# DOST PCIEERD ETDD: Formulation of Roadmap and Sectoral Plan for Five Emerging Technologies

Advanced Materials and Nanotechnology

Final Report

Building a better working world

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# FOREWORD

Clear vision and strategic action are necessary components to accomplish great things.

The Department of Science and Technology – Philippine Council for Industry, Energy and Emerging Technology Research and Development (DOST-PCIEERD) proudly presents its latest formulation of roadmap and sectoral plan for advanced materials and nanotechnology.

This roadmap is a collective work from experts from the academe, government, private sector, research community, and other relevant institutions that aim to drive the attainment of sustainable development goals (SDGs) agenda on the road to 2024 and beyond. It is a powerful communication tool that will guide the development of specific research programs including evaluation and processes of such to achieve our goals and bring research ideas into fruition.

This Roadmap defines the path at which the unique potentials of advanced materials and nanotechnology can be harnessed a platform to to enable various applications in industries such as semiconductor and electronics, food and agriculture, chemicals, aerospace and aeronautics, among others. It clearly lays out c decisive and innovative action to boost the country's competitiveness and productivity in the supply chain. By sharing this document, it hopes to inspire the next generation of researchers, scientists, and entrepreneurs to pursue research and development activities that will maximize the benefits of emerging technologies.

To spur innovation and transformation, the Council will fully unleashing the power of emerging technologies, expanding technology development and innovation for the industry, energy, and develop S&T interventions and solutions to solve the challenges of today, and growing more businesses and sectors of tomorrow. It will continuously revitalize local and international foster to foster a more efficient and effective implementation of its supported projects and initiatives, as well as the fulfillment of its mandate.

We enjoin our partners in the industry and researchers to ork with us as we can truly make innovation work for the people.

**DR. ENRICO C. PARINGIT**
PCIEERD Executive Director

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# 1. Introduction

Advanced Materials and Nanotechnology have high potential in increasing the country's economic growth and improving society's general well-being. These can transform the way in which industries operate for greater effectivity and efficiency. A general definition of advanced materials refers to new materials or modifications of existing materials to achieve superior performance and outperform conventional uses. To be more specific, these are any materials, that through the control and modification of its internal structure, features a series of exceptional properties (mechanical, electric, optic, magnetic etc.) or functionalities (self-repairing, shape change, decontamination, transformation of energy etc.) that differentiate it from the rest of traditional materials. Nanotechnology, on the other hand, is characterized as the branch of science and technology conducted at the nanoscale of about 1 to 100 nanometers. These have applications that cuts a variety of sectors including health services, manufacturing, agriculture, utilities, and businesses.

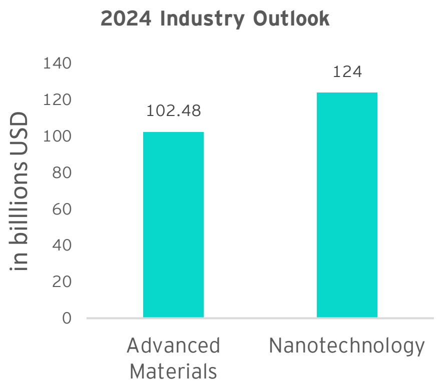
To implement advanced materials and nanotechnology in the Philippines, the strategy focuses on establishing capacity and stakeholder engagement to increase awareness and collaboration among research and private sectors. Two key frameworks that were used to assess the appropriate strategic approach include the Innovation Matrix and S-Curves. Industry targets were identified based on three criteria which are a) immediate financial and economic impact to the country b) availability of local skill and knowledge base and c) present status of the product/technological development in the Philippines. We emphasize the need to improve and maximize existing infrastructure and programs, as well as build new ones to build local capacity. Part of this is having the Advanced Materials and Nanotechnology Hub, that would serve as the focal facility for research and development initiatives. Thereafter, the Global Research Program aims to deploy talent overseas to gain critical knowledge and technology that the country currently has no means of supporting. We also emphasize other programs such as the Balik Scientist Program, currently in place. In this way, we overcome the hurdles in acquiring certain technology while building our local capacity for Advanced Materials and Nanotechnology. With this, the sectors of Rail, Food/Agriculture, Sustainable Environment, Aerospace, ICT/Semiconductor, and Automotive were identified as sector focus areas for Advanced Materials and nanotechnology.

Forwarding development in advanced materials and technology includes maximizing collaboration between stakeholders which include industry, government, and researchers. These players must be willing to adapt to change, receptive towards groundbreaking innovations, and able to go through the process that science and technological innovations require.

# 2. Advanced Materials and Technology Landscape

## Global Landscape

Among others, the fields of Advanced Materials & Nanotechnology have been a priority area for most research & development; as most countries and industry investors have been aware of the many applications that it can offer. For recent years, the Advanced Materials market was valued at $ 42.76B in 2015 and is forecasted to expand at a CAGR of 10.4% in less than 10 years, reaching $ 102.48B by 2024 (Transparency Market Research, 2015). On the other hand, the global nanotechnology market size totals $ 39.2B in 2016 and is segmented in the chart below.



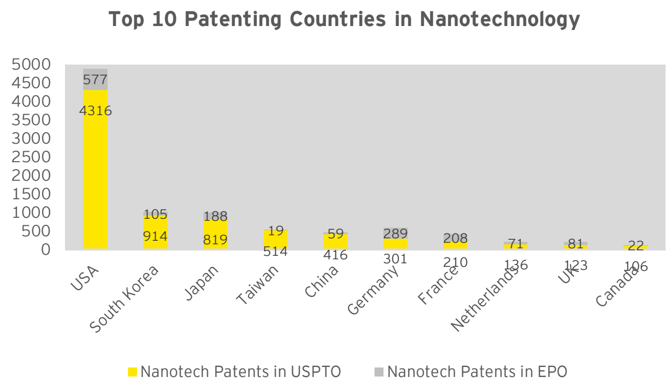




Figure 1. Industry Outlook for 2024; Figure 2. Top 10 Patenting Countries in Nanotechnology

The following table summarizes some of the emerging technologies in advanced materials and nanotechnology and their respective values. These serve as potential research areas and investment priorities in research and development initiatives:

Global Advanced Materials and Nanotechnology Market

| | | |
|---|---|---|
| **NANOBIOTECHNOLOGY NANOMEDICINE** $293.1 Bn *2022 Market Size* | **NANOPHOTONICS** $66.03 Bn *2022 Market Size* | **NANOMATERIALS/ NANOCHEMISTRY** $55 Bn *2022 Market Size* |
| **ADVANCED CARBON MATERIALS** $22.97 Bn *2024 Market Size* | **FUEL CELLS** $24.81 Bn *2025 Market Size* | **MEDICAL POLYMERS** $17.05 Bn *2020 Market Size* |
| **BIO BASED POLYMERS** $9.91 Bn *2025 Market Size* | **SUPERCONDUCTORS** $8.8 Bn *2022 Market Size* | **NANOSENSORS** $4.62 Bn *2023 Market Size* |

*Source: 2015 Transparency Market Research; Global Nanotechnology Market Outlook, BIS Research*

Figure 3. Global Advanced Materials and Nanotechnology Market

Of the total nanotechnology patents published in US Patent and Trademarks Office in 2016, majority is published from the United States, followed by Asian countries South Korea, Japan, & Taiwan by a big distance (StatNano, 2016). The nanotechnology efforts of the United States of America have been integrated by the country's National Nanotechnology Initiative (NNI), and as the field was introduced into the "High Tech" manufacturing industries, it was able to increase the country's GDP by $511 billion in 2014. This leads to a provision of a $1.2 billion budget for the institution in the President's 2018 Budget.

Nanotechnology has also been flourishing in the Asian region. South Korea, for example, has invested $626 million in the research & development and commercialization of nanotech in 2018. According to their Ministry of Science & ICT, the investment will be focused on areas that will have the biggest commercial impacts, such as nanomaterials that are applied to the fields of artificial intelligence, big data, and the Internet of Things (IoT). Malaysia also begins its stride in the nanotechnology industry, with the government initiative of NanoMalaysia, predicting a $ 809 million GNI contribution over 5 years, 51 products developed, and 12 products commercialized.

**Use Case: USA's National Nanotechnology Initiative**

One of the interesting initiatives for nanotechnology in the world is USA's National Nanotechnology Initiative. This is an active collaboration between 20 Federal agencies and Cabinet-level departments with shared interests in nanotechnology research, development, and commercialization.

Since its inception in 2001, the intiiative has already made a total of 23 B USD of investments in nanotechnology. Moreover, the agencies under NNI are required to develop an updated Strategic Plan every 3 years, which will then play into their comprehensove agenda.

Shown below are some of the agencies in the NNI collaboration ecosystem:

*Source: Nano, www.nano.gov*

Aside from being the country holding the most patents, the US also houses a various advanced materials and nanotechnology companies. Participation of the private sector is essential for successful promotion and development of an emerging technology. Some of the largest advanced materials and nanotechnology company in the world are Thermo Fisher Scientific, 3M, Bruker, and Huntsman.

**Thermo Fisher Scientific** is a company in the US that primarily provides medical equipment and supplies. The company provides analytical instruments, equipment, reagents and consumables, software and services for research, manufacturing, analysis, discovery and diagnostics. Thermo Fisher offers a combination of innovative technologies, purchasing convenience and comprehensive services through the brands – Thermo Scientific, Applied Biosystems, Invitrogen, Fisher Scientific and Unity Lab Services. It has a market value of **$118 billion** with focal areas in the field of material sciences such as nanomaterial, polymer, biomaterial, composites, metal and metal alloys, and energy material.

**3M** has a market value of **$95 billion**. The US company's extensive portfolio of advanced materials is uniquely suited to survive and perform in many of today's most challenging applications and environments – from deep in the earth to the depths of space. Its products benefit customers from various industries including plastics processing, oil and gas, automotive, defense, and nuclear power. Examples of advanced materials provided by the company are advanced ceramics, ceramic microspheres, ceramic sand screens, defense protection systems, fluoropolymers, friction shims, glass bubbles, polymer processing additives, and stable isotopes.

**Bruker** is a German company that primarily designs and manufactures scientific instruments, and analytical and diagnostic solutions. It caters to a wide array of industries utilizing nanotechnology and materials sciences in their applications. Its focal areas are materials science, life sciences, electronics, chemical, environment, food and agriculture, aerospace, and semicon. The company has a market value of **$6.7 billion**.

**Huntsman,** based in the US, has a market value of **$5.3 billion**. Its chemicals are sold worldwide to a variety of customers in the adhesives, construction products, aerospace, energy, and home furnishings. Huntsman operates manufacturing and research and development facilities worldwide. It has various innovations in the fields of transportation, construction, energy and fuels, and clothing and footwear through its company research and partnerships with other companies.

Performing research in advanced materials and nanotechnology requires various special tools and equipment. Various facilities exist in countries trying to make advancements in advanced materials and nanotechnology to facilitate researchers from different backgrounds. The US has several facilities for advanced materials and nanotechnology research funded by the NNI. The **NIST Center for Neutron Research** is a facility for nanotechnology research that provides facilities, access, and assistance to members of the U.S. scientific and industrial communities interested in using neutrons for their research with an estimated annual budget of **$50 million**. The **National Nanotechnology Coordinated Infrastructure (NNCI)** provide researchers from academia, small and large companies, and government with access to university user facilities with leading-edge fabrication and characterization tools, instrumentation, and expertise within all disciplines of nanoscale science, engineering and technology. The total level of funding for NNCI sites and the National Nanotechnology Infrastructure Network Coordinating Office is approximately $16 million annually. Research undertaken within NNCI facilities is incredibly broad, with applications in electronics, materials, biomedicine, energy, geosciences, environmental sciences, consumer products, and many more. The **London Centre for Nanotechnology**, occupying a purpose-built eight-story facility in Gordon Street, Bloomsbury, UK (opened in 2006), as well as extensive facilities at other areas, was funded by **$15 million** higher education grant in 2004. It is a multidisciplinary enterprise operating at the forefront of science and technology with a purpose to solve global problems in information processing, healthcare, energy and the environment through the application of nanoscience and nanotechnology. **Tsukuba Innovation Arena** gathers world-class leading nanotechnology research facilities and personnel aiming at forming a global nanotechnology base. It has a research funding of **$49 million** in 2018 and a business scale of **$1.4 billion**. The facility has 6 core research domains: power electronics, nanoelectronics, NMEMS, nano-green, carbon nanotube, nano-material safety and 3 core infrastructures- nanodevice research foundry, nanotech open use facilities, networking school of nanotech.

## Regional Landscape

Notable developments in surrounding Southeast Asian countries in the fields of Advanced Materials and Nanotechnology are as follows:

| SEA Countries | Projects / Company | Details |
|---|---|---|
| Thailand | Kuraray GC Advanced Materials Co., LTD. | Three companies co-invested in this project to develop a Performance and Specialty Chemicals Business to manufacture Super Engineer Plastic (High-Heat Resistant Polyamide-9T) and Hydrogenated Styrenic Block Copolymer (HSBC) Products in Thailand. This supports Thailand as the biggest automotive producer in SEA and a renowned producer in electronics parts. |
| Malaysia | NanoMalaysia (A Federal Agency of Thailand) | NanoMalaysia has four programs listed below:<br>a. iNanovation<br>b. National Graphene Action Plan<br>c. Advanced Materials Industrialization<br>d. NANOVerify |

| | | |
|---|---|---|
| | | NanoMalaysia offers these four programs to industries, universities and research institutions. |
| Vietnam | Hyosung Advanced Materials Co., Ltd. | The company has expanded its market in Vietnam by building a new tire cord factory. This tire cord is a reinforcement material that is put into car tires for improvement of safety, durability, and driving performance. |
| | Vietnam Pharmaceutical Corporation | Introduced a nanotechnological cancer treatment product that is accepted in the Hanoi market. |

Figure 4. Regional Developments in Advanced Materials and Nanotechnology

## Current Local Capacity

There are a wide array of research and development initiatives in advanced materials and nanotechnology in different research and academic institutions. The following table summarizes some of the advanced materials and nanotechnology applications in different industries that are done in the Philippines:

| Sector | Applications |
|---|---|
| Energy storage, production and conversion | • Photovoltaic cells and organic light-emitting devices based on quantum dots<br>• Carbon nanotubes (graphene) in composite film coatings for solar cells<br>• Superconductors<br>• Solid oxide electrochemical cells<br>• Lithium ion batteries |
| Agricultural productivity enhancement | • Nanoporous zeolites for slow-release and efficient water and fertilizers for plants, and of nutrients and drugs for livestock<br>• Nanocapsules for herbicide delivery<br>• Nanosensors for soil quality and for plant health monitoring<br>• Nanomagnets for removal of soil contaminants<br>• Plasma technologies for harvest |
| Water treatment and remediation | • Nanomembranes for water purification, desalination, and detoxification<br>• Nanosensors for the detection of contaminants and pathogens<br>• Nanoporous zeolites, nanoporous polymers, and attapulgite clays for water purification<br>• Magnetic nanoparticles for water treatment and remediation<br>• Sensors for heavy materials and wastes |
| Healthcare | • Nanocapsules, liposomes, dendrimers, buckyballs, nanobiomagnets, and attapulgite clays for slow and sustained drug release systems<br>• Quantum dots for disease diagnosis<br>• Wound healing<br>• 3D printing for skin |
| Semiconductor | • Nanosilica in concrete<br>• Recovery of metal from waste solutions<br>• Advanced fibers |

Figure 5. Local Developments in Advanced Materials and Nanotechnology classified per Sector

Local researchers are looking into advanced fields such as plasma science, terahertz, etc. for their researches. A lot of the research efforts are placed in the localization of the ingredients needed for manufacturing of various products. Through the modification of properties of nanoparticles, natural materials found locally can be used as replacements for ingredients imported from abroad. Examples include development of natural fibers from indigenous, natural, and sustainable materials for composites instead of using carbon fiber, using plasma technology to modify cocofiber for concrete reinforcement, substituting imported components of rubber with processed local materials, etc. The impact of the technology to the environment is also a consideration for the researches performed, which can be seen from projects such as development of cyanide-free extraction process, development of greener electrolyte, and recovery of metals from waste solution. This is evidence that there is significant capacity in advanced materials and nanotechnology development. Furthermore, the research and development initiatives in the Philippines are clearly aligned with emerging technologies stated in the global capacity.

On the commercial side, a lot of local companies have been starting to make their strides in the field of nanotechnology and its applications to the industry. Some of these companies are Beta-Nano Coating who is the pioneer for using cutting-edge PVD coating technology in the country, Chemrez Technologies who is into manufacturing of customized food ingredients and specialty raw materials & oleochemicals, and Nano Fix-it who utilizes nanotechnology to develop a whole range of products that benefits electronic devices and automotive. This shows that there is already existing industry involvement and interest in advanced materials and nanotechnology initiative. Collaborations between companies in the industry and researchers exist in forms of consultancies and funded researches. There are also efforts by the researchers that aim to help SMEs by performing services such as surface coating, extraction process for mining, and electroplating. The crucial step is to be able to stimulate this further.

The Philippines has also been doing its initiatives on the R&D of advanced materials & nanotechnology through the Department of Science and Technology (DOST). In the year 2018, additional budget totaling around $ 3 million were allocated to projects on these sectors. According to PCIEERD's data of their R&D sector yearly expenditure, their budget for Nanotechnology programs was increasing from 2011 to 2014 but has been continually decreasing since then until recently.

