WHITE PAPER AP10
ADVANCED MATERIALS AND NANOTECHNOLOGIES

EXECUTIVE SUMMARY

AP10 includes interdisciplinary skills for the synthesis, characterization, modelling and development of innovative materials and nanotechnologies for industrial processes, environmental, energy and bio-medical applications. The activity addresses both the H2020 (EU) and PNR (IT) programs in particular the Leadership Action in Enabling Industrial Technologies, Future and Emerging Technologies, Nanotechnologies, Advanced Materials, Biotechnology and Advanced Manufacturing and Processing.
The materials and nanotechnologies developed in AP10 have a strong social and economic impact in particular for the industrial leadership and societal challenges.
CNR institutes have developed and established high-level skills aimed at the nanoscale level production of new or advanced inorganic, polymeric and hybrid materials. The main objectives are addressed to the development of materials and nanotechnologies for electronics and magnetism, optoelectronic devices, plasmonic systems, photonics, nanofluidics, for (bio-) sensors and for energy. Electronics materials include nanostructures for high power electronics, 2D materials like graphene or dichalcogenides, Qdots, organics, semiconductor and functionalized oxide nanostructures. In the energy sector, materials for catalytic processes, e.g. CO_2 recycling, electrochemical storage, nanofluids, electrolysis, hydrogen and CO_2 storage and high efficiency fuel cells fed with hydrogen and alternative fuels, adsorption heat pumps, photocatalysis and photovoltaics are currently developed.
Nanotechnology offers radical alternatives for numerous medical problems, e.g. in the contexts of oncology and biosensors. The materials range from multifunctional optical and/or magnetic contrast agents, capable to systemically recognize malignant lesions and enable their diagnostic imaging and treatment, to tissue engineering developing of scaffolds for bone and articular tissue regeneration, to bio-mimetic hybrids for biocompatible electronic systems, to optical devices to assess the effect of new drugs on individual cells and to hybrid solutions for intracellular delivery of nanoprobes.
All these activities are supported by increasingly important numerical modelling and simulation studies for the prediction and processing of data and processes.
The AP involves multi- and interdisciplinary aspects since the development of advanced materials and nanotechnologies for a wide range of applications is strongly based on the use of highly complementary and converging skills. This is confirmed by the quality and the number of research projects, both at European (20) and National (21) level and the relevant number of person months per year (743) involved on this theme.

1. STATE OF THE ART OF THE RELEVANT SCIENTIFIC AREA

Advanced materials introduce new functionalities, improve properties, and, at the same time, add value to existing products and processes, in a sustainable approach. Nanotechnologies can be used to create nano-materials having new properties due to the nano-scale, or can be used to develop nano-devices.

1.1 Advanced materials for industrial processes.
Electronic industry requires materials for high power electronics. SiC and Ga_2O_3 are considered very promising for these applications. CdZnTe is considered the best material for preparing room temperature operating spectroscopic x- and gamma ray detectors. Semiconductor and metal oxide **nanostructures** (µtubes, nanowires, nanosheet) as well as **graphene** and C-base nanostructures (1D sheets, nanoribbons) were proposed for novel sensors, energy storage, optoelectronics, nanoelectronics, nanocatalysis. **2D**

