DEPARTMENT OF SCIENCE AND TECHNOLOGY
PHILIPPINE COUNCIL
FOR INDUSTRY, ENERGY
AND EMERGING TECHNOLOGY
RESEARCH AND DEVELOPMENT
(DOST-PCIEERD)

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

Photonics

Final Report

SGV
Building a better working world

FOREWORD

Addressing the gaps and identifying the future direction of photonics supply chain in the country, the Department of Science and Technology Philippine Council for Industry, Energy and Emerging Technology Research and Development (DOST-PCIEERD) releases its latest formulation of roadmap and sectoral plan for photonics.

Photonics utilizes lasers, optics, imaging and more to impact every area of modern life, from communications and information processing to lighting, agriculture and medicine, manufacturing, transportation, aerospace and much more. This Roadmap is a collective effort by the leading industry experts from the academe, government, private sector, research community, and other relevant institutions to provide an overview about the s tatus of photonics in the country and where the field is destined to reach including its potentials. Likewise, it emphasizes the significance of optics and photonics in lasers, fiber optics and other optical electronics devices to usher innovation in various fields such as optical sensing for life sciences and health care applications.

As DOST-PCIEERD is geared towards harnessing the potential of emerging technologies, and expand technology development and innovation for the industry, energy and transport sectors, it will remain constant to finding and developing efficient and eco friendly S&T interventions and solutions. It will empower the country's R&D community by supporting our human resources, enabling the development of research and academic institut ions, and generating more S&T policies, strategies, and technologies to elevate our society.

By working with us, we can truly make innovation work for the people.

DR. ENRICO C. PARINGIT
PCIEERD Executive Director

Table of Contents

Introduction

Photonics is the physical science of light (photon) generation, detection, and manipulation through emission, transmission, modulation, signal processing, switching, application and detection/sensing. Photonics technology detects light emission, then converts lights into electric signals through integrated fiber optics. The global photonics market has reached more than $600 billion and is continually growing. Countries such as Europe, United States, China, Singapore and Taiwan have heavily invested in photonics to further their economic development through science and technology. Given its current local capacity, the Philippines can benefit from the use of photonics. Our primary industries in agriculture, manufacturing and services as well as public goods such as utilities, environment and healthcare have photonics applications.

To implement Photonics 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.

With this, the sectors of Food/Agriculture, Sustainability/Environment, National and Civil Applications, Aerospace, and ICT/Semiconductors were identified as sector focus areas for Photonics 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 Philippine Photonics Center, that would serve as the focal facility for research and development initiatives. 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 emphasie 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 Photonics.

According to this study, the Philippines has huge potential in improving its economic development through Photonics. Maximizing this requires key stakeholders which include industry, government, and researchers to willingly collaborate and fulfill their individual roles to successfully implement this in the Philippines. 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.

Photonics Technology Landscape

Global Landscape

Photonics technology uses the emission, processing and detection of light. Its application cuts across different sectors. Photonics technology can be used to generate solar electricity, create valuable equipment in medical, construction, and manufacturing sectors, aid in medical diagnosis and treatment, and sensing technologies. Several countries have started initiatives towards the development of technologies in this area.

Global photonics industry grew from 228 billion euros in 2005 to 447 billion euros in 2015 and has a compounded annual growth rate of 6.8%. Main players are Europe, North America, Taiwan, Korea, Japan and China with only 6% shared by other countries. Photonics applications is multi-disciplinary, and the following chart summarizes global leaders in photonics development in 2019.

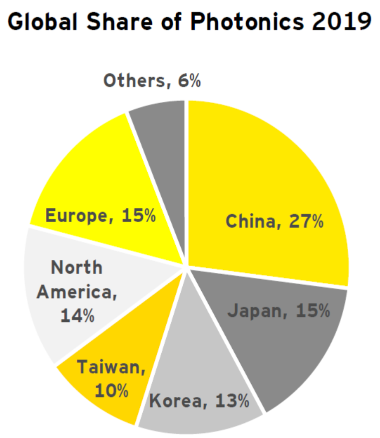


Figure 1. Global Share of Photonics

The photonics strategic direction among Europe, China and United States have similar emphasis across different industries. Photonics technology is seen to have the highest impact in the information and communication, food security, health, manufacturing, environmental and energy sectors. Ultimately, the common vision is to achieve a digitized ecosystem characterized by highly interconnected networks, systems and processes with greater automation and efficiency, and a more sustainable way of living.

Photonics is critical to achieving these. Sensors that will be used for smart cities, detection of health and diseases, and environmental health will be enabled through photonics. Optical and quantum technology solutions are needed to have resilient and agile ICT industry in order to store and connect a large amount of data. High-powered lasers, advanced imaging technologies, and advanced manufacturing processes must be integrated in the current operations of factories and hospitals for greater efficiency. Other technologies are provided in the annex containing roadmap of specific photonics applications across industries.

To elaborate further, the following discussion highlights primary technologies invested on by global leaders, namely Europe, China and United States focus in their research and developments. As will be discussed later, some of the technologies to be mentioned are already being done in the Philippines. This information may be considered in determining which technologies the country can leverage on in order to stimulate photonics innovations. Industries emphasized in their strategic direction are information and communication, health, energy, manufacturing, food and agriculture, and the circular economy.

The following table shows monetary values of emerging photonics technologies:

Global Photonics Market

GLOBAL LASER MARKET $ 3.8 Bn *2024 Market Size*	**LI-FI** $ 51 Bn *2023 Market Size*	**QUANTUM COMMUNICATION** $ 13.3 Bn *2023 Market Size*
HEALTH SENSORS $ 31.2 Bn *2023 Market Size*	**LiDAR** $ 3.89 Bn *2025 Market Size*	**TERAHERTZ** $ 932 Mn *2024 Market Size*
BIOPHOTONICS $ 63.1 Bn *2022 Market Size*	**FIBER OPTICS** $ 18.5 Bn *2024 Market Size*	**SILICON PHOTONICS** $ 1 Tn *2024 Market Size*

Figure 2. Global Photonics Market

Regional Landscape

In 2014, the ASEAN Commission on Optics and Photonics was formed, which is an organization directed towards photonics efforts in the region. (icOPEN, 2019). China, Taiwan, Singapore and Japan are the main players within Asia in photonics. China recently outranked Japan and the EU in photonics technology, holding first place in developing technologies in this area. Its production share in the global market increased from 10% in 2005 to 21% in 2011 and to 27% in 2015.

The success of the Chinese Photonics industry is based on five segments: photovoltaics, information technology, lighting, displays, and communication.

Japan and Malaysia governments are integrating photonics as part of their development programs. In Japan, the Center for Photonic Innovation was founded as part of the Strategic Promotion of Innovative Research and Development Program of the Japan Science and Technology Agency and is engaged in a project to develop quantum photonics information technology using nano optical fiber. In the Eleventh Malaysia Plan, photonics development will continue focused on the healthcare, food security, environment and aquaculture sectors. The National Research foundation of Singapore's LUXPhotonics Consortium in partnership with Palomar Technologies from the United States launched an Innovation center in Jurong which aims to give access and support to manufacturing firms to translate photonics research into industrial applications. Its focus is to develop technologies that enable IoT and 5G wireless networks. This is the first in South-east Asia of its kind.

Current Local Capacity

Photonics research and development is centered on photonics-based instrumentation and measurement systems for enhancing environmental monitoring and assessment, domestic semiconductor industry and biomedical sectors.

Most of the research done in photonics are carried out in universities. These are the University of the Philippines, Ateneo de Manila University, De La Salle University, University of San Carlos and University of Santo Tomas.

The National Institute of Physics (NIP) in the University of the Philippines strengthened its fiber optic research and development efforts for the communications, information technology and semiconductor industries. It has also created a laboratory catered to the learning of students in the technology of optical fibers to provide manpower to the local telecommunications industry. Private institutions are also present in the country such as Perkinelmer Optoelectronics and Avago.

In the University of the Philippines, projects completed include imaging techniques for the healthcare sector and optical fibers for communication. In the semiconductor industry, projects related to optical processing techniques include holographic data storage and variable elastomeric optical devices.

Other notable projects in the area of photonics are the Automated Rapid Reef Assessment System (ARRAS), Coral Reef Assessment and Visualization Advanced Tools (CRAVAT), and Cartography of Old Informs New (COIN). The first two projects developed advanced coral reef monitoring tools. CRAVAT was able to obtain videos of 2,000 km of coral reefs out of the 10,000 km total area of coastlines in the Philippines. COIN, on the other hand aligns historical and modern maps with the same area to determine causes of flooding and other hazards through digital scanning. LIDAR research for detection and measurement of various atmospheric pollutants was also done. These projects are beneficial to sustain a circular economy.

In the optics industry, the Philippines currently has manufacturing capability in this field with the existence of private corporations, in the part of the value chain making products such as lenses, imaging devices, optical fibers and microscopes, among others.

However, we do not have engineering capability in design. Recently, the University of the Philippines, inaugurated the University Laboratory for Small Satellites and Space Engineering Systems or UlyS3ES. This is in support to one of the research programs of DOST which is the STAMINA4SPACE where small satellites, optical payloads and remote sensing products will be developed.

There are existing local developments that are aligned to the research and development priorities globally. We have photonics innovations in the treatment and remediation of disease, ensuring environmental sustainability, and industry-focused photonics applications. Moreover, we also have capacity to produce photonics-based instrumentation such as lasers, microscopes, lenses and satellites. However, there are still barriers that disallow the country to reach its fullest capacity in photonics, as will be elaborated later. Ultimately, specialized skills and equipment are still needed in order to support a wider array of research and development initiatives. On top of this, government and industrial support are needed to deploy these technologies to have concrete applications.

Some of the research and development efforts undertaken in the country are:

Industry	Technology
Environmental monitoring	LIDAR research for detection and measurement of various atmospheric pollutants
Semiconductor	Optical processing techniques: holographic data storage, variable elastomeric optical devices
Biomedical	Nuclear medicine, chemosensors for the detection of tuberculosis

Figure 3. Local Research and Development in Photonics

Barriers to Photonics Development

In constructing the strategic direction for Photonics 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.

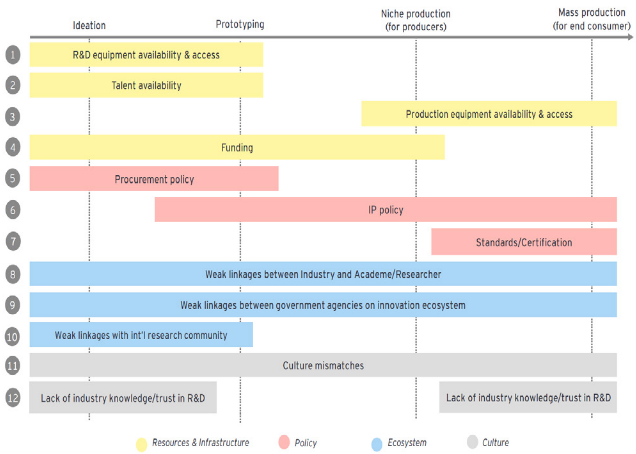


Figure 4. Barriers to Development of Photonics

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 Photonics, 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.

Strategy and Direction for Photonics

The sector of Photonics is an intermediate sector, which means that its value is as input or enablers in the industry and will not be for immediate consumption by ordinary users. Thus, we cannot treat this 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 Photonics 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 Photonics 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 5: 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.

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.

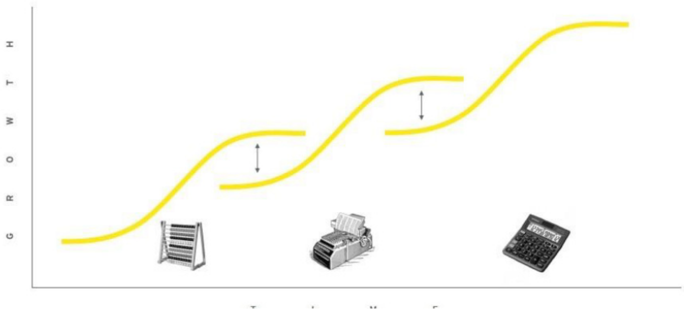


Figure 6: The overlapping S-curves show how technology evolves over time - from birth to maturity - before eventually reaching disruption and being displaced by a new technology

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 Upskilling Frugal innovation Local R&D in niche areas	International collaboration International joint research Local research	International exposure International collaboration
Financing	Private sector - Large corporates, SMEs Private sector - Startups, Incubators	Private sector - Large corporates PPP	Public R&D funding
Metric/ Output	**Partnerships:** Adopters of technology, consumers **Product:** Saleable commercial product **Policies:** Safety standards, certifications **People:** Trained technical personnel, High-skilled practitioners	**Patent:** New processes, formulations **Places:** Joint facilities for research, industry use (testing, fabrication) **Partnerships:** Willing hosts for facilities, laboratories, research personnel **People:** High-skilled practitioners, researchers, professors.	**Publication:** Exposure in scientific journals of Filipino research **Patent:** New processes, formulations **People:** Specialized researchers

Figure 7. 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.

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 Food/ Agriculture, Sustainable Environment, and National & Civil Applications as quick wins; then Aerospace and ICT/Semiconductor, 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:

Food

Government as customer for relief distribution, military rations, food sustainability

Industry: Nestlé, Unilever, Mondelēz International

PROBLEMS	SOLUTION
Agri Production Food Packaging Safety, Shelf Life	LiDAR, hyperspectral imaging, and other sensors and tools for monitoring soil health, optimal harvests, and temperature Adjusted light for urban farming (Special LEDs, UV LEDs) Sensitive imaging, spectrometry, laser scanning, hyperspectral imaging, fluorescence spectroscopy for food quality monitoring

Sustainable Environment

Government as customer for city rehabilitation, environmental sustainability initiatives, renewable energy

PROBLEMS	SOLUTION
Pollution detection and remediation Monitoring and sustainability Energy generation Disaster Risk and Management	Emitters, diodes, light sources from indigenous materials Photodetectors, photosensors, ranging, visual sights, periscopes, hyperspectral imagers, and other sensing, imaging, and measurement tools Photovoltaics LiDAR for disaster analysis and response, and natural resource management

National and Civil Applications

Government as customer for defense, governance, communication, and civilian use

PROBLEMS	SOLUTION
Security Connectivity/ Internet of Things Enhanced Protection	Fiber-optic wiring, Optical cross-connects, Optical amplifiers, Quantum communication, LiFi, Optical beamforming and steering, Space division multiplexing, Analog radio over fiber, Terahertz communication Infrared night vision systems; advanced lasers

Aerospace

Government as customer for PUVs, Rail, electric vehicles

Industry: Lufthansa Technik Philippines, ASIAN AEROSPACE

PROBLEMS	SOLUTION
Communication/Connectivity Composite/Lightweight materials Monitoring/ Surveillance Manufacturing Process Efficiency	Optical communication networks, quantum communication Fiber-optic sensors and wiring Terahertz imaging; LiDAR navigation Laser specific materials development, laser beam distribution, parallelized beam sources, laser beam sources (diode, solid state, high-energy), beam guidance, beam shaping, optimization by multi-space algorithms

ICT/Semicon

Government as customer for communication, data storage, IT infrastructure

Industry: Texas Instruments, intel, TOSHIBA

PROBLEMS	SOLUTION
Computing ability for AI Security Accessibility/ Connectivity Miniaturization/ Efficiency Manufacturing Efficiency	Quantum computing; quantum cryptography; Photonic neural networks; Neuromorphic photonics Optical Fiber Networks; Optical Wireless Access Photonic Integrated Circuits, Monolithic Integration, Ultra dynamic photonic devices, Optical packet switching, Optical Field Programmable Gate Arrays 3D manufacturing, Photolithography

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.

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 photonics 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 photonics 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. Moreover, this also involves initiatives aimed at improving the retention of skilled experts at research institutions.

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 photonics 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 being able to execute for industry applications or solutions.

(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. With regard to 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 Photonics. This will be done through the introduction of targeted training electives in Photonics 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 Photonics 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 photonics, highlighting its value. There must be favorable receptivity among the public of commercial applications for these fields. These initiatives must also ensure that effective collaboration will be formed among researchers and industry adopters.

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 expertise on photonics. This can be done through incentivizing foreign experts to conduct training programs or teach in the Philippines.

2024: Achieve

In the last phase, we will improve workforce preparation for opportunities with multinational partners in priority areas such as Food/Agriculture, Sustainability/Environment, ICT/Semiconductors and Aerospace. 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. We should also be able to establish Centers of Excellence for photonics knowledge and training.

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 stakeholder engagement which aims to establish a network for private and research sector partnerships. This will be done through the establishment of programs to obtain visibility into 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 photonics 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 this 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 photonics development.

Lastly, as the pilot for industry collaboration, the first two years of the roadmap will establish partnerships with at least ten local government units and small-scale manufacturers for applications in food/agriculture, sustainability, and national and civil applications. This is primarily because, technology adoption these fields is an easy win given that the government is highly involved in different programs concerning the growth and development of these sectors, making them highly receptive to government intervention where we can easily implement photonics technology applications.

2022-2023: Build Up

Thereafter, the next two years will have photonics R&D applied across more industries. After proving successfully use cases in the sectors identified as quick-wins in the first two years, we must develop partnerships with local entities to promote additive manufacturing for small-scale fabrication in aerospace and semiconductor/electronics. Given that the application of photonics during the first two years showed a significant improvement in the productivity and growth of the food/agriculture, sustainability and national and civil sectors, 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 photonics to establish manufacturing base in the Philippines and facilitate joint research and investment ventures with five different foreign institutions.

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 Photonics Center. This includes setting standards for Photonics and constructing facilities for research and development.

2020-2021: Lay Foundations

One of the hurdles in adopting photonics in the country include the lack of regulations and standards around photonics. 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 Photonics. 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 Philippine Photonics Center. The value and specific responsibilities this facility will fulfill will be discussed in more detail in Section 5 of this paper. Linkages must be established between the Photonics Center and other institutions and laboratories for more immediate industry applications. This means that this center 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 Philippine Photonics Center 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 center to serve R&D needs of researchers and industry particularly in sensing, imaging, and production technology. 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 Photonics technologies. 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. We must also be able to harmonize local and international standards for photonics safety.

2024: Achieve

In the last phase, we will co-invest in facilities and equipment to augment ability of the Philippine Photonics Center to serve research and development needs of researchers and industry specifically for integrated photonics and quantum capabilities, or the more advanced levels in the field of photonics.

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:

- Delivery of Information: Fiber-optic sensors & wiring, Optical communication networks, Optical Fiber Networks, Optical Wireless Access, Optical cross-connects
- Imaging: Hyperspectral imaging; Infrared night vision systems; LIDAR; Sensitive imaging, spectrometry, laser scanning, fluorescence spectroscopy, Photodetectors, photosensors, ranging, visual sights, periscopes
- Lasers: Laser specific materials development
- Light Providing: Adjusted light for urban farming (Special LEDs, UV LEDs)
- Information Processing: Optical Field Programmable Gate Arrays
- Manufacturing - Materials: Photovoltaics, emitters, diodes, light sources from indigenous materials
- Manufacturing - Methods: Space division multiplexing
- Non-destructive Testing: Neutron imaging and FIR Imaging for ware and tear testing

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:

- Delivery of Information: LiFi, optical beamforming and steering, analog radio over fiber
- Imaging: Terahertz imaging, Beam shaping (bessel beam)
- Lasers: Laser beam distribution, parallelized beam sources, laser beam sources (diode, solid state, high-energy), beam guidance, beam shaping, optimization by multi-space algorithms
- Manufacturing - Methods: 3D manufacturing, Photolithography; Optical amplifiers
- Non-destructive Testing: Holographic Interferometry, Neutron Scattering
- Photonics
- August 2020
- 19 Photonics Final Report
- Information Processing: Photonic neural networks; Ultra dynamic photonic devices, Optical packet switching; Photonic Integrated Circuits, Monolithic Integration
- Manufacturing - Materials: Photovoltaics, perovskite solar cells, conductive nanocomposites, solar cells with nanostructures for solar power harvesting;

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:

- Information Processing: Quantum communication, computing, and cryptography; Neuromorphic photonics
- Manufacturing - Methods: Material synthesis through high flux radiation

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.

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 photonics 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.

Philippine Photonics Center

The concept of the Philippine Photonics Center 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 photonics 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 photonics. 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 photonics 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 photonics 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.

Other Roles

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

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:

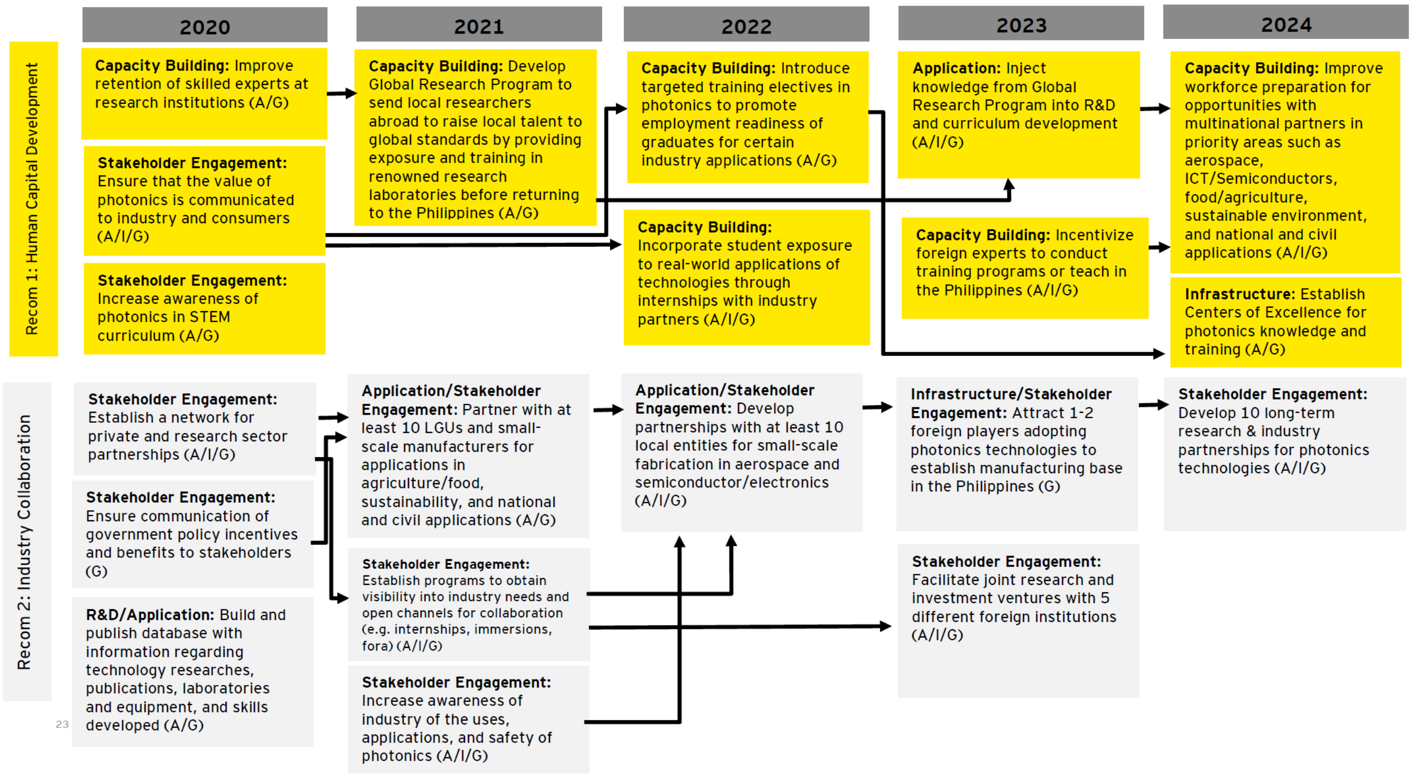
- Assist in industry policy formulations that will serve as the framework by which industry will efficiently be able to participate in research and development initiatives
- Provide support services for industry players who want to connect to the innovation landscape
- Manage relationships within industry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

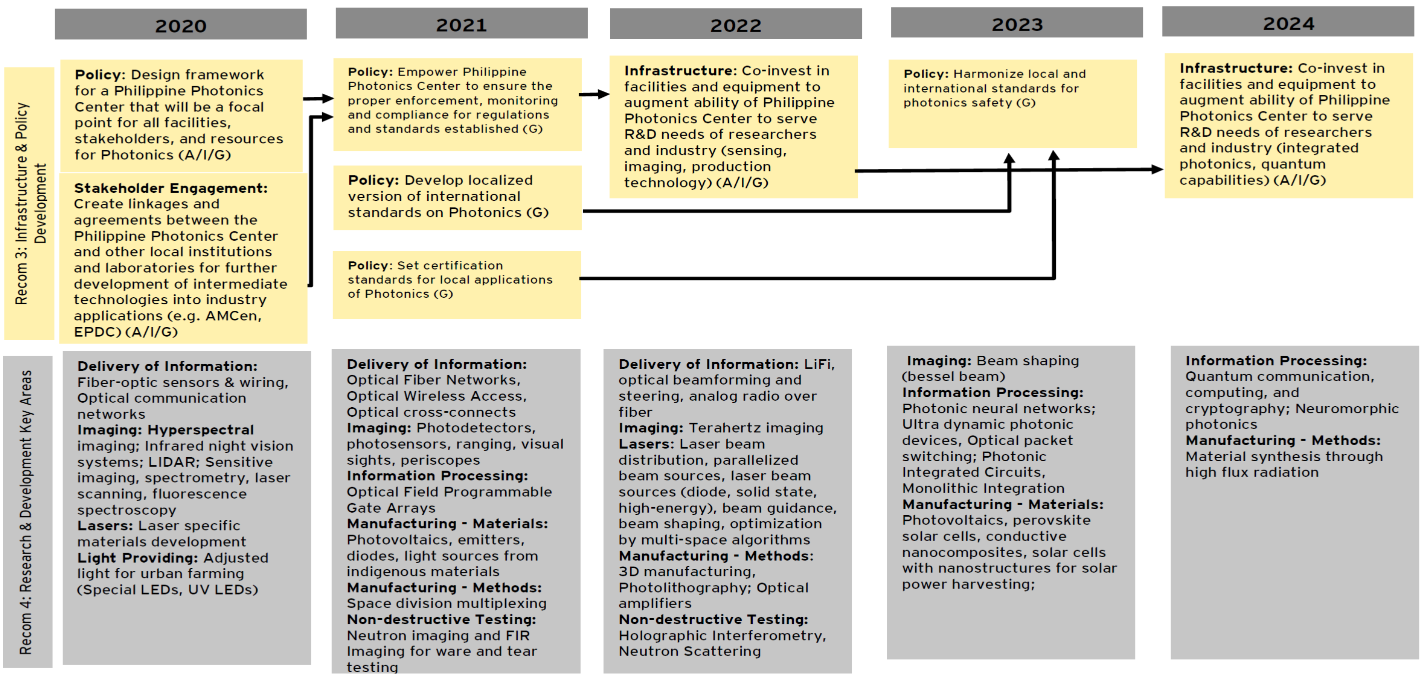
Department of Finance (DOF)

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. Photonics Program Roadmap





B. Photonics Technology Roadmap

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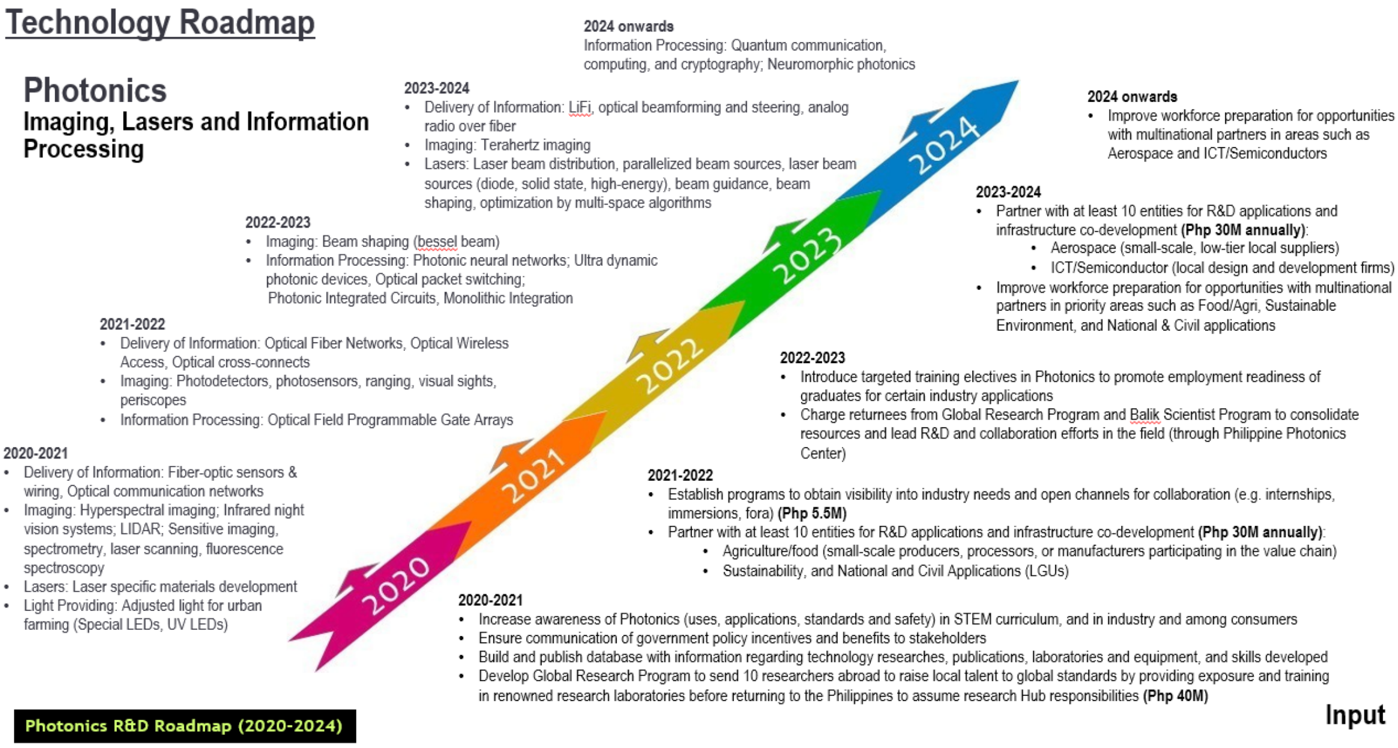

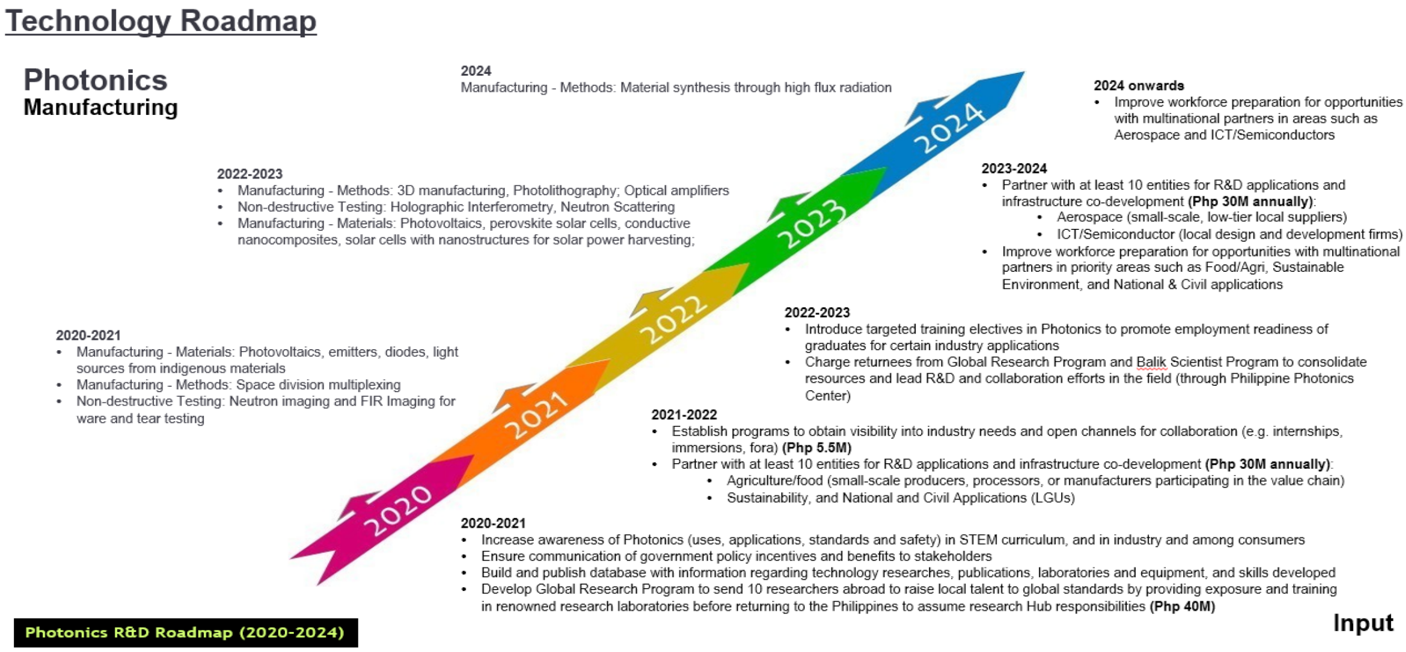

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