For Advanced Materials, projects have recently been focused on additive manufacturing, terahertz technologies, and electronics and semiconductors materials. Initiatives for smart farming have also been prioritized as part of developing solutions for societal problems through the advanced material technologies. As of 2019, 17 projects are currently ongoing for the advanced materials sector and 10 projects for Nanotechnology, but all still in the laboratory stage & not yet ready for commercialization. Below is a sample of projects completed and ongoing for both sectors:

| Projects | Duration | Budget (USD) | Accomplishments/ Expected Outputs |
|---|---|---|---|
| Advanced Manufacturing Center (AMCen) | Feb 2019 onwards | 495,229,730.60 | • Establishment of 2 additive manufacturing laboratories, the Materials Development Lab & the Prototyping Facility<br>• Will increase the country's readiness for Industry 4.0 |
| Development, Characterization and Performance Evaluation of Polymeric Separation Membrane for Industrial Applications using Local Materials (Phase 1) | 01 Jan 2017 - 31 Dec 2017<br>Extension: 01 Jan 2018 - 31 Mar 2018 | 21,987,112.00 | • Establishment of Polymeric Separation Membrane Research Facility<br>• 4 Patents for application<br>• 2 publications |
| ADMATEL Expansion and Business Continuity | 01 Jan 2018 - 31 Dec 2020 | 131,883,164.20 | • Expand capabilities of the facility to better serve the industry<br>• Increase revenue to 380,000 USD<br>• Aggressive marketing efforts |
| Smart Plant Production in Controlled Environments (SPICE) | 16 January 2018 – 15 January 2021 | 33,084,563.84 | • Development of an efficient and intelligent farm system that can |

| | | | |
|---|---|---|---|
| | | | perform the different tasks in operating an urban farm automatically based on sensor data |
| Environmental, Health and Safety Research in the Risk Assessment of Nanomaterials (Phase I) | 1 June 2018 – 31 May 2020 | 26,965,287 | • Testing manuals on nanomaterials reviewed and assessed based on international standards<br>• 2 publications & conference paper presentations |
| Up-Scaled Solution-Phase Synthesis of Metal Nanowires and its Application in Transparent Metal Nanowire Touch Panel | 1 May 2017 – 30 April 2019 | 12,873,211 | • Upgrading of Smart Materials Laboratory<br>• 6 publications<br>• 3 conference paper presentations |

Figure 6. Local Developments in Advanced Materials and Nanotechnology

There is also an existing roadmap that displays research areas for advanced materials and nanotechnology. However, among consultation with different research institutions, this is not utilized. It is only relevant to them when obtaining funding from government for projects that they already decided to initiate internally.

Over the years, the agencies' programs have produced competent S&T graduates, local & international paper presentations, and research publications covering a variety of scientific disciplines. Worth highlighting is the establishment of specialized research & testing centers similar to ADMATEL, AMCEN, & EPDC that propel the country's research efforts towards the more advanced areas of study.

The Advanced Materials & Nanotechnology personnel of DOST is composed of 47 bachelors graduates, 22 masters, and 34 PHDs – each having their own expertise and fields of specialization. Fields vary from Physics, Chemistry, Materials Science & Engineering, Agricultural Engineering, and Forestry. The facilities also boast of 49 units of equipment that they use in their projects and research efforts.

## Facilities

One of the main projects of DOST for Advanced Materials is the Advanced Device and Materials Testing Laboratory or ADMATEL, which is a revenue-generating testing laboratory for materials failure analysis and characterization. Since its fruition in 2013, the lab has already served clients from a wide range, including Automotive, Construction, Foods, Plastics, Paints & Coating, Metal Fabrication, Petrochemical, Batteries, Industrial Gases and Telecommunications. The facility was able to triple its revenue from P 5.02M in 2015 to around P17M in 2018.

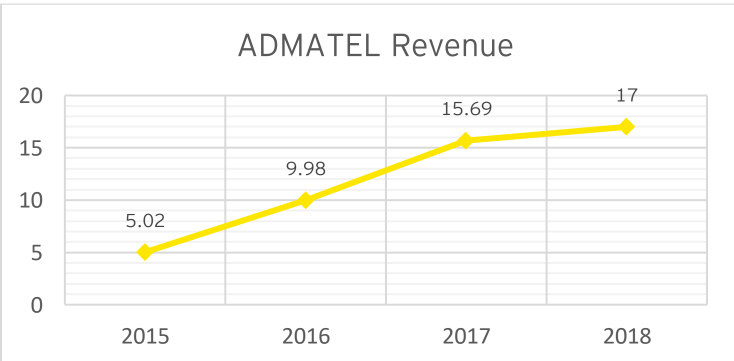



Figure 7. ADMATEL Revenue

Another DOST facility that generates revenue is the Electronics Product Development Center (EPDC), which is part of the agency's 2-year long EPIC (EPDC as Platform for Innovation and Collaboration) Program. Inaugurated in 2015, its main thrust is to function as a house for hardware & software tools for use in design, development, & testing for electronic products of companies and the academe. In 2016 until 2017 Q2, EPDC services were offered for free to its clients to be able to maximize the capacity of the Facility. 2018 revenue is around P 1.9M. and the facility serving around 45 clients.

In 2015, the Department of Science and Technology - Industrial Technology Development Institute (DOST-ITDI) opened the NanoTech Lab to the public to "provide R&D opportunities and technical services to local industries via world-class equipment and devices." This lab is equipped with the Atomic Force Microscope, Particle Surface Area Measurement, Scanning Electron Microscope, Dynamic Light Scattering Particle Size Analyzer, and the high-resolution field emission transmission electron microscope (FE-TEM).
However, at this stage, these aforementioned facilities focus on fully maximizing the capability and capacity of their facilities rather than their profitability. In fact, EPDC even offered their services for free until 2017 to ensure full utilization, even if it means sacrificing their profits. Tracking of the facilities' income is still being worked out by the administration.

# 3. Barriers to Advanced Materials and Technology Development

In constructing the strategic direction for Advanced Materials and Technology Development, we take into consideration the main challenges faced in this field. These challenges were placed under two primary classifications. The first classification considers these barriers according to their nature which are a) resources and infrastructure b) policy c) ecosystem and d) culture. The second classification, on the other hand, considers these under which phase of research and development these are usually encountered which are a) ideation b) prototyping c) niche production and d) mass production.

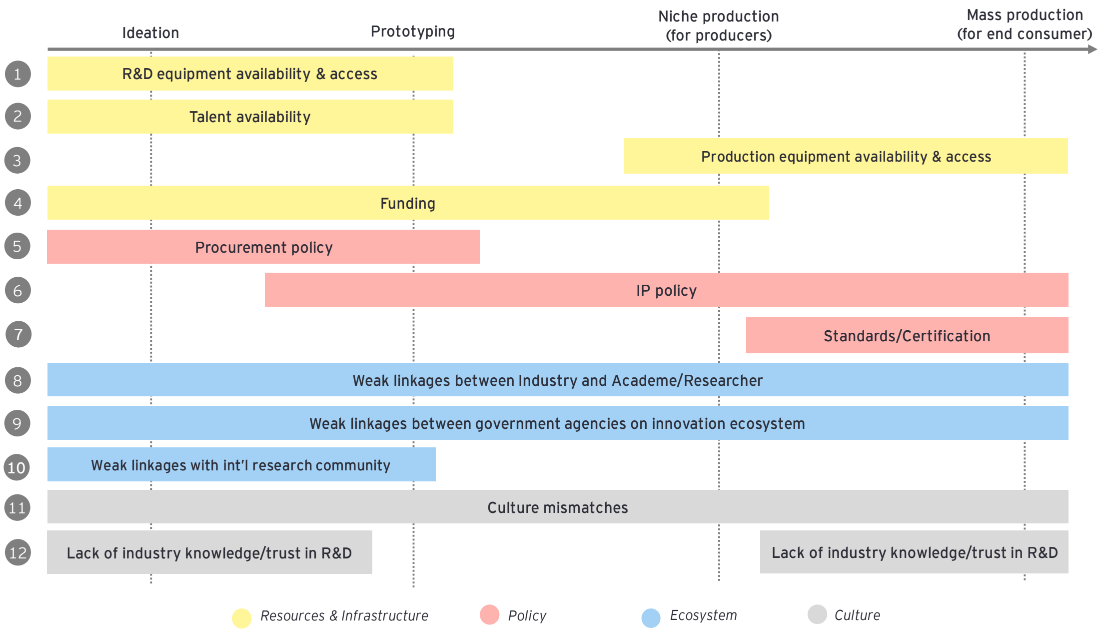



Figure 8. Barriers to Development of Advanced Materials and Nanotechnology

## Resources and Infrastructure

R&D equipment availability and access: This issue is relevant especially in the first phases of development, which are ideation and prototyping. As research and development begins, execution becomes a challenge as there are inadequately equipped laboratories, inaccessible laboratories that have unideal locations or are too far from universities, and limited access to prototyping equipment for certain types of manufacturing (i.e. electronics/semiconductors). Moreover, there is also a lack of facilities for Visayas and Mindanao as most of these are in Metro Manila, limiting research and development that can happen outside the capital. Lastly, there are also equipment that are no longer functional.

Talent availability: Similar to R&D equipment availability and access, the lack of talent availability is crucial for the phases of ideation and prototyping. There is a lack of experts who can train students/researchers in advanced technologies, techniques or concepts that can upgrade R&D initiatives. In the same light, there are also a lack of experts who can use the equipment available and analyze the results.  This limits the industry to capture higher-value segments in research and development (i.e. design).

Production equipment availability and access: Small-scale enterprises and producers do not have the facilities to adopt the technologies developed. There is a lack of small-scale fabrication capability for SMEs and no access to small-scale production equipment for certain types of manufacturing (i.e. electronics, semiconductors). This limits the potential of technologies to be adopted for commercial and industrial use.

Funding: Researchers performing basic research find difficulty in securing funds to do basic research since the outputs are non-commercializable though they have strategic and capacity-building benefits. There is also difficulty in securing funding without industry partners. This is exacerbated by the fact that there are no incentives or funding for companies to engage in R&D.

Policy

Procurement Policy: Government procurement process is slow and tedious since it requires many documents and approvals before the actual acquisition can be done. The long time-horizon needed for procuring the equipment may cause project timelines to be extended.

IP Policy: Researchers are not knowledgeable enough about business and regulatory requirements for procuring IP and thus might not be able to obtain reasonable terms in industry partnerships since industry partners want as much control and monetization rights as possible over technology.

Standards and Certification: Users and mass producers are apprehensive about adopting new technology without safety standards/certification that give some assurance that population, potential users are not at risk (i.e. nanotech for food applications, effects of nanotech on environment).

Ecosystem

Weak linkages between Industry and Academe/Researcher: Collaborations between industry developers and the academe usually arise from informal channels such as personal contacts, conferences, etc. There is no available ground to facilitate connection between the industry and the academe. The weak linkage causes R&D and skill development to be performed independently from industry outputs, causing low adoption of research results and skill mismatches.

Weak linkages between government agencies on innovation ecosystem: There isn't enough collaboration between different government agencies for R&D and innovation needs of researchers and private/public adopters.

Weak linkages with international research community: There is a lack of collaborative research and technology transfer between foreign players/experts and local researchers.

Culture

Culture mismatches: The difference in cultures of researchers, academicians and industry players make collaboration among the parties difficult since there are often disagreements on the needs, timeline, and other aspects of cooperation that discourage the different parties from working together.

Lack of Industry Knowledge/Trust in R&D: Industry is apprehensive & hesitant to adopt or make investments in technologies that have not yet been fully tried and tested. There is a lack of awareness on the benefits of technology developed which is caused by limited visibility to the functionalities and usefulness of these technologies and R&D to their productions and processes.

Upon a comprehensive review and understanding of both the local and global landscapes of

Advanced Materials and Nanotechnology, there are a lot of opportunities where the Philippines can progressively develop its infrastructural capabilities and the skills of its people. Although some difficulties still persist, we cannot disregard the potential of growth and expansion of local talent & expertise. In order to make this happen, the different stakeholders involved must be able and willing to contribute their resources and be open for collaboration with the others – thereby ensuring an environment that does not always just try to catch up with its peers, but stands out and flourishes in the global paradigm.

# 4. Strategy and Direction for Advanced Materials and Nanotechnology

The sectors of Advanced Materials and Nanotechnology are intermediate sectors, which means that their value is as input or enablers in the industry and will not be for immediate consumption by ordinary users. Thus, we cannot treat these sectors in the same way as other technologies, which are mainly product-based & therefore easier to transition towards commercialization. After consultations with stakeholders from the academe, industry, and government, the following are the primary challenges identified in Advanced Materials and Nanotechnology research and development:

- Lack of infrastructure and difficulties in resource sharing: Inaccessible or unavailable equipment and facilities to further research
- Low awareness: Technological benefits are not widely known by industry users, taking much convincing to adopt
- Lack of collaborative efforts: No readily available database of Filipino subject matter experts & sectoral projects for open access to researchers
- Lack of private sector collaboration and funding: Low receptivity of industry toward researcher outputs; Low interest from private funding; No national database of private sector companies
- Shortage of talent in the academe and in research: Finding people for research institutions & faculty in the academe; Quality of HS graduates
- Difficulties in negotiating IP sharing: Length of processing time for IP applications; Inconsistent IP policies between universities & industry

One key framework we used to emphasize the difference between R&D expectations in Advanced Materials and Nanotechnology versus sectors more geared towards final products is the Innovation Matrix. This attempts to classify R&D according to how well it serves to solve a specific problem and whether it falls under a domain where solutions can be expected to arise. Depending on where in this matrix the R&D falls, the responsibility for funding and enabling development may skew more towards the private sector (for sustaining innovation, where problem and solution domain are well-defined – e.g. Miniaturizing electronics) or more towards the public sector (for basic research, where there is no well-defined problem and solution domain – e.g. Tinkering with new materials with unusual properties).

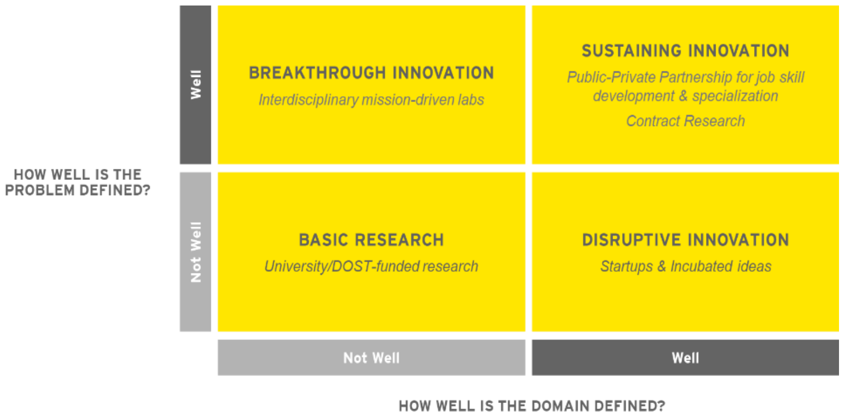



*Figure 9: The 4 Types of Innovation give us a framework for how to strategize for or fund R&D depending on how well the solution domain and problem statement is defined.*

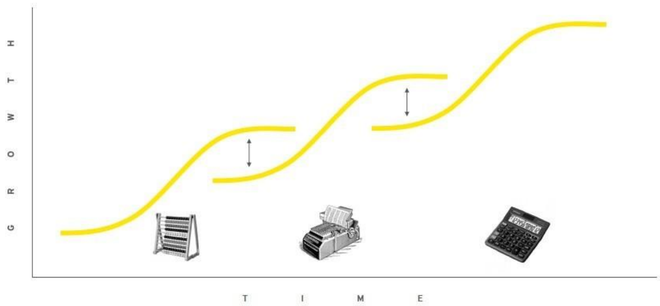



*Figure 10: The overlapping S-curves show how technology evolves over time - from birth to maturity - before eventually reaching disruption and being displaced by a new technology*

Another framework that we employed in conceptualizing the roadmap is Innovation S-Curves. The S-Curves illustrate technological growth over time and show the major phases of a technology life cycle – ferment, take-off, maturity, and discontinuity – the latter characterized by the jump from one S-Curve to the next. Applying this to the roadmapping activity, stakeholders identified technologies under the three different curves, according to their technological viability and maturity.

What the S-Curves emphasize is that different strategic & funding approaches will be applicable for each technology research area, depending on what curve it is perceived to be on. The metrics for evaluation will also differ according to the curve the technology is on.

| | Curve 1: Mature globally, but may be new to PH | Curve 2: Mainstream R&D | Curve 3: Advanced R&D, even in advanced economies |
|---|---|---|---|
| **Strategy** | Capacity Building<br>Upskilling<br>Frugal innovation<br>Local R&D in niche areas | International collaboration<br>International joint research<br>Local research | International exposure<br>International collaboration |
| **Financing** | Private sector - Large corporates, SMEs<br>Private sector - Startups, Incubators | Private sector - Large corporates<br>PPP | Public R&D funding |
| **Metric/ Output** | **Partnerships:** Adopters of technology, consumers<br>**Product:** Saleable commercial product<br>**Policies:** Safety standards, certifications<br>**People:** Trained technical personnel, High-skilled practitioners | **Patent:** New processes, formulations<br>**Places:** Joint facilities for research, industry use (testing, fabrication)<br>**Partnerships:** Willing hosts for facilities, laboratories, research personnel<br>**People:** High-skilled practitioners, researchers, professors. | **Publication:** Exposure in scientific journals of Filipino research<br>**Patent:** New processes, formulations<br>**People:** Specialized researchers |

Figure 11. Strategic and Funding Approaches based on S-Curves

The first curve would refer to technology that is mature by global standards, regardless of whether the knowledge or capability exists in the Philippines. Since these technologies are already established internationally, it is a huge opportunity to enhance capacity building of researchers & upskilling of the workforce in the country. The outputs from initiatives for this curve will be more tangible, such as commercially viable products, industry-academe partnerships for research and training, and successful transfer and licensing of technology.

The second curve would refer to R&D that is considered mainstream all over the world. These are innovations that are expected to have technical viability but are not fully ready for commercial viability. Local talent may be exposed to these ideas, but still have limited understanding and insufficient experience to execute R&D in these emerging fields. For these technologies, it will be a good strategy to collaborate with international researchers and do some local research with the participation of some large corporates who are conscious about remaining at the forefront of R&D. Outputs will include partnerships and willing hosts for shared facilities, skilled practitioners and specialists, and new patents and processes.

The third curve would refer to advanced R&D, for which some technical viability is anticipated, but not yet established. This still requires further research and refinement even on a global level, before commercial viability can even be explored. The strategy is to expose the local scientific community internationally and create collaborations that will broaden our horizons for research and development. Due to the remoteness of commercial viability for these technologies, private funding can be scarce. This is where government can primarily provide funding, acknowledging the potential risk yet high returns that these fields can give.

## 4.1 Industry Targets

The technologies that were identified & classified through the S-Curves will then factor as key research areas per industry. The criteria for selection of priority industries include the following:

a.) **Immediate financial & economic impact to the country**: In classifying prioritizations, it is essential to know the value of the technology to the country. The financial valuation aspect is the normal project evaluation which takes into consideration the inflows that the project will generate as well as the costs to be incurred from such. Economic valuation creates a more holistic view that takes into consideration even non-financial revenues as it contemplates the overall impact of the project to the economy and welfare of the country and its citizens.

b.) **Availability of local skill and knowledge base:** This item pertains to the current capability of local talent in the targeted technology. It involves looking into technical knowledge and skills that is required from the Filipino researchers in order to execute the projects at the hand. More than that, it also takes into account the willingness and ability of the local base to support the development of particular project, in an effort to further the capacity building in the country. The availability of local Philippine talent would be essential in prioritizing the projects because this would factor well into which projects are easily achievable in the short run, and which would need further capacity building for achievement in the long run.

c.) **Present status of the product/technological development in the Philippines:** It is relevant to take a look at where the country is now with respect to the R&D of the product or technology locally, taking into consideration whether the local R&D expertise has already made progress on developing the technology. This will allow us to assess whether there is a need to first increase understanding about the research area through international exposure or trainings before homegrown research can be attempted.

With this, we have identified Rail, Food/Agriculture, and Sustainable Environment as quick wins; then Aerospace, ICT/Semiconductor, and Automotive as long-term target industry applications.

The quick wins were identified because these have immediate adopters who can commercialize or utilize the technologies. The long-term target industries have high impact to the country in terms of exports or economic value but would still require more capacity building before the industry players can be convinced to form more extensive partnerships or make bigger investments.

The following are some research areas in the fields that were identified:

## 4.2 Programs

In our roadmaps, we emphasize the need for extensive capacity building that goes beyond mentioning specific technologies but also includes programs that would further equip our scientists, research, and facilities with a holistic support system needed to form effective research and development and bring them closer to industry involvement.

Although DOST has already put numerous programs in place to promote the right kinds of partnerships and cultivate more talent, we put emphasis on two program frameworks that can be used to design initiatives moving forward.

1. **Global Research & Balik Scientist Program.** The main goal for the Global Research & Balik Scientist Program is to cultivate experts to go beyond their scientist role and be directly involved with the other facets of development – **facility design**, **operations, & oversight**, **capacity building programs**, **industry & international liaisons**, and the like. Each scholar or Balik Scientist may have unique roles and responsibilities, but these must still be integrated into the entire strategic direction of development.

2. **Facilities and research centers.** There is a need to design facilities to suit the needs of all parties involved in the R&D ecosystem: Researchers, Academe, and Industry. The capabilities of existing facilities should be elevated to be more accessible to all three kinds of stakeholders that would provide a collaborative environment. Currently, there is a culture of closedness and working in silos. It must be ingrained in the administrators of all facilities that they are not merely custodians or users of the equipment but are also stewards tasked with maximizing the reach of the shared resource.

# 5. Action Plan

The success of the roadmap is contingent on continuous capacity building, investment, and simultaneous preparation. The 'quick-wins' of the first year of implementation will carry on throughout the entire course of the presented roadmap as the purpose they serve is cumulative in their effect. The roadmap integrates existing programs and initiatives to ensure planned activities are in-line with the national technological vision and mission.

The implementation of the roadmap will best be achieved through a stated-led sectoral incubation where the different agencies will work together and perform their respective mandates towards three common goals - co-investment, co-financing, and co-development – described in the following bullets:

- Expanding pool of resources for advanced materials and nanotechnology development by creating multiple, varied channels for government participation
- Innovation and development financed by government
- Adoption guaranteed through various government channels

**Recommendation 1: Human Capital Development**

Human Capital development involves building knowledge and expertise on advanced materials and nanotechnology targeted for the public, industry users and experts in the field. This will be done through extensive knowledge-sharing activities through conducting forums and relevant programs, emphasizing curriculum across educational levels and institutions, and partnering with foreign institutions and experts to assist in knowledge-sharing.

**2020-2021: Lay Foundations**

(1) Awareness in secondary and tertiary levels of education

For the first two years, human capital development will focus on engaging two stakeholders namely the potential practitioners/experts in the field and future users from industry or the general public. This will be done through integrating secondary and tertiary levels across educational institutions to encourage students to pursue studies in the field. It must be ensured that STEM students have a good foundation on the subject areas necessary for pursuing studies in the field of advanced materials and nanotechnology and being able to apply it to solve real-world problems. At the tertiary level, industry inputs must be considered for students to understand the field not just in a theoretical and scientific standpoint, but also in the standpoint of how to solve industry problems.

(2) Global Research Program

The long-term objective of the Global Research Program is to bring global-standard research, knowledge, and connections to the Philippines. This involves sending talented and committed researchers with a pioneering mindset overseas for extensive learning, exposure, and research. Regarding the latter, the researcher's involvement must remain as far into the process as possible, even up to spin-off and commercialization. Part of the program design is to task these researchers with repatriating their experience and any IP they may develop for implementation in the Philippines. Aside from the usual responsibility of teaching, they must be prepared to launch a start-up with assistance and grants from the DOST, who must ensure that provisions for knowledge transfer are also put in place to deploy the research outcomes in the Philippines for economic growth or public good. If in the course of his expatriation, the researcher is able to develop something with a potential foreign adopter, attempts can be made to encourage the industry partner to consider the

Philippines as a manufacturing destination.

### 2022-2023: Build Up

Upon building the critical foundations, the country must then exploit this knowledge and capability for industry wide applications of advanced materials and nanotechnology. This will be done through the introduction of targeted training electives in advanced materials and nanotechnology to promote employment readiness of graduates for certain industry applications and incorporation of student exposure to real-world applications of technologies through internships with industry partners. The training will also involve foreign experts and institutions facilitating knowledge-sharing activities in the country. While research and innovation in advanced materials and nanotechnology is a productive endeavor among research and academic institutions, there is a lack of awareness among the public and industry with regards to how critical these technologies are in the progress of their activities, thus, hindering their adoption. Facilitating forums and programs aimed at educating industry and consumers must effectively communicate relevant information regarding advanced materials and nanotechnology, highlighting its value. There must be favorable receptivity among the public of commercial applications for these fields. Furthermore, we can improve on the existing capacity of our research and academic institutions by gaining more knowledge and increasing our capability for research and development in these fields through collaboration with foreign institutions that have more extensive knowledge on advanced materials and nanotechnology.

### 2024: Achieve

In the last phase, we will improve workforce preparation for opportunities with multinational partners in priority areas such as aerospace/automotive/rail, and ICT/semiconductor. This means that at this point of development, knowledge-sharing and training must be at par with global standards and must move to higher areas of research. Moreover, knowledge and skills transmission from the Global Research Program must be evident here through concrete applications in the local research and development landscape.

## Recommendation 2: Industry Collaboration

This aims to create interdependence among research and industry sector in addressing each other's needs. For the next five years, there must be an increase in private investments from large corporations, SMEs and venture capital investors, maximization of private sector in utilizing national laboratory and other facilities for their R&D and commercial development, and utilization of tax and non-tax benefits by private corporations and SMEs.

### 2020-2021: Lay Foundations

The first two years focuses on laying down the framework upon which partnerships between these will be established between research and industry sectors to technology adoption for concrete applications of advanced materials and nanotechnology. To do this, we will increase awareness of the uses, applications and safety of these fields. This will be done through the establishment of programs that will highlight the value of advanced materials and nanotechnology to solve industry needs through various means such as internships, immersions and forums. One of the roadblocks discussed in this study is the lack of visibility of how advanced materials and nanotechnology can provide value to process and supply chains across different sectors. Thus, on-the-ground collaborations among research and industry will facilitate effective knowledge-sharing that will allow industries to see the how advanced materials and nanotechnology can concretely benefit their value chains. There also needs to be clarity on the safety and adverse effects of these technologies to build confidence among those who are hesitant to adopt these new and relatively untested technologies.

Furthermore, we will build and publish a database with information regarding technology researches, publications, laboratories and equipment, and skills developed. As discussed, professionals among industry and research sectors often find it difficult to search for contacts and information necessary to address their needs. This database will allow stakeholders to quickly access information that they need and communicate more effectively.

Beyond facilitating knowledge-sharing, further cooperation will be encouraged among sectors, through the communication of government policy incentives and benefits to crucial stakeholders. They must be informed of the fiscal incentives provided by the TRAIN law that will give them tax deductions for research and development, training, and infrastructure expenditures and income tax holidays/reduced CIT for pioneer enterprises. The application of laws catering to R&D which includes the Philippine Innovation Act, Innovative Startup Act, and DOST Balik Scientist program must be exploited in the pursuit of advanced materials and nanotechnology development.

Lastly, as the pilot for industry collaboration, the first two years of the roadmap will establish partnerships with farms and small-scale agribusiness for applications in agriculture. This is primarily because, technology adoption in agriculture is an easy win given that the government is highly involved in different programs concerning the growth and development of this sector such as in improving yield and production, ensuring food security, and securing livelihood of farmers. Thus, this sector is highly receptive to government intervention where we can easily implement advanced materials and nanotechnology applications.

### 2022-2023: Build Up

Thereafter, the next two years will have advanced materials and nanotechnology R&D applied across more industries. After proving successfully use cases in agriculture and cultivating awareness and capacity in the first two years, we must develop partnerships with local entities to promote additive manufacturing for small-scale fabrication in aerospace, automotive, semiconductor/electronics, and construction sectors. Given that the application of advanced materials and nanotechnology during the first two years showed a significant improvement in the productivity and growth of the agricultural sector, other industries should be encouraged to adopt technologies in this field for the enhancement of their products, systems and processes. On top of this, we will attract foreign players in advanced materials and nanotechnology to establish manufacturing base in the Philippines.

### 2024: Achieve

In this last phase, we will create research and industry long-term partnerships with success examples. There must be existing collaborations between industry and research, improved alignment between R&D direction and industry needs and greater industry confidence in local R&D.

Recommendation 3: Infrastructure & Policy Development

In order to ready industries for adoption locally and internationally, supporting infrastructures and policy are critical in maximizing the capability of the Philippines in Advanced Materials and Nanotechnology. This includes setting standards for Advanced Materials and Nanotechnology and constructing facilities for research and development.

**2020-2021: Lay Foundations**

One of the hurdles in adopting nanotechnology in the country include the lack of regulations and standards around advanced materials and nanotechnology. These include guidelines with regards to its safety, testing legislation and regulation and protocols for environmental safety and risk management. A special committee with individuals composed of scientists, engineers, government advisers and others who have the expertise can be formed to spearhead the creation of standards. Existent protocols from other countries can be adapted to be applied to the Philippine context. Creating standards is important to foster trust in the use of products and processes in advanced materials and nanotechnology. Moreover, these must be localized to be appropriate for the Philippine context.

During the first two years, one of the primary action steps is the designing of the framework for the Advanced Materials and Nanotechnology Hub. The value and specific responsibilities this facility will fulfill will be discussed in more detail in Section 5 of this paper. To emphasize, linkages must be established between Advanced Materials and Nanotechnology Hub and other institutions and laboratories for more immediate industry applications. This means that this hub must have strong networks with laboratories and research institutions across the Philippines (e.g. National Rail Institute, Food Innovation Facility, AMCen) as well as with industry. This will ensure that any problem statements and new discoveries made across different institutions will be communicated to the central hub for its efficient dissemination to relevant stakeholders to ensure its visibility and adoption. Moreover, communication between research institutions will be done effectively which means that they can easily tap for assistance among each other to hasten the research and development process.

**2022-2023: Build Up**

In this phase, we will co-invest in facilities and equipment to augment ability of local hub to serve R&D needs of researchers and industry. These must fulfill MSTQ-type (metrology, standards, testing, quality). Ideally, these laboratories should be accredited internationally through proficiency testing. These must also have necessary tools and equipment to accommodate extensive testing and research in a variety of advanced materials and nanotechnology. Most importantly, these facilities must have the capability for characterization, functionalization and packaging in the research and development process.

Lastly, we will build up administrative support for researchers in patent filing and publication. One of the primary goals in this phase is to launch the Advanced Materials and Nanotechnology Hub. The key functions and features of this was already discussed in the previous section. Connecting this to the programs mentioned, there have been exceptional cases in the past where Balik Scientists formed new facilities in their host universities to enhance research capabilities there. Ideally, the people that will oversee the proposed

Center should have a similar mindset, one that is characterized by a global perspective and a conscious & persistent effort to bring such perspective to the Philippine context.

**2024: Achieve**

In the last phase, we will harmonize local and international standards for nanosafety. This simply means that our standards must be at par globally. To further advanced materials and nanotechnology development and move up the value chain in various industries, this phase also includes co-investing in facilities and equipment for fabrication of nanorobotics, NEMs and other more advanced areas. This may serve as a case for global players to locate part of its operation or R&D in the country.

**Recommendation 4: Research & Development Key Areas**

Identifying key areas for research and development will enable acceleration of the development progress of the selected areas. Full support must be provided to these areas to generate productive output. As discussed, the identification and classification of these technologies across different years depend on their phase of development in the S-curve and the criteria for R&D prioritization which are immediate financial and economic impact to the country, availability of local skill and knowledge base, and present status of the product/technological development in the Philippines.

**2020-2021: Lay Foundations**

For the first two years, six areas are identified as focal areas of research and development. The six areas are considered primarily because these technologies are ready for adoption based on their current state of development and availability of human capital. These are also technologies that are already being extensively used abroad. Moreover, these are areas that will positively impact development to industries applicable in terms of financial value, economic and environmental welfare, among others. These areas are:

- **Coating- Materials:** Coatings of nanomaterials (ex. nano-structured polymers) for lightweight & strength applications
- **Manufacturing - Materials:** Nano-enabled materials from Natural/Indigenous raw materials and waste/by-products (bioplastics, nanocellulose, etc.)
- **Nanosensors - Applications**: Sensors to detect emerging diseases
- **Supercapacitors:** Development of supercapacitors energy storage and generation out of advanced materials (ex. electrolytes)
- **Fuel Cells:** Component development
- **Manufacturing - Materials:** Nanofiber materials as food packaging; Development of metal powder for additive manufacturing
- **Nanosensors - Applications:** Smart packaging; Sensors to detect harmful substances in food
- **Supercapacitors:** Development of supercapacitors out of indigenous materials and waste/by-products

**2022-2023: Build Up**

For the third and fourth year, the technologies considered are expected to have a positive impact on development as well. However, these technologies are still under material development even on a global scale.. Some of these have also been developed but there is still lack of capability to produce them on a wider scale for adoption. In this phase, the focal areas determined are:

- **Coating - Materials:** Coatings of nanomaterials (e.g. Diamond-Like-Carbon (DLC), MAX phase) for lightweight & strength applications
- **Manufacturing - Methods:** Additive manufacturing for Semiconductor/Electronics, Aerospace, Automotive, and Rail applications
- **Manufacturing - Materials:** Strong and light-weight materials from nanocomposites, nanocement, magnesium-alloys, etc.
- **Nanodelivery - Applications:** Nanofertilizers and nanovaccines to increase crop health and quality
- **Nanosensors - Applications**: Nanodiagnostic devices such quantum dots for health monitoring
- **Supercapacitors**: Develop solid-state supercapacitors and high-capacity supercapacitors out of better materials (conductive polymers, nanometal-oxides, lithium-air)
- **Fuel Cells:** Deployment for energy generation and storage
- **Nanodelivery - Applications:** Nanodevice fabrication for drug delivery and diagnostics (nanobots)
- **Nanosensors - Applications:** Agricultural detection of pathogens, pesticide residues and determination of crop quality
- **Supercapacitors:** Develop composite supercapacitors from conductive polymer and nano metal-oxide composites

### 2024: Achieve

Technologies in this phase are areas that currently have minimal to no local research but have high potential for development. Research on these are still ongoing internationally as well. Once we are ready for higher areas of research and technology, these are technologies to focus on. In this phase, the following focal areas determined are:

- **Manufacturing - Methods:** Nanofabrication techniques for electronics and materials manufacturing (NEMS, memory tech, blow spinning)
- **Manufacturing - Materials:** Adoption of advanced materials such as intermetallics, nanoclays and smart fibers
- **Supercapacitors:** Flexible solid-state and composite supercapacitors for electronics manufacturing

# 6. Business Cases

The following section will describe institutions that would help further the development of emerging technologies. The establishment of facilities and institutions is not new to DOST, but the execution of these has not necessarily contributed to the holistic development of the technology due to inadequate representation from certain sectors (academe, research, or industry). Some points raised include the following:

- Facilities are inaccessible to researchers in terms of distance, availability, and receptivity of administrators
- Facilities do not have immersion, internship, or other exposure and training programs
- The state-of-the-art equipment is a great learning opportunity, but they are understaffed and take in few operators and no intern operators
- The products and services are more expensive and not necessarily at par with global standards of quality/accuracy

The result has been facilities whose usefulness skews towards certain sectors only, instead of becoming a platform for achieving true synergy between industry, research, and academe – a hotbed of innovation and application.

## 6.1 SEIPI Science and Technology Center (SSTC)

In the recently developed Product and Technology Holistic Strategy (PATHS) roadmap, a project funded by DTI and administered by DOST, SEIPI envisions the SEIPI Science and Technology Center as a facility that will enable more advanced research & development through several laboratories all throughout the country:

- IC Design Lab, which will train faculty & students in host universities
- Lab-scale Wafer Fabrication Facility, which may be a possible showcase for Industry 4.0, and
- R&D Laboratory

SEIPI targets the establishment of the first IC Design Lab in DLSU Laguna, and the others are planned to be in certain universities in Visayas and Mindanao. The group reached out to other countries with similar facilities to gain insights in the development of the Center.

Once these facilities are established, these will be highly beneficial to both researchers and industry alike since they now have access to facilities and equipment that they usually must bring to other countries for them to be tested or developed. These will expand the possibilities of research and bring it to the next level.

However, as these facilities are being developed, it is important to steer them in a direction that will maximize the utility for the country. For instance, the IC Design Labs, rather than being a mere training facility, can be designed with research collaborations in mind. Similarly, the lab-scale wafer fabrication facility should be designed and set up to cater to academe for trainings and researchers for novel prototyping. These facilities should be open to researchers in advanced materials and nanotechnology as well, since the products focused on are important application of these three technologies. Most importantly, the founders and the administrators of these facilities must be given a clear and comprehensive mission to cover the needs of, and keep their doors open to, academe, industry, and researchers.

## 6.2 Advanced Materials and Nanotechnology Hub

The concept of the Advanced Materials and Nanotechnology Hub is not new, but we redefine it out of the need for a focal facility that would integrate all the resources and efforts for the nanotechnology sector, in an attempt to reduce the difficulty of having numerous yet dispersed initiatives. The governing body will be composed of experts among industry, research, academe and government, ensuring holistic representation.

The responsibilities of this Center should cover:

a. **Facilities.** Acquire, operate, and maintain equipment necessary for studies and R&D in nanotechnology. Ensure accessibility to users of all backgrounds (research, academe, industry) and from all over the country. Maintain a database of and foster relationships with other facilities nationwide and coordinate on procurement, usage, and access for any entity who needs it.
b. **Programs.** Implement programs to encourage greater collaboration between sectors (e.g. Joint research for researchers of different backgrounds or affiliations, Immersion and internships for student exposure to industry and to the facility, Fora and conferences for facilitating partnerships and network building).
c. **Liaison and Network.** Build and maintain relationships with foreign counterparties to elevate local R&D environment to global standards. Actively grow usage, clientele, and partnerships.
d. **Database & knowledge repositories.** Actively monitor relevant publications and studies, and maintain a database of past and present studies and efforts in the sector. Build up and maintain a database of connections with:
    - Subject Matter Experts and Researchers, indicating their technology sectors, specializations and contact
    - Industry stakeholders for commercialization and scale up – manufacturers, fabricators
    - Funding sources – Venture capital, Private equity, Incubators
    - Foreign collaborators, institutions
    - International contacts in Academe, Research, and Industry
e. **Training.** Allow greater access and immersion for researchers and students long term to complete projects and studies. Adopt student interns as staff and trainees. Produce more trained superusers of specialized equipment.
f. **Research direction.** Establish the strategic direction of priority investment areas for advanced materials and nanotechnology research, according to global scientific trends and the needs of industry and government.
g. **Enablement.** Streamline the processes on acquiring intellectual property rights, procuring necessary equipment, and approval of subsidies and grants.
h. **Standardization & Certification.** Study foreign policies on nanotechnology use and safety and create local standards aligned to the former for greater credibility and appreciation by local industry. Manage certification programs to accredit laboratories, facilities, equipment, and products.

The sustainability of the Center will be ensured through private and public investments. The initiation of this facility will primarily be handled and facilitated by the government. Subsidies and grants must be acquired from relevant stakeholders among government, industry and research institutions by acquiring partnerships and collaborations. Collectively, this must ensure successful establishment of a governing body, a physical facility, hiring relevant personnel, and research and development initiatives. Eventually, investments from public and private sectors including large corporations, SMEs and even venture capitalists who will conduct their research, testing, and fabricating in this facility must be continuous.

Connecting this to the programs mentioned in the previous section, there have been exceptional cases in the past where Balik Scientists formed new facilities in their host universities to enhance research capabilities there. Ideally, the people that will oversee the proposed Center should have a similar mindset, one that is characterized by a global perspective and a conscious & persistent effort to bring such perspective to the Philippine context.

# 7. Other Roles

## 7.1 Industry

To maximize the economic impact of the R&D initiatives of the research sector and the education and training provided by the academe, industry must have an active participation with research and academe. The objective is to ensure that the R&D culture is deeply ingrained in local companies, so that they will be comfortable in participating in collaborations such as contract research and product adoption. Some of the roles they must fulfill are as follows:

- Initiate and participate in opportunities that will allow industry to constantly interact with research and academe
- Actively find and involve themselves in research and development that will be value-adding to their companies
- Participate in programs such as Balik Scientist, stakeholder meetings, and the like to be involved in research and development discourse
- Utilization of research laboratories and facilities for their research and development initiatives

## 7.2 Department of Trade and Industry (DTI)

Because this approach aims to involve the industry at a larger scale, the DTI must play an active role in cultivating an R&D culture across Philippine industries. In order to do this, the following are some of the roles DTI must fulfill:

- Assist in industry policy formulations that will serve as the framework by which industry will efficiently be able to participate in research and development initiatives
- Provide support services for industry players who want to connect to the innovation landscape
- Manage relationships within industry and among other stakeholders to foster cooperation and collaboration

## 7.3 Department of Finance (DOF)

To encourage companies to engage in innovative endeavors, new laws make incentives available in the form of tax credits or deductions. In line with this, the DOF must consider the direction of DOST and DTI in promoting R&D in industry and monitor the granting of innovation incentives. These should also be reviewed regularly to assess if they are still effective and justifiable to support innovation.

# Appendix: Roadmaps

## A. Advanced Materials and Nanotechnology Program Roadmap

| | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|
| Recom 1: Human Capital Development | **Stakeholder Engagement:** Increase awareness of advanced materials and nanotechnology in STEM curriculum (A/G)<br><br>**Stakeholder Engagement:** Ensure that the value of advanced materials and nanotechnology is communicated to industry and consumers **(A/I/G)**<br><br>**Capacity Building:** Improve retention of skilled experts at research institutions (A/G) | **Capacity Building:** Integrate advanced materials and nanotechnology industry principles and practices into tertiary curriculum (A/G)<br><br>**Capacity Building:** Develop Global Research Program to send local researchers abroad to raise local talent to global standards by providing exposure and training in renowned research laboratories before returning to the Philippines (A/G) | **Capacity Building:** Introduce targeted training electives in advanced materials and nanotechnology to promote employment readiness of graduates for certain industry applications (A/G)<br><br>**Capacity Building:** Incentivize foreign experts to conduct training programs or teach in the Philippines (A/G) | **Capacity Building:** Incorporate student exposure to real-world applications of technologies through internships with industry partners (A/I/G)<br><br>**Capacity Building:** Promotion of achieved results in the R&D of advanced materials and nanotechnology to highlight its value (A/G) | **Capacity Building:** Improve workforce preparation for opportunities with multinational partners in priority areas such as food/agriculture, aerospace/automotive/rail, ICT/Semiconductor (A/I/G)<br><br>**Application:** Inject knowledge and lessons from Global Research Program into local research and development landscape (A/I/G) |
| Recom 2: Industry Collaboration | **Stakeholder Engagement:** Increase awareness of industry of the uses, applications, and safety of advanced materials and nanotechnology (A/I/G)<br><br>**Stakeholder Engagement:** Ensure communication of government policy incentives and benefits to stakeholders (G)<br><br>**Stakeholder Engagement:** Establish a network for private and research sector partnerships (A/I/G) | **Stakeholder Engagement:** Establish programs to obtain visibility into industry needs (e.g. internships, immersions, fora) (A/I/G)<br><br>**R&D/Application:** Build and publish database with information regarding technology researches, publications, laboratories and equipment, and skills developed (A/G)<br><br>**Stakeholder Engagement:** Partner with farms and small-scale agribusiness for applications in agriculture (A/I/G) | **Stakeholder Engagement:** Develop partnerships with local entities to promote additive manufacturing for small-scale fabrication in aerospace, automotive, semiconductor/electronics, and construction sectors (I/G)<br><br>**Application:** Application of advanced materials and nanotechnology in value chain of industries (I/G) | **Infrastructure/Stakeholder Engagement:** Attract foreign players in advanced materials and nanotechnology to establish manufacturing base in the Philippines (G) | **Stakeholder Engagement:** Create research and industry long-term partnerships with success examples (A/I/G) |

| | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|
| Recom 3: Infrastructure & Policy Development | **Policy:** Design framework for Advanced Materials and Nanotechnology Hub (facilities, network, and council) (A/I/G)<br><br>**Policy:** Streamline approval process and monitoring and increase availability of grants and subsidies for research (G)<br><br>**Policy:** Develop localized version of international standards on Nanosafety (G) | **R&D/Stakeholder Engagement:** Create linkages between Advanced Materials and Nanotechnology Hub and other institutions and laboratories for more immediate industry applications (e.g. National Rail Institute, Food Innovation Facility, AMCen) (A/G)<br><br>**Policy:** Empower Hub to ensure the proper enforcement, monitoring and compliance for regulations and standards established (G)<br><br>**Policy:** Set certification standards for local applications of Advanced Materials and Nanotechnology (G) | **Infrastructure:** Launching of Advanced Materials and Nanotechnology Hub (A/I/G)<br><br>**Policy:** Increase administrative support for researchers in patent filing and publication (A/G) | **Infrastructure:** Co-invest in facilities and equipment to augment ability of local Hub to serve R&D needs of researchers and industry: characterization, functionalization, packaging (A/I/G)<br><br>**Policy:** Ensure that safety standards and regulations formed are at par with international testing and assessment standards (G) | **Infrastructure:** Co-invest in facilities and equipment for fabrication of nanorobotics, NEMS, etc (A/I/G)<br><br>**Policy:** Harmonize local and international standards for Nanosafety (G) |
| Recom 4: Research & Development Key Areas | **Coating - Materials:** Coatings of nanomaterials (ex. nano-structured polymers) for lightweight & strength applications<br>**Manufacturing - Materials:** Nano-enabled materials from Natural/Indigenous raw materials and waste/by-products (bioplastics, nanocellulose, etc.)<br>**Nanosensors - Applications:** Sensors to detect emerging diseases<br>**Supercapacitors:** Development of supercapacitors energy storage and generation out of advanced materials (ex. electrolytes) | **Fuel Cells:** Component development<br>**Manufacturing - Materials:** Nanofiber materials as food packaging; Development of metal powder for additive manufacturing<br>**Nanosensors - Applications:** Smart packaging; Sensors to detect harmful substances in food<br>**Supercapacitors:** Development of supercapacitors out of indigenous materials and waste/by-products | **Coating - Materials:** Coatings of nanomaterials (e.g. Diamond-Like-Carbon (DLC), MAX phase) for lightweight & strength applications<br>**Manufacturing - Methods:** Additive manufacturing for Semiconductor/Electronics, Aerospace, Automotive, and Rail applications<br>**Manufacturing - Materials:** Strong and light-weight materials from nanocomposites, nanocement, magnesium-alloys, etc.<br>**Nanodelivery - Applications:** Nanofertilizers and nanovaccines to increase crop health and quality<br>**Nanosensors - Applications:** Nanodiagnostic devices such quantum dots for health monitoring<br>**Supercapacitors:** Develop solid-state supercapacitors and high-capacity supercapacitors out of better materials (conductive polymers, nanometal-oxides, lithium-air) | **Fuel Cells:** Deployment for energy generation and storage<br>**Nanodelivery - Applications:** Nanodevice fabrication for drug delivery and diagnostics (nanobots)<br>**Nanosensors - Applications:** Agricultural detection of pathogens, pesticide residues and determination of crop quality<br>**Supercapacitors:** Develop composite supercapacitors from conductive polymer and nano metal-oxide composites | **Manufacturing - Methods:** Nanofabrication techniques for electronics and materials manufacturing (NEMS, memory tech, blow spinning)<br>**Manufacturing - Materials:** Adoption of advanced materials such as intermetallics, nanoclays and smart fibers<br>**Supercapacitors:** Flexible solid-state and composite supercapacitors for electronics manufacturing |

## B. Advanced Materials and Nanotechnology Technology Roadmap

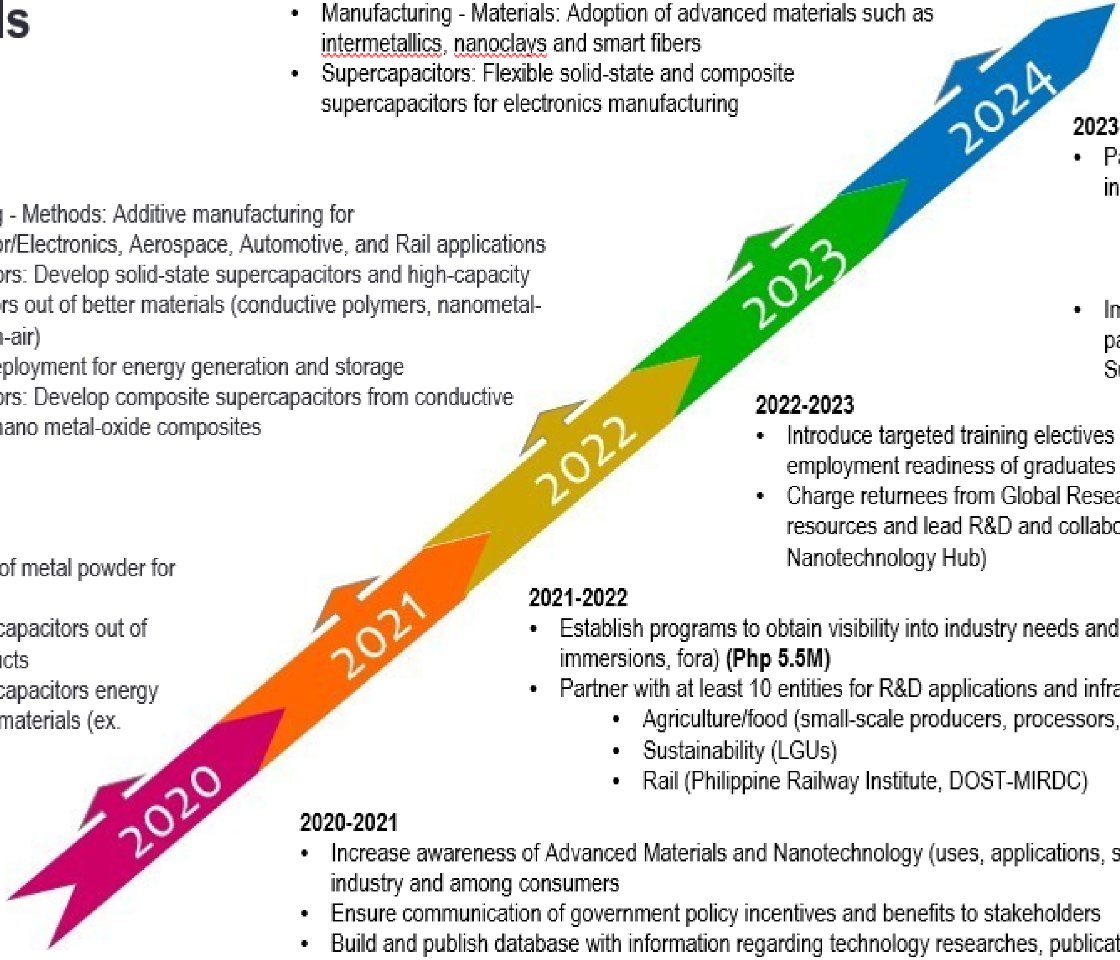
# Technology Roadmap

## Advanced Materials

**2020-2021**
- Fuel Cells: Component development
- Manufacturing - Materials: Development of metal powder for additive manufacturing
- Supercapacitors: Development of supercapacitors out of indigenous materials and waste/by-products
- Supercapacitors: Development of supercapacitors energy storage and generation out of advanced materials (ex. electrolytes)

**2022-2023**
- Manufacturing - Methods: Additive manufacturing for Semiconductor/Electronics, Aerospace, Automotive, and Rail applications
- Supercapacitors: Develop solid-state supercapacitors and high-capacity supercapacitors out of better materials (conductive polymers, nanometal-oxides, lithium-air)
- Fuel Cells: Deployment for energy generation and storage
- Supercapacitors: Develop composite supercapacitors from conductive polymer and nano metal-oxide composites

**2024**
- Manufacturing - Materials: Adoption of advanced materials such as intermetallics, nanoclays and smart fibers
- Supercapacitors: Flexible solid-state and composite supercapacitors for electronics manufacturing




**2024 onwards**
- Improve workforce preparation for opportunities with multinational partners in areas such as Aerospace, ICT/Semiconductor, and Automotive

**2023-2024**
- Partner with at least 10 entities for R&D applications and infrastructure co-development **(Php 30M annually)**:
  - Aerospace and Automotive (small-scale, low-tier local suppliers)
  - ICT/Semiconductor (local design and development firms)
- Improve workforce preparation for opportunities with multinational partners in priority areas such as Rail, Food/Agriculture, and Sustainable Environment

**2022-2023**
- Introduce targeted training electives in Advanced Materials and Nanotechnology to promote employment readiness of graduates for certain industry applications
- Charge returnees from Global Research Program and Balik Scientist Program to consolidate resources and lead R&D and collaboration efforts in the field (through Advanced Materials and Nanotechnology Hub)

**2021-2022**
- Establish programs to obtain visibility into industry needs and open channels for collaboration (e.g. internships, immersions, fora) **(Php 5.5M)**
- Partner with at least 10 entities for R&D applications and infrastructure co-development **(Php 30M annually)**:
  - Agriculture/food (small-scale producers, processors, or manufacturers participating in the value chain)
  - Sustainability (LGUs)
  - Rail (Philippine Railway Institute, DOST-MIRDC)

**2020-2021**
- Increase awareness of Advanced Materials and Nanotechnology (uses, applications, standards and safety) in STEM curriculum, and in industry and among consumers
- Ensure communication of government policy incentives and benefits to stakeholders
- Build and publish database with information regarding technology researches, publications, laboratories and equipment, and skills developed
- Develop Global Research Program to send 10 researchers abroad to raise local talent to global standards by providing exposure and training in renowned research laboratories before returning to the Philippines to assume research Hub responsibilities **(Php 40M)**

**Advanced Materials R&D Roadmap (2020-2024)**

**Input**

# Technology Roadmap

## Nanotechnology

**2024 onwards**
Manufacturing - Methods: Nanofabrication techniques for electronics and materials manufacturing (NEMS, memory tech, blow spinning)
Manufacturing - Materials: Adoption of advanced materials such as intermetallics, nanoclays and smart fibers

**2023-2024**
- Nanodelivery - Applications: Nanodevice fabrication for drug delivery and diagnostics (nanobots)
- Nanosensors - Applications: Agricultural detection of pathogens, pesticide residues and determination of crop quality

**2022-2023**
- Coating - Materials: Coatings of nanomaterials (e.g. Diamond-Like-Carbon (DLC), MAX phase) for lightweight & strength applications
- Manufacturing - Materials: Strong and light-weight materials from nanocomposites, nanocement, magnesium-alloys, etc.
- Nanodelivery - Applications: Nanofertilizers and nanovaccines to increase crop health and quality
- Nanosensors - Applications: Nanodiagnostic devices such quantum dots for health monitoring

**2021-2022**
- Coating - Materials: Coatings of nanomaterials (ex. nano-structured polymers) for lightweight & strength applications
- Manufacturing - Materials: Nano-enabled materials from Natural/Indigenous raw materials and waste/by-products (bioplastics, nanocellulose, etc.)
- Nanosensors - Applications: Sensors to detect emerging diseases

**2020-2021**
- Manufacturing - Materials: Nanofiber materials as food packaging; Development of metal powder for additive manufacturing
- Nanosensors - Applications: Smart packaging; Sensors to detect harmful substances in food

**Nanotechnology R&D Roadmap (2020-2024)**

**2024 onwards**
- Improve workforce preparation for opportunities with multinational partners in areas such as Aerospace, ICT/Semiconductor, and Automotive

**2023-2024**
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**Input**

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