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Scaling up Opportunities in the Nanotechnology Sphere in Penang

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EXECUTIVE SUMMARY

- Penang's existing industrial strength is well-aligned with the national focus sectors for nanotechnology applications. This can furthermore be aligned to NanoMalaysia's strategic jumpstart sectors that are expected to present opportunities in the medium to long-term, such as food and agriculture, wellness, medical and healthcare, energy and environment, and electronics devices and systems.

- Penang may position for greater focus into graphene technology in radio frequency (RF) electronics and conductive ink applications. The RF electronics and conductive ink applications plans (collaborations under National Graphene Action Plan 2020) bode well, given the comparative advantages of Penang-based companies involved in the semiconductor, semiconductor-related and E&E sectors. Besides that, a number of organisations and industry members are involved in the Gallium Nitride on Gallium Nitride LED collaborative research.

- Penang's established ecosystem allows for more collaboration and joint efforts in nanotechnology and nanotechnology-based industries. Small and medium enterprises are also involved in nanotechnology and nanotechnology applications projects under iNanovation and Advanced Materials Industrialisation.

- Policymakers should also encourage adjacent collaboration or development of nanotechnology applications by companies that already have a presence in Penang.

- The main issues for nanotechnology and nanotechnology applications in Penang are (1) obstacles in the development and commercialisation process, (2) the level of willingness of MNCs to collaborate, (3) access for SMEs and local companies to ongoing projects, (4) the rate of adoption of nanotechnology applications products in the market, and (5) continued funding for the development of nanotechnology applications and materials.

- Nanotechnology and nanotechnology applications cut across different spheres of industries and technological applications. This paper proposes that Penang align nanotechnology and nanotechnology applications to focus especially on the electronics devices and systems segment and at the same time concentrate on the national key jumpstart sectors.

[1] The author is grateful to NanoMalaysia Berhad, Institute of Nano Optoelectronics Research and Technology (INOR), Universiti Sains Malaysia, and Collaborative Research in Engineering, Science and Technology Centre (CREST) for their invaluable input on this paper.

Introduction

Nanotechnology[2] is defined as the design, characterisation, production and application of structures, devices and systems by controlling shape and size at the nanoscale. A nanoscale refers to one or more dimensions of the order of 100 nm or less (European Commission, 2006).

Needless to say, there are vast opportunities in nanotechnology, its applications and materials. The global nanotechnology market is expected to hit USD5.76 trillion in 2022, up from the estimated market size of USD3.68 trillion in 2018. Asia's market share is expected to grow from USD1.3 trillion in 2018 to USD2 trillion in 2022 (NanoMalaysia, 2018). It is expected that there will be significant developments in the applications of nanotechnology in the fields of electronics, energy and biomedical.

This paper analyses the opportunities for Penang to further scale up in the nanotechnology sphere. This is advisable especially since the state's existing industrial strength is well-aligned with the national focus sectors for nanotechnology applications. The following sections discuss Penang's competitive advantage and the national jumpstart sectors, opportunities in graphene development and applications, small and medium enterprises (SMEs) participation in nanotechnology, prevailing and potential opportunities, challenges and proposed solutions, and the Quadruple-Helix model within Penang's nanotechnology context.

Aligning competitive advantage and national jumpstart sectors

About RM3.5 billion in direct (and RM17.5 indirect) potential GNI contribution is expected to be generated by the nanotechnology and nanotechnology-related segments in Malaysia by 2025, along with 1,858 direct and 8,855 indirect jobs (NanoMalaysia, 2019). Based on global trends, nanotubes are now a major application of nanotechnology in the fields of electronics, energy and automotive; and nanoceramics are a major application in the electronics and biomedical field.

According to NanoMalaysia Berhad[3], the national addressable markets in four areas for nanotechnology applications are valued cumulatively at RM7.12 billion in 2025. These are food and agriculture; wellness, medical and healthcare; energy and environment; and electronics devices and systems. Table 1 illustrates the the proposed focus for Penang, suitably aligned to NanoMalaysia's strategic jumpstart sectors which can be expected to present opportunities in the medium to long term.

[2] One proposed way to view nanotechnology is not as an industry on its own, but rather as a general-purpose technology, like electricity and computing, that is used in many industries (Vault, n.d.).

[3] A company under the Ministry of Science, Technology and Innovation (MOSTI). Under the 11th Malaysia Plan (2016 – 2020), NanoMalaysia has been granted RM75 million over five years to advance the nanotechnology agenda. See Box Article 2 for information on NanoMalaysia.

Table 1: Proposed focus for Penang, aligned to NanoMalaysia's strategic jumpstart sectors

Strategic jumpstart sectors	Food and agriculture	Wellness, medical and healthcare	Energy and environment	Electronics devices and systems
National addressable market (2025)	RM1.31 billion	RM1.93 billion	RM2.1 billion	RM1.78 billion
Subsector and applications	- Food processing and management (smart packaging)	- Packaging and systems (Nanonetworks for healthcare applications, RFID)	- Li-ion battery anode/ultra-capacitors (Power system) - Advanced materials (Nanogenerators, nanochip)	- Nanosensors (scalar sensors and systems) - Nanoelectronics (Processes, NEMS) - Nanodevices (Phones, cameras etc.)

Source: Author's suggestion based on NanoMalaysia Strategic Report 2018, 2019

Currently, nanotechnology applications in Penang are linked closely to the electrical and electronics (E&E) sector and related industries for which Penang is a regional hub[4] (see Table 6 for Penang's approved manufacturing investments 2016-2019), especially in the back-end semiconductor equipment segment, and in industries such as medical devices, avionics, and food manufacturing. One can expect more potential opportunities to come since significant developments in nanotechnology are in the fields of electronics, energy and biomedical (NanoMalaysia, 2020). Furthermore, NanoMalaysia also plans to extend collaborations under NGAP2020 into radio frequency (RF) electronics and conductive ink applications.

Growth of graphene applications

Graphene is a carbon-based material which is the strongest-known material currently. Graphene consists of a lightweight honeycomb sheet of carbon atoms, almost transparent and flexible, yet highly conductive to heat and electricity (Nanowerk, n.d.). According to Geim (2009), graphene is a wonder material, the thinnest known in the universe and the strongest ever measured. As of 2017, 50 companies were identified and have been working closely with Malaysian Investment Development Authority (MIDA) and NanoMalaysia to explore the applications of graphene as a product enhancer in various sectors (MIDA, 2017).

NanoMalaysia's programmes also include the National Graphene Action Plan 2020 (NGAP2020). NGAP2020 is a commercialisation programme focusing on graphene applications and high value-add graphene-enabled manufacturing processes with intellectual properties (IP) in five key applications:

1. lithium-ion batteries and ultracapacitors;
2. rubber additives;
3. nanofluids;
4. conductive inks and;
5. plastics additives.

[4] In February 2020, Penang announced the investment by Lam Research, a global leading supplier of wafer fabrication equipment. The spillover effect of this for Penang is expected to be far-reaching. Several new investments for the front-end semiconductor equipment supporting segment include several from Ultra Clean Technology (UCT) and Inari Amertron-Comet Group collaboration.

Based on NanoMalaysia Strategic Reports, two Penang-based companies are involved with projects in the NGAP under conductive inks applications areas (Table 2). The first company, Penchem Technologies Sdn. Bhd., designs, manufactures and supplies advanced polymers and composite materials to the electrical and electronics (E&E) industry. NanoMalaysia has assisted Penchem in successfully developing graphene-based conductive inks for flexible circuits. The other company is Q-DOS Flexcircuits Sdn. Bhd., a manufacturer of Flexible Printed Circuits (FPC) in Malaysia, and a unit of a Bursa Malaysia-listed conglomerate. The company is involved in graphene-based printed flexible circuit or electronic application.

Table 2: Penang-based companies involved in National Graphene Action Plan

Company	Business focus	Involvement in graphene application
Penchem Technologies Sdn. Bhd.	The company's current business focus is on light emitting diodes (LEDs) in the form of epoxy and silicone encapsulants, and thermal interface materials (TIM); fiber optics in terms of ultraviolet (UV) and heat curable adhesives; and photovoltaics in the form of silicone coatings and conductive interconnects.	Graphene-based conductive inks for printed circuit board
Q-DOS Flexcircuits Sdn. Bhd.	The company provides a comprehensive FPC solution, covering circuit design, prototype fabrication, mass-production and surface mount technology (SMT) assembly.	Graphene-based printed flexible circuit or electