the words of an expert consulted: "*we have been working metals for more than 2,000 years, plastics for more than 100 years, we feel comfortable when we process these materials, but we have only been knowing about the nanomaterials and nanofabrication the last 20 years only. We need time*."

In fact, most experts (53%) agree that **safety issues** are an important obstacle to introducing nanofabrication in the European industrial ecosystem. Even some of them consider that the lack of safety is more a perception than a reality, there are concrete topics that are not already solved. For example, recycling issues of wastes associated to the use of nanoparticles are an important obstacle to introduce nano in the conventional manufacturing processes, because there is a lack of knowledge about what to do with them at the end of their life cycle. In this sense, technical solutions to identify and separate nanoparticles at the product's end-of-life would facilitate the uptake of nanofabrication.

All this reluctancy impacts also in the **economic aspects** of nanofabrication. The investors, especially the private ones, do not want to put money on issues that society perceives with a high degree of uncertainty. Because of that, 46% of the consulted experts point economic issues as one of the most important barriers to introducing nanofabrication in the industrial ecosystem. For SMEs, investments could be too high and technological complexity could make the adoption unaffordable, so mechanisms to help them to access the funding and infrastructures are particularly valuables, especially at regional level. There is an important consensus that the added value provided by nanotechnologies should be perceived as high enough to cover the costs associated to raw materials and transformation processes.



Both, safety and cost perception are closely linked to **regulatory issues**, that are considered to be very important by 40% of those interviewed. In this topic there is an apparent paradox: some thinks that some aspects are too regulated, and others think that there is no sufficient regulation. On one hand, regulation seems to be strict in some issues such as the sale of big quantities of nanoparticles, on another hand, a lack of safety regulation is perceived in concrete areas such as medical sector, where safety is a critical issue.

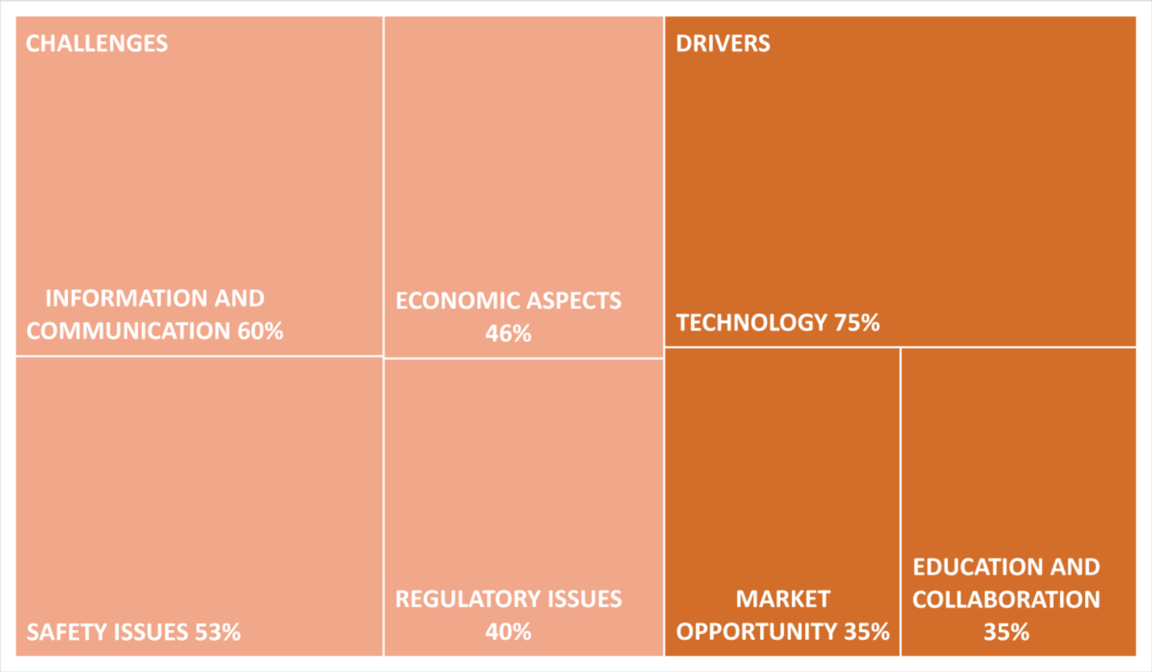


Figure 15. Main challenges and drivers pointed out by the experts consulted (% of experts). Source: SUSNANOFAB

Drivers:

More than 75% of the interviewees coincide in mentioning specifically the **technological driver** as the most relevant to promote nanofabrication in the European industrial ecosystem. There is a clear consensus that the exceptional nature of nanotechnology can bring high added value, improvements of performance, safety and sustainability, and differentiation both to products and to industrial processes, adding extra functionalities (i.e. more resistance to overheating) and new properties. Also, nanotechnology can solve problems that cannot be solved using conventional techniques offering new and innovative solutions.

Other important driver mentioned by more than 35% of experts is **the economical.** There is a market opportunity of using nanofabrication because in some cases is the only way to get specific properties in a product or a process. Besides, nanofabrication can bring an improvement in the final cost of the products and can have an impact in the final sales increasing the business value proposition. The same percentage of experts (35%) indicate the **communication, education and collaboration** as important drivers to increase the level of acceptance of nanotechnologies and nanofabrication. On one hand, the acceptance of society is critical to foster nanofabrication in the European industrial ecosystem; on the other hand, technicians and students need to be formed to increase the general understanding of nanotechnologies in business and technological ecosystem. In this sense, some experts underline the importance of having a holistic vision of the ecosystem to foster nanofabrication; not only companies, not only market, but the whole ecosystem.

Measures suggested by the experts interviewed

According to the experts, European society in general and the industrial ecosystem in particular need to be **less risk averse and learn to tolerate the failure**. The attitude is fundamental to have good ideas and taking them to the market. Europe need to be more technological ambitious and change the traditional culture. This change in the culture is closely linked to a more intense presence of venture capital in specific nanotechnology projects and new companies.

International cooperation in **regulatory issues** is also needed, because standard harmonisations and a common reference framework could ensure a higher level of confidence in nanotechnology, and also, can guarantee environmental and health safety aspects, that are some of the main barriers for companies and also for society. Clear and controlled regulations can help to restore user's confidence. Besides, this international cooperation should extend to increasing industry partnerships and engagement in common projects.

Other important suggested measure is related to improve the **communication and dissemination** of the advantages of nanofabrication since, in general, European industry has an important lack of knowledge about its potentialities and benefits. The European Commission should dedicate more efforts to bring the potential of nanofabrication closer to the industry; in this sense the arguments for expanding nanofabrication could be e.g. cheaper production processes, higher efficiency and optimized use of resources, better properties, or less resource consuming process, among others.

Also, **communication to the society** is important for it to understand and to better know the benefits of using products with nanotechnology, because, if society perceive nanomaterials as beneficial products, then it will help to implement favourable policies for their market uptake. To get that, it is important to stop talking about "theoretical nanotechnology" and go down to the reality of concrete technologies and their applications in the day to day social and industrial applications.

Other important measure concerns to **education**. European society and industry are still nano illiterate, so it is important to make a global effort to introduce nano in the educational agenda as part of the scientific and technological curricula.

Cost effective production, regulatory clarified environment, public awareness of nanotechnologies and all the mentioned measures have a great potential for societal and environmental welfare, and also for employment and economic growth. Both nanofabrication and nanotechnologies should be viewed as vehicles of competitiveness for Europe and prosperity for the whole of European society.

8 Conclusions and Recommendations

The development of nanofabrication can be an important incentive to foster a digital and sustainable European industry for next years and to position Europe as a leading location for the production of innovative products with nanotechnologies. Also, nanofabrication can be a source of high skilled employment in Europe and the way to improve the European productive system increasing the global competitiveness in face of other competitors such as USA or some Asian countries. This is especially important now, when Europe is more aware than ever of the need to promote a digitised and sustainable industry, to make the territory more resilient against current crisis -such as that of COVIC-19- and future ones.

The introduction of nanofabrication into the European industrial ecosystems depends on both technological improvements and also, on non-technological issues such as the concerns about safety, regulation, education and skills, cost reductions, market acceptance and others. Besides, each considered sector has some specific barriers and drivers in the very nature of the sector, that also should be considered.

In this sense, there is a certain consensus in the prioritization of drivers and challenges carried out in the desktop research, and the opinion of the experts consulted in the course of this task. Thus, both agree that the main driver for the introduction of nanofabrication in the European industrial ecosystem lies in the advantages derived from the use of the technology itself to improve functionalities, properties and general performance. Also, the introduction of nanofabrication can help to achieve the sustainability targets defined by the European industrial strategy, since nanofabrication can reduce material and energy consumption and also can promote a rational use of resources.

And not only in terms of environmental sustainability, but also in economic aspects can nanofabrication improve the actual situation; the introduction of nanofabrication has the potential to reduce the cost of industrial processes, to improve sales figures and to open new market opportunities.

Furthermore, nanofabrication has to face important challenges to realise its full potential, as the lack of scale capacity in certain areas, the lack of private investors and the reluctancy that comes both from industry and from society. This lack of knowledge about the advantages of nanofabrication is perceived by the experts as one the biggest barriers to introduce nanofabrication in the industrial ecosystem. For its part, there is a certain duality in positions on regulation: regulation is considered to be a barrier to the fully implantation of nanofabrication, but, on the other side, It is recognised that there are aspects that need to be regulated for the industry and society to fully accept nanotechnology,

Research and development activity is crucial to foster nanofabrication and to increase the potential of nanotechnology to replace conventional technologies offering more functionalities and solutions that are not possible with current knowledge application. However, it is also important to work to fill the gap between research and market, and between research and society: the lack of knowledge, the lack of communication education, the fear of the unknown, the lack of a standardised legal framework to give confidence and trust, and the absence of citizen involvement in nano issues are, all of them, factors as important as the technology itself, and all of them necessary to guarantee a successful introduction of nanofabrication in the European industrial ecosystem.

Annex. Information about the interviews

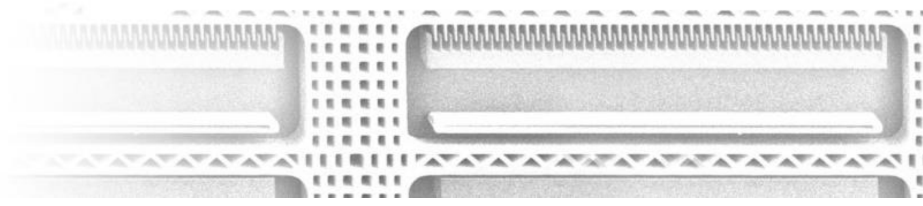
The interviews for this task were conducted from May 2020 to August 2020. The semi-structured interviews were conducted via telephone or via telematic channels (Skype, Zoom and Teams) by SUSNANOFAB partners, and the conversations were guided by a formal **questionnaire** with the following questions:

- What is the main market sector your organisation is engaged in?
- Do you currently manufacture or use nanomaterials or nanofabrication techniques in any of your products or services? If yes, what products/ services. If no, are you considering using nanomaterials or nanofabrication techniques in your products or services?
- If previous answer is no: Is there a reason why you do not use nanomaterials/ nanofabrication in your products or services?
- What are your current target areas for R&D or product development in which nanomaterials or nanofabrication could be used?
- What would you say that are the main consideration that would stop or slow the use of nanomaterials/ nanofabrication in your sector?
- What would you say are the main drivers for the use nanomaterials/ nanofabrication in your sector?
- Can you give us some examples about exemplary target products in your sector, in which nanotechnology has already been integrated?
- In your opinion, what would the market/ technological/ regulatory/ conditions need to be to help improve the rate of uptake for nanomaterials/ nanofabrication and who would you look to help deliver the right conditions?

Although the result of the interviews is offered in an anonymised form. The profile of the interviewees is indicated in the following table:

TYPE OF STAKEHOLDER	JOB TITLE	GENDER	COUNTRY
ASSOCIATION	CEO	FEMALE	BELGIUM
COMPANY	CEO	MALE	SPAIN
RTO	CEO	MALE	AUSTRIA
COMPANY	FOUNDER	MALE	SPAIN
RTO	HEAD STRATEGY	MALE	SPAIN
COMPANY	TECHNOLOGY DEVELOPMENT MANAGER	MALE	PORTUGAL
COMPANY	PRESIDENT	MALE	FRANCE
RESEARCH CENTER	PROFESSOR	MALE	SPAIN
COMPANY	PRONCIPAL RESEARCHER	MALE	SPAIN
COMPANY	SCIENTIFIC DIRECTOR	FEMALE	SPAIN
RESEARCH INSTITUTE	DIRECTOR	MALE	FRANCE
INDUSTRY ASSOCIATION	GENERAL DELEGATE	FEMALE	FRANCE
CLUSTER	GENERAL MANAGER	MALE	FRANCE
PUBLIC AGENCY	MANAGING DIRECTOR	MALE	UNITED STATES
RTO	CENTER COORDINATOR	MALE	POTUGAL
UNIVERSITY	PROFESSOR-HEAD OF RESEARCH UNIT	MALE	AUSTRIA
UNIVERSITY	SENIOR SCIENTIST	FEMALE	AUSTRIA
RTO	SENIOR SCIENTIST	FEMALE	GERMANY
RTO	PROJECT MANAGER	MALE	GERMANY
UNIVERSITY	PROFESSOR	MALE	USA
COMPANY	R&D MANAGER	MALE	FRANCE
COMPANY	TEECHNICAL DIRECTOR	MALE	IRELAND

Figure 16. Profile of the international experts consulted from May to August 2020. Source: SUSNANOFAB



References

Ahmed, M., Khawaja, M., Notarianni, M., Wang, B., Goding, D., Gupta, B., . . . Iacopi, F. (2015). A thin film approach for SiC-derived graphene as an on-chip electrode for supercapacitors. *Nanotechnology 26(43)*.

Alexander, M. (2017, February 23). *Smart strategies for smart sensors.* Retrieved from Roland Berger: https://www.rolandberger.com/en/Publications/Smart-strategies-for-smart-sensors-2.html

Alsen, E. (2019, November 14). *Carbon Taxes in Europe*. Retrieved from Tax Foundation: https://taxfoundation.org/carbon-taxes-in-europe-2019/

Anguselvi, V., Masto, R., Mukherjee, A., & Singh, P. (2019). CO2 capture for indsutries by algae. 10.5772/intechopen.81800.

Baumgartner, T., Heid, B., Fleishman, J., & Freund, H. L. (2020). *Coronavirus: a response framework for advanced industrial companies.* McKinsey&Co.

BCC Research. (2018). *MEMs: biosensors and nanosensors market.* BCC Research. Report Code IAS027E.

Bernhart, W., & Riederle, S. (2019). *Time to think smart. Uncertainties signal a need for new approaches to mobility.* Roland Berger GMBH.

Bernhart, W., HAsenberg, J.-P., Karlberg, J., & Winterhoff, M. (2018). *A new breed of cars. Purpose-built electric vehicles for mobility on demand.* Roland Berger GMBH.

Bernhart, W., Olschewski, I., Burkard, C., & Yoon, M. (2018). *Automated vehicles index. Q4 2017.* Munich: Roland Berger GMBH.

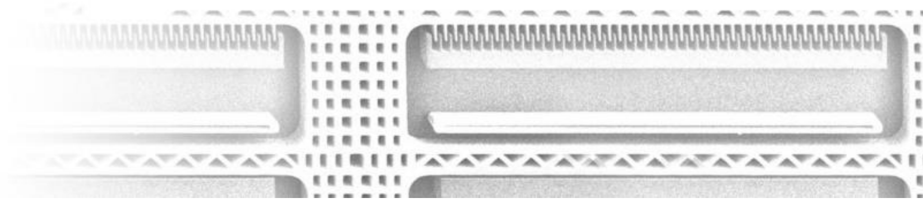
Bernhart, W., Olschewski, I., Busse, A., Riederle, S., G, P., & Hotz, T. (2019). *E-mobility index 2019.* Roland Berger GMBH.

Bhandari, K., Collier, J., Ellingson, R., & Apul, D. (2015). Energy payback time EPBT and anergy return on energy inested EROI of solar photovoltaic systems: a systematic review and meta-analysis. *Renewable and sustainable energy reviews,vol 47*, 133-141.

Bumbudsanpharoke, N. K. (2015). Nano-food packaging: an overview of market, migration research and safety regulations. *Journal of food science, 80*.

Carlson, E., Kopf, P., Sinha, J., Sriramulu, S., & Yang, Y. (2005). Cost analysis of PEM fue cell systems for transportation. *Natl. Renew. Energy Lab*.

Chaditidis, C., Georgiou, P., Koklioti, M., TRompeta, A., & Markakis, V. (2014). Manufacturing nanomaterials, from research to industry. *Manufacturing Rev.1 11*.



Chen, L., Liu, Y., Zhao, Y., Chen, N., & Qu, L. (2016). Graphene-based fibers for supercapacitor applications. *Nanotechnology, vol 27, numer 3*.

Cherradi. (2019). Solar PV technologies. what's next? *Becquerel Institute Brussels*.

COM(2019) 640 final. (2019, December 11). Communication From the Commission. The European Green Deal. Brussels: European Commission.

COM(2020) 456 final. (2020). *Comminication from the Commission to the European Parliament, the European Council, the Council, the European Econmic and Social Committee, and the Committee of the Regions. Europe's moment: repair and prepare for the next generation.* European Commission.

COM(2020)102final. (2020). *A new industrial strategy for Europe.* Brussels: European Commission.

Costentin, C., Robert, M., & Saveant, J.-M. (2013). Catalysis of the electrochemical reduction of carbon dioxide. *Chamical Society Review, issue 6*.

Crane, M., Lim, M., Zhou, X., & Pauzauskie, P. (2017). Rapid systems of transition metal dichalcogenide-carbon aerogel composites for cupercapacitor electrodes. *Microsystems and Nanoengineering 3*.

Deloitte. (2020). *Understanding the sector impact of Covid-19. Consumer products: food and beverage.*

Ding, B., Yu, J., & Wang, X. (2019). *Electrospinning: nanofabrication and applications.* ISBN 978-0-323-51270-1.

Dressler, N. (2019, October 7). *Global mobility trends and emission requiremens will bring unknown challeges for the automotive industry - an interview.* Retrieved from Roland Berger: https://www.rolandberger.com/en/Point-of-View/New-mobility-The-radical-transformation-of-an-industry.html

ECS. (2019). *Electronic Components and Systems. Strategic Research Agenda 2019.* AENEAS, ARTEMIS and EPoSS.

European Commission. (2018). *Smart sustainable mobility: glimpses of the future from the Bohemia study.* DG for Research and Innovation .

Food Drink Europe. (2019). *Food Drink Europe Annual Report 2019.*

Fortune Business Insights. (2018). *Semiconductor Market Size, Share and Industry Analysis, by components, by application and regional forecast 2019-2026.* Retrieved from https://www.fortunebusinessinsights.com/semiconductor-market-102365

Frangoul, A. (2020). As the coronavirus continues to imact renewables industry, another turbine manufacturer suspends guidance. *CNBC Business News Sustainable Energy*, https://www.cnbc.com/2020/04/22/as-coronavirus-impacts-renewables-siemens-gamesa-suspends-guidance.html.

Fraunhofer. (2020). *Photovoltaics Report.* Freiburg: Fraunhofer Institute for Solar Energy Systems ISE & PSE Projects GMBH.

Frewer, L., Norde, W., Fisher, A., & Kampers, F. (2011). Nanotechnology in the agri-food sector: implications for the future. *Technology and Engineering*.

Ghaffarzadeh, K. (2020, February). *Quantum dot materials and technologies 2020-2030. Trends, markets and players.* Retrieved from IDTECHEX: https://www.idtechex.com/en/research-report/quantum-dot-materials-and-technologies-2019-2029-trends-markets-players/654

Goodall, W., Fishman, T., Bornstein, J., & Bonthron, B. (2017). The rise of mobility as a service. Reshaping how urbanities get around. *Deloitte Review. Issue 20.*

Gouvernement République Français. (2020). *Faire de la France una économie de rupture technologique. Soutenir les marchés émergents à forts enjeux de compétitivité.* Rapport aux Ministre de l’Économie et des Finances et Ministre de l’Enseignement Supérieur, de la Recherche et de l’Innovation.

Grand View Research. (2020). *Fuel cell market size, share, and trends, analysis report by raw material, by product, by application and segment forecast (2020-2027).* ID 9781680380873.

Grumelli, D., Wurster, B., Stepanow, S., & Kern, K. (2013). Bio-inspired nanocatalysts for the oxygen reduction reaction. *Nature Communications 4, Article Numer 2904*.

Gsteiger, H., Kocha, S., Sompali, B., & Wagner, F. (2005). Activity benchmarks and requirements for Pt, Pt-alloy and non-Pt oxygen reduction catalysts for PEMFCs. *Applied Catalysis B Environmental 56*, 9-35.

Hasenberg, J.-P. (2018, May 29). *Purpose-built vehicles for mobility services.* Retrieved from Roland Berger: https://www.rolandberger.com/en/Publications/Purpose-built-vehicles-for-mobility-services.html

Hausler, S., Heineke, K., Hersley, R., Möller, T., Schwedhelm, D., & Shen, P. (2020). *The impact of Covid-19 on future mobility solutions.* McKinsey Cneter for Future Mobility.

He, X., & Hwang, H. (2016). Nanotechnology in food science: functionality, applicability and safety assessment. *Journal of food and drug analysis, vol24, issue 4*.

Hernandez-Sánchez, H. (2015). Food nanoscience and nanotechnology. *Springer*.

HLG on Energy-Intensive Industries. (2019). *Masterplan for a competitive transformation of EU energy-intensive industries enabling a climate neutral circular economy by 2050.* EU Publications.

Horn, M., MacLeod, J., Liu, M., Webb, J., & Motta, N. (2019). Supercapacitors: a new source of power for electric cars? *Economic Analysis and Policy, vol61*, 93-103.

IEA. (2019). *Perspectives for the clean energy transition. The critical role of buildings.* International Energy Agency - IEA.

Industry 2030 HLG. (2017). *A vision for the European industry until 2030.* European Commission.

International Technology Roadmap for PV. (2019). International Technology Roadmap for Photovoltaic 10th edition. . *ITRPV and VDMA*.

IRENA. (2019). *Global energy transformation. A roadmap to 2050.* International Renewable Energy Agency. IRENA.

Jensterle, M., NArita, J., Piria, R., Samadi, S., Prantner, M., Crone, K., . . . These, J. (2019). The role of clean hydrogen in the future systems of Japan and Germany. *Adelphi*.

Kumar, A. (2018). *The global market for composites: resins, fillers, reinforcements, natural fibers and nanocomposites through 2022.* BBC Research. Report Code PLS029F.

Li, J., Kuang, Y., Meng, Y., Tian, X., Hung, W.-H., Zhang, X., . . . Dai, H. (2020). Electroreduction of CO2 to formate on a cooper-based electrocatalyst at high pressures with energy conversion efficiency. *Journal of the American Chemical Society, 142, 16*, 7276-7282.

Ling, Z., Yu, C., Fan, X., Liu, S., Yang, J., Zhang, M., . . . Qiu, J. (2015). Freeze-drying dor sustainable synthesis of nitrogen doped porous carbon cryogel with enhanced supercapacitor and lithium ion storage performance. *Nanotechnology, 18; 26(37)*.

Luo, Q.-P. H., Gao, X., Cheng, Y., Yao, B., Hu, Z., WAn, J., . . . Zhou, J. (2015). Activated carbon derived from melaleuca barks for outstanding high-rate supercapacitors. *Nanotechnology 31;26(30)*.

Luther, W. (2008). *Application of Nanotechnologies in the Energy Sector.* Hessian Ministry of Economy, Transport, Urban and Regional DevelopmentVol 9 of Series Aktionslinie Hessen-Nanotech.

MacDowell, N., Fennell, P., Shah, N., & Maitland, G. (2017). The role of CO2 capture and utilization in mitigating climate change. *Nature Climate Change, 7*, 243-249.

Markets and Markets. (2019). *Nanotechnology in medical devices market by product and application. Global Forecast 2019.*

Matteuci, F., Ginnantonio, R., Calabi, F., Agostiano, A., Gigli, G., & Rossi, M. (2017). Deployment and exploitation of nanotechnology nanomaterials and nanomedicine. *AIP Publishing*.

Mc Williams, A. (2018). *Nanocomposites, nanoparticles, nanoclays and nanotubes: global markets to 2022.* BCC Research. Report Code NANO21H.

Mc Williams, A. (2018). *Nanodevices and nanomachines: the global market.* BCC Research Report Code NANO62A.

Meissner, F., Shirokinskiy, K., & Alexander, M. (2020). *Computer on wheels. Disruption in automotive electronics and semiconductors.* Roland Berger. Focus.

Mishra, K., & Hussain, M. (2018). Nanotechnology for sustainabkle water resources. *Scrivener Publishing*.

Mishra, K., Kyu Ha, S., & Verma, K. T. (2018). Recent progress in selected bi-nanomaterials and their engineering applications: an overview. *Journal of Science. Advances Materials and Devices 3, 3*.

Moca, T., Matea, C., & Pop, T. (2017). Development of nanoparticled-based optical sensors for pathogenic bacterial detection. *J. Nanobiotechnol 15, 25*.

Mordor Intelligence. (n.d.). Supercapacitors market. Growth, trends, and forecast (2020-2025). *Mordor Intelligence*.

Nakazato, G., Kobayashi, R., Seabra, B., & Duran, N. (2017). Use of nanoparticles as a potential antimicrobial for food packaging. *Nanotehnology in the agri-food industry. Food presenvation. Academic Press*.

Nature Energy. (2020). Perovskites take steps to industrialization. *NAture Energy. Editorial, vol 5*.

NEREID PROJECT. (2014). *Nanoelectronics Roadmap for Europe.* Retrieved from The electronics sector has a critical leverage effect on other industrial and service sectors. In particular, the electronics industry plays a key role in Industry 4.0 and the energy transition.

Oliver, J. (2018). *Bioinspired and nanoengineered surfaces: technologies, applications and global markets.* BCC Research. Report Code AVM089B.

Othman, R., Dicks, A., & Zhu, Z. (2012). Non precious metal catalysts for the PEM fuel cell cathode. *International Journal of Hydrogen Energy, vol 37, Issue 1*, 357-372.

Patel, S., Nanda, R., & Sahoo, S. (2015). Nanotechnology in healthcare: applications and challenges. *Medicinal Chemistry 5:12*.

Pei, P., Yuan, X., Chao, P., & Wang, X. (2010). Analysis on the PEM fuel cells after accelerated life experiment. *International Journal of Hydrogen Enregy, vol 35, issue7,* , 3147-3151.

Pisoni, S., Fu, F., Fuerer, T., Makha, M., Bissing, B., Nishowaki, S., . . . Buecheler, S. (2017). Flexible NIR-transparent perovskite solar cells for all-thin-film tandem photovoltaic devices. *Journal of MAterials Chemistry, Issue 26*.

Pitkethly, M. (2004). Nanomaterials - the driving force. *Materials Today, vol 7, Issue 12*.

Pleutin, S. (2019). *Nanotechnology in energy applications.* BCC REsearch. Report Code NANO44C.

Prabhin, V., Jeyasubramanian, K., Benitha, V., Veluswamy, P., & Cho, B. (2020). Fabrication and evaluation of hybrid supercapacitor consisting of nano cobalt oxide and manganese oxide deposited electrochemically on nanoporous AU-electrode. *Electrochimica Acta Vol 330*.

Rashid, H., Yu, K., Umar, M., Anjum, M., Khan, K., Ahmad, N., & Jan, M. (2015). Catalyst role in chemical vapor deposition CVD process: a review. *Rev.Adv.Mater.Sci. 40*, 235-248.

Raza, W., Ali, F., Raza, N., & Kim, K. (2018). Recent advancements in supercapacitor technology. *Nano Energy 52*.

Reinhard, P., Chirila, A., Blosch, P., Pianezzi, F., & Nishiwak, S. (2013). Review of progress towards 20% efficiency flexible CIGS solar cells and manufacturing issues of solar modules. *IEEE Journal of Photovoltacis, vol3, Issue 1*, 572-580.

Remane, G., Hildebrandt, B., Hanelt, A., & Kolbe, L. (2016). Discovering new digital business model types. A study of technology start-ups from the mobility sector. *Association for Information Systems. PACIS 2016 Proceedings*.

Ren, R., Faber, M., Dziedzic, R., Wen, Z., Jin, S., Mao, S., & Chen, J. (2015). Metallic CoS2 nanowire electrodes for high cycling performance supercapacitors. *Nanotechnology, vol 26, numer 49*.

REN21. (2020). *Renewables 2020. Global Status Report.* Paris: REN21 Secretariat ISBN 978-3-948393-00-7.

Research&Markets. (2020). *The film solar PV market: growth, trends and forecast 2020-2025.*

Rhim, P., & Whan, J. (2014). Nano and nanocomposite antimicrobial materials for food packaging applications. *Chapter. DOI: 10.4155/9781909453258.EBO.13.303*.

Sekhon, B. (2010). Food nanotechnology. An overview. *Nanotechnology, science and applications 3*.

Sheberla, D., Bachman, J., Elias, J., Sun, C.-J., Shao-Horn, Y., & Dinca, M. (2017). Conductive MOF electrodes for stable supercapacitors with high areal capacitance. *Nature Materials, 16,* , 220-224.

Singh, R. (2017). *Applications and global markets for nanoelectromechanical systems - NEMS.* BCC Research Report Code IAS114A.

Singh, S., & Tandon, P. (2014). Catalysis: a brief review on nano-catalyst. *Journal of Energy and Chemical Engineering, vol 2, Issue 3*, 106-115.

Song, C., Liu, Q., Chen, G., Song, Y., Kansha, Y., & Kitamura, Y. (2019). Absorption-microalgae hybrid CO2 capture and biotransformation strategy - a review. *International Journal og Greenhouse Gas control, vol 88*, 109-117.

Sooveichik, G. (2017). Future of ammonia production: improvement of Haber-Bosch process or electrochemical synthesis? *NH3 Fuel Conference. Minneapolis AIChE Annual Meeting, Topical Conference: NH3 Energy*.

Stephen, B., & Inbaraj, B. C. (2016). Nanomaterial-based sensors for detection of foodborne bacterial pathogens and toxins as well as pork adulteration in meat products. *Journal of food and drug analysis, vol24, issue 1*.

Strategic Forum IPCEI. (2019). *Strenghthening Strategic Value Chains for a future Ready EU Industry.* European Commission.

SusChem SIRA. (2019, December 15). *Technology priorities towards 2030 for a better future of Europe.* Retrieved from SUSCHEM: http://www.suschem.org/newsroom/suschem-sira-2019-technology-priorities-towards-2030-for-a-better-future-of-europe

Taheri Najafabadi, A. (2013). CO2 chemical conversion to useful products: an engineering insight to the latest advances toward sustainability. *International Journal of Energy Research, vol37, Issue 6.*

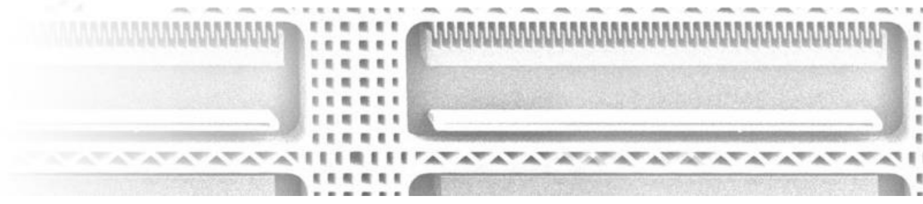
Trepti, S., Shruti, K., Predeep, W., Verinder, B., Vivek, K., & Irfan, A. (2017). Application of nanotechnology in food science. Perception an overview. *Frontiers in microbiology 8*.

United Nations. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development.* General Assembly of United Nations. Seventieth Session. 21 October.

Vikesland, P. (2018). Nanosensors for water quality monitoring. *Nature Technology 13*.

von der Leyen, U. (2019). *A union that strives for more. Political Guidelines for the next European Commission 2019-2024.* European Commission.

Williams, M. (2019). *Advanced ceramics and nanoceramics powders.* BCC REsearch Repor Code NANO15J.



Wood Mackenzie. (2020, May 12). *The future of energy after Covid-19: three scenarios*. Retrieved from https://www.woodmac.com/news/feature/the-future-of-energy-after-covid-19-three-scenarios/