transition metal dichalcogenides (MoS_2) are alternatives to the gapless graphene. MBE-grown **semiconductor QDs** are 0-dymensional systems with quantum-mechanical properties that can be managed, tailored and implemented into device-like structures. Thin films of small molecules are the basis for organic electronics. **Surface functionalization** can be the key for enhancing material properties such as inorganic nanowires with organics for sensing and biomedicine or graphene and polymers with biomolecules for high sensitivity/selectivity biosensing.
Multifunctional magnetic materials, with functional properties (e.g. thermal, mechanical, electrical, optical) tuneable by the combined application of external stimuli are gaining an increasing interest. Magnetic thin films and spatially confined nanostructures show emerging properties that can be suitably applied in non-volatile memories, magnetic MEMS, and sensors. The synthesis and study of new magneto-electric **multiferroics** (MF) materials is a hot topic.
Nanofluids are fluids or solids added with nanoparticles of various metals with the following potentialities to increase the heat transfer coefficient of the base fluid, thus enhancing its the thermal conductivity without increasing its viscosity, to improve the tribological properties of lubricants to enhance the efficiency of machines or to increase the thermal conductivity of phase change materials (PCM) to enhance heat conduction in heat storage devices and in building materials.
Structured catalysts are widely used in large and small-scale applications due to the high specific geometric area, the low pressure drop and the enhanced mass transport. **Reactors foams** with high pore density are generally preferred to honeycombs thanks to their outstanding gas-to-solid heat- and mass-transfer properties and high specific geometric surface areas.
Nanomaterials are largely exploited for industrial devices and processes, such as the deposition of coatings by Physical Vapour Deposition.
Sustainability in **machining process** is facing the difficulty to cut materials for aeronautic and aerospace applications. An open issue is the development of hybrid preparation methods (additive/subtractive) combining sustainability and high production rate.
Rare-earth-doped glasses and **nano-glass-ceramics** are studied for optical amplification, lighting and photovoltaics.
Modelling of complex systems has become an essential tool, in particular for: i) dynamic processes and complex flows ii) suspensions, emulsions, gels, foams, etc.; these materials are described as viscoelastic liquids with a rheological model provided in the form of constitutive equations. Specific challenges include modelling and simulation of micro and nanoflows and manufacturing processes (composite and laminated materials, yarns).

1.2 Enhanced materials and nanotechnologies for energy and environment

Nanosized and nanostructured materials based on metal alloys, semiconductors, oxides, and carbonaceous systems have shown excellent potentialities for energy conversion and storage systems. Most of the relevant processes make use of **critical raw materials** (CRMs) in large amounts, thus determining high capital costs. An improvement of efficiency and durability in the next generation energy processes requires developing new nanostructures, such as core-shell systems and mesoporous morphologies, while providing a better comprehension of surface properties. Development of **electrorheological materials** to enhance the performance of military vehicles and medical devices used for rehabilitation will represent an important area of application in the next future.
Out-of-equilibrium deposition techniques allow the growth of **thin films for photovoltaic** conversion with desired stoichiometry.
The emerging class of **magnetocaloric materials** is gaining an increasing attention for its possible exploitation in power generation and magnetic refrigeration, an eco-friendly alternative to current cooling technology.
Magnetic materials play a crucial role in low-carbon technologies. A significantly growing interest is devoted to their multiscale optimisation and to the design of new materials based on non-critical and easy-recyclable elements.
Metal oxide nanomaterials are used also for **energy harvesting**. The design of flexible, efficient, versatile piezoelectric devices is a challenging issue.
Organometal halide perovskites are promising materials for energy production.

Photocatalytic nanomaterials are exploited for air and water depollution, both as remediation and prevention approaches. Main obstacles to a widespread adoption of photocatalytic depollution technologies are the low activity and the requirement for UV radiation.

1.3 Advanced materials and nanotechnologies for bio-medical use

The clinical practice for **bone repair** is still based on the use of transplants and/or autografts. Treatment options for articular cartilage defects are just palliative. The level of biomaterials development is still inadequate in terms of long-term effectiveness and final patient outcome. Engineering functional tissues requires effective organization of cells into grafts with morphological and physiological features resembling those in vivo. The development of nano-functionalized materials mimicking the nano-features of physiological tissues could be an effective strategy. A challenge is the development of a material having mechanical properties similar to bone and good osseointegration.

Magnetic and multifunctional properties of **magnetic nanostructures** allow new-concept diagnostic and therapeutic approaches.

Plasma processes are useful for sterilization or decontamination of nanomaterials for bio-medical applications.

Functionalization of oxides surfaces and nanomaterials paves the way to tune the system electronic properties, to achieve biocompatibility or sensitivity to specific analytes, and offers newly designed alternatives in the oncological and tissue regeneration context.

The thriving field of **biophotonics** is pushing for new materials, such as plasmonic substrates for surface enhanced Raman scattering (SERS)-based biosensing of markers and pathological conditions in trace amounts, nanoparticles for systemic delivery of theranostic agents and nanotechnology-enabled photonic devices as intracellular probes, scaffolds for controlled drug release, photothermal or photoacoustic transducers, etc.

Drug release in biomedical devices can be **modelled**. In particular, the dynamics of a drug, diffusing from a polymeric matrix towards a biological tissue, affect its absorption properties, in order to optimize its therapeutic efficacy. Applications are for drug-eluting stents, medicated patches or orthopaedic implants.

2. CONTRIBUTION TO THE RELEVANT SCIENTIFIC AREA

Activities carried out in AP10 are characterised by a transversal nature since they involve Physics, Chemistry, Mathematics, Engineering, Biology and Medicine. For sake of simplicity, the developed materials and nanotechnologies are grouped into specific categories according to their relevant properties and fields of application.

2.1 Advanced materials for industrial processes

IMEM is focused on materials development for electronics and magnetism. **Magnetic materials** are studied for applications in eco-sustainable technologies. The activity is addressing the design, synthesis and multiscale magnetic, structural and functional characterization of **rare-earth-free materials** and **nanocomposites** for permanent magnets, **nanostructured alloys** with giant magnetocaloric and magnetomechanical properties, new **metastable multiferroics**, Si-integrated magnetic and magneto-optical materials for memories and sensors.

Significant efforts are carried out at IMEM on materials for electronics with the aim to advance in sensing technologies, semiconductor devices, light emission, telecommunications etc. The new nanostructures regard **low-D materials**, e.g. **quantum dots (QDs)**, and **2D-materials** such as **graphene** deposited on metal or SiC exhibiting enhanced reactivity to CO and H_2 gases. Thin **FeOx films** on metals are studied as catalyst for N_2O decomposition. **2D MoS_2** is prepared by chemical vapor deposition and ion jet deposition to control the electronic properties by defects creation and organic functionalization. Advanced deposition methodologies such as molecular beam epitaxy are used to form **In(Ga)As-based QDs** for telecom wavelengths emission.

Graphene monolayers are grown at IMEM by supersonic molecular beam deposition (SuMBD) of C60 on Cu and by dehydrogenation of hydrocarbons. The reactivity of defected/N-doped graphene towards CO is studied for gas sensing purposes. SuMBD is also used for functionalization of SiO_2 or TiO_2 surfaces by organic molecules for synthesis of 3C-SiC nanoislands on Si at room temperature rather than 1000°C as of traditional approaches and to deposit thin films with higher structural/charge transport properties for advanced organic field-effect transistors (FETs) and light-emitting FETs.

A field of incresing interest is the growth and characterization of electronic materials, from bulk crystals to nanostructures. This involves development at IMEM of **CdZnTe crystals** for x-ray detectors, semiconductor and oxide thin films by PED, CVD for photovoltaics, epitaxial growth of **SiC and Ga_2O_3 films** for high power electronics and UV photodetectors, MBE growth and fabrication of **InGaAs/GaAs** strain-induced rolled-up microtubes, **metal oxide nanostructures** for gas sensing, memristors, optoelectronics, transducers, catalysis, energy harvesting and storage. The fabrication of nanostructured devices is carried out by optical photolithography and FIB.

ITC is strongly involved in the characterisation of **nanofluids** of different nature with the aim to optimise their formulation in terms of nanoparticles dispersion, size and material selection, thermophysical and tribological properties with reference to heating, ventilation and air conditioning and for building applications.
Fluids are also actively studied at IAC by using **modelling and simulation of dynamic processes and complex flows** (suspensions, emulsions, gels, foams). Materials are described as viscoelastic liquids with a rheological model in the form of constitutive equations. Modelling and simulation at IAC include **micro and nanoflows** as well as manufacturing processes for composite and laminated materials, and yarns.
Of particular interest is the activity developed at IMAMOTER on **metal oxide nanomaterials** for applications in gas sensing with environmental implications. The developed nanotechnologies for chemical and biological sensors allow real-time monitoring for the environment, process and quality control, and for degradation processes. IMAMOTER also boasts excellent expertise in improving sustainable methods for machining **Ti alloys and Inconel** materials for aeronautic and aerospace applications.
IFP has been engaged in intensive research on **plasma processes** that can be used into future application areas. The study of plasma treatment of materials creates the prerequisites for innovative new manufacturing processes.

2.2 Enhanced materials and nanotechnologies for energy and environment

IRC is developing advanced materials for green chemistry processes, such as highly **porous foams** characterized by hierarchical porosity, optimized pore structure and high strength. Significant efforts are addressed to the implementation of nanomaterials such as **graphene, hybrids/composites of metal organic frameworks** and graphene related materials, **superhydrophobic and hydrophilic coatings** prepared by cost-effective solvothermal or flame synthesis one-pot methods. Innovative approaches are aimed to re-use waste materials (biomasses) in order to produce **added-value nanomaterials**.
In the energy sector, IRC is addressing the development of advanced materials for sustainable processes in particular graphene materials, supported systems and metal nanostructures used in heterogeneous catalysis.
ITAE is instead essentially focused on the development of advanced materials for hydrogen technologies, electrochemical energy storage (batteries and supercapacitors), fuel cells fed with hydrogen, alternative fuels and biofuels. Efforts are addressed at ITAE to develop innovative materials for the capture and conversion of CO_2, for adsorption heat pumps and next-generation solar cells. Materials developed at ITAE include **catalysts and membranes** for sustainable processes, **ceramics** and structured components, such as **electrode-electrolyte assemblies**, for energy conversion purposes. Advanced formulations include **metal and metal-oxide nanostructures**, e.g. core-shell, **biochar, perovskites, transition metal catalysts, zeolites, oxide-based nanofillers** dispersed in polymeric matrices etc. (ITAE). The enhanced energy materials and nanostructures have achieved improved efficiency and reliability in electrochemical systems and for the production of sustainable fuels from CO_2 recycling (ITAE).
IMAMOTER synthesizes **oxidic nanostructures embedded into a polymer** to develop novel flexible, efficient, versatile coatings of easy fabrication and low environmental impact for application in renewable/alternative energy technologies.

In the field of renewable energy, IFP studies **innovative semiconductors** for use in advanced device for energy production such as solar cells etc. With regard to environmental sustainability, IFP studies "green processes" in the context of the deposition of coatings with tailored functional properties to decrease the impact of the wetting chemistry.
Perovskites are also produced at IMEM by vacuum flash evaporation to improve their usability in multilayer devices.
Heterogeneous photocatalysts are developed at ITC for their depollution activity in air and in water. The gas/solid phase depollution activity is assessed in true environmental conditions.
In general, energy materials are actively studied to advance in sustainable/renewable processes, to facilitate system integration and simplification while providing a perspective for market uptake of the most advanced technologies within 5-10 years.

2.3 Advanced materials and nanotechnologies for bio-medical use
IMAMOTER develops **composite materials** for biomedical applications. Their expertise covers the field of **oxidic materials** for dental prosthesis and the synthesis and characterization of **polymer composites**. This knowhow can lead to the development of **oxide reinforced polymers**, with reduced rigidity compared to that of bare oxide and with enhanced osseointegration properties with respect to the neat polymer.
Modelling drug release in biomedical devices is carried out at IAC in order to characterize the dynamics of the drug diffusing from a polymeric matrix towards a biological tissue and to identify the characteristic parameters that affect its absorption properties with the goal to optimize its therapeutic efficacy.
Applications for drug-eluting stents, medicated patches, and orthopaedic implants are other relevant topics studied at IAC.
IFAC is active in the development of **advanced plasmonic substrates** for photonic sensing of markers of neurodegenerative conditions and hybrid materials for photonic theranostics of e.g. cancer and hypertrophy, by the intracellular delivery of genetically-encoded probes and silencers and the use of bionic contrast agents for photoacoustics and thermics. A variety of photonic devices are developed, such as **whispering gallery mode resonators** and **optical fibre nanotips** for biosensing, **scaffolds for controlled drug release and wound healing** or tools for **genetic amplification**.
IMEM researchers use their expertise on materials for electronics for the development of **SiO_xC_{1-x} based nanosystems** for nanomedicine (NWs for local, in deep-tissue cancer treatment) and **tissue engineering** (porous bioactive 3D scaffolds for dentistry and NEMS structures for subretinal prosthesis). Particular interest is also devoted at IMEM to advanced **magnetic and magnetoplasmonic nanostructures** for therapeutic and diagnostic purposes. Self-assembly mechanisms are of particular interest for drug delivery applications. Studies are focused on the chemical nature of **self-assembled amino acids** on Ag and TiO_2.
In the field of human health, IFP studies **plasma processes for sterilization or decontamination** in order to support the development of new technologies against the microbial infections.
The IEIIT institute leads advanced scientific and technological research in the fields of **tissue engineering** by developing **scaffolds for bone and articular tissue regeneration**. Nano-functionalized substitutes are developed by using graphene-derived nanomaterials or ceramic nanoparticles to enhance the biomechanical features of the materials without impairing the potential of the implants to promote new tissue formation and regeneration.

3. IMPACT

The ability to design and produce innovative materials and nanostructures with tailored properties to activate and control physical/chemical processes will have a strong influence on economics, energy sector, environment, health & safety with a large expected socio-economic impact.

3.1 Impact of enhanced materials and nanotechnologies on industrial processes
Optimization of **magnetic materials** at IMEM is crucial for the development of low-carbon technologies that will benefit different strategic sectors, such as hybrid and electric transportation, wind power generation, energy harvesting, refrigeration/air conditioning. **Micro/nano structures** pave the way to new classes of

memories, sensors and smart devices exploitable in important technological sectors, such as ICT, consumer electronics and nanomedicine. **Organic electronics and optoelectronics** and **low-D systems** are growing sectors. Their impact concerns environment preservation, development of rare-metal-free devices, compact and efficient electronics, ICT and sensing devices. An increasing role is favoured by the possibility to gain control over fundamental quantum-mechanical properties of materials through advanced synthesis, characterization and modelling at the nanoscale. New **deposition techniques** and **3D integrated nanoarchitectures** will have an impact on thin film solar cells, sensors, superconductors, transparent conducting oxides for multiple optoelectronic applications (IMEM). The power electronic sector represents a key technology to address the challenges of energy efficiency and energy saving in green economy wireless infrastructure, broadcast and communication satellites, power conversion and defence applications (radar). New spectroscopic x-ray detectors will allow manufacturing advanced systems for baggage screening, non-destructive testing, and medical applications (IMEM).

Nanofluids developed by ITC hold strong scientific and industrial interest because of their potential to produce an increase of energy efficiency and a reduction in energy consumption, global warming and pollution associated with heating, ventilation and air conditioning systems, and buildings materials. **Nanostructured photocatalytic materials** will play a similar role on reducing air pollution.

Studies currently carried out at IAC on fluids have a relevant impact on the capability of inspiring and realizing the design of **microfluidic devices** for the synthesis of novel porous materials and bio-engineering applications. From a computational point of view, a great challenge is due to the full-scale simulation of microfluidic devices at nanometric resolution.

Metal alloys developed at IMAMOTER by additive manufacturing are expected to grow in the next future especially for aeronautic and aerospace applications. The replacement of conventional lubrorefrigerants will result in a reduction of the environmental impact. Low-cost **nanostructured metal oxide sensors** for early detection and monitoring of poisonous and hazardous chemicals will allow advancing on environmental security and healthcare.

Physical vapour deposition processes for **green coatings**, developed at IFP, will eliminate potentially harmful chemicals or hazardous wastes present today in many chemical processes.

The new materials, devices and standards developed at IFAC are of specific interest within the fast-developing markets of **biophotonics** and **lighting** and will have an impact on new industrial products.

3.2 Impact of advanced materials and nanostructures on energy and environment

The research on **sustainable processes** at IRC impacts on relevant aspects of community by providing solutions for energy and environmental applications, meeting the pollution concerns including climate change issues (**advanced sorbents for CO_2 capture, water remediation, DeNOx technology**), production of sustainable energy (production of synthetic natural gas, catalytic combustion of CO and hydrocarbons, purification of H_2 streams), health (antibacterial, biocompatible materials) and technological issues (low-cost materials for sensors and bio-organic electronics).

The new materials and nanotechnologies developed at ITAE for the energy system address the strategies of promoting the deployment of **new sustainable energy technologies** with the following expected outcomes: improvement of the **energy supply autonomy** (lower dependency from external energy suppliers); **competitiveness** of national companies in renewable power/energy sources; capability to achieve the targets established by the European Strategic Energy Technology (SET) Plan; decrease of pollution, **improvement of air quality** with associated health cost reduction; new environmental friendly and **cost-effective solutions** for power plants and carbon-intensive industry, new markets and job creation in innovative industrial sectors.

Development and synthesis of **metal oxide nanomaterials** at IMAMOTER will play an important role on **gas sensing** in environmental applications and as **polymer filler for energy harvesting**. The latter will help to engage the global energy demand, by capturing otherwise lost energy. This will be beneficial both for the environment and for the financial performance of companies and households. By using mechanical energy that is otherwise wasted, energy harvesters could reduce energy consumption and associated carbon emissions (IMAMOTER).

Photonics based tools developed at IFAC aim to improve the **energy efficiency** of **biochemical reactors** whereas hydrogen production by photochemical water splitting will supply in the future a potential renewable fuel contributing to the energy independence of the EU.

3.3 Impact of nanotechnologies on bio-medical applications

The development of **composite materials** for **biomedical applications** in particular for hard tissues replacement at IMAMOTER will provide a significant cost reduction, thus making such systems accessible to a large number of people for an increase in well-being.

The materials developed at IFAC will give rise to new tools to manipulate light at nanoscale for much more sustainable and effective **sensing, diagnosing, treating** and **monitoring** of conditions as neurodegeneration, cancer and hyperthrophy or for point-of-care or homecare solutions.

The field of **bone graft substitutes** is one of the largest markets in the orthopaedic field, being expected to reach $3.2 billion in the United States, by 2022. The **biomaterials** with favourable nano- to micro-scale, typical cues fabricated at IEIIT aim at improving the quality of life for patients, thus producing significant scientific, societal as well as economic impact.

Plasma processes for sterilization or decontamination at IFP will help to fight against the microbial infections with a positive impact for human health.

Development of **functionalized/hybrid materials** pursued at IMEM is a key point towards multifunctionality, to improve **biocompatibility of implants**, **drug delivery** and biosensing applications in **nanomedicine**.

4. EMERGING RESEARCH CHALLENGES

The emerging challenges that this AP is going to face have already been summarized in the previous paragraphs. More generally, whatever the application field, the future developments cannot disregard a few hot issues. Efforts should be addressed to the development of materials, processes, and technologies that: i) replace the use of Critical Raw Materials ii) limit the energy consumption iii) reduce the emission of greenhouse gases iv) enable innovative solutions in sensitive contexts as healthcare and iv) are a relevant part of the circular economy. These challenges will be addressed by the AP by implementing specific strategies: a) strengthening the multidisciplinary approach b) increasing the critical mass of the research groups by means of a stronger cooperation, especially among the Institutes involved in this AP c) an easier sharing of relevant scientific facilities and infrastructures d) improving the exploitation of modelling and e) improving coordination activities aimed at a more successful participation in large multidisciplinary research projects.

5. CONCLUSIONS

AP10 focuses on materials and nanotechnologies for three main applications *industrial processes, energy and environment, bio-medical use.*

The first pillar essentially concerns with magnetic materials, semiconductors, oxides, alloys, multilayers and systems characterized by physical confinement, complex nanofluids and innovative catalytic formulations. These advanced materials and nanotechnologies are used in a range of applications covering magneto-opto-electronics, industrial processes, catalysis, sensors etc.

The second pillar addresses a broad spectrum of innovative materials for application in the energy sector and in sustainable processes. The most advanced formulations concern with graphenics, hybrid perovskites, metal nanostructures, transition metals catalysts, zeolites, nano-fluids etc. This sector is particularly involving research on hydrogen, fuel cells, air conditioning, heating and refrigeration, and solar cells.

The third pillar is covering a range of nanotechnologies for bio-sensing and diagnostic devices as well as materials directly used in solving medical problems, particularly in the oncological sector. The materials range from multifunctional optical and/or magnetic agents, to nanoprobes for non-invasive investigations, to

systems for tissue engineering. The developed nanosystems are differently functionalized for e.g. anticancer treatments and intelligent drug delivery.
Modelling and numerical simulation applies to all these different themes offering advanced methodologies to progress in each field.
All these sectors are characterized by emerging challenges, such as the need to avoid/reduce the use of Critical Raw Materials and improve nanotechnologies to achieve cost-effective solutions while allowing for a rapid deployment of the developed systems. Efficiency, reliability and sustainability are relevant aspects to focus the research efforts in the fields of green-chemistry and energy-related processes. Research advances are addressed to innovative materials and nanotechnologies for the reduction of polluting emissions while promoting a circular economy. A roadmap is identified to overcome relevant issues by increasing the critical mass of research groups, sharing relevant infrastructures with wider and coordinated participation to multidisciplinary projects.
A large expected socio-economic impact is expected for the new materials and related technologies affecting economics, improving the sustainability of industrial processes, with beneficial effects on the energy sector, on environment, on health & safety.

PROJECT AREA 10: ADVANCED MATERIALS AND NANOTECHNOLOGIES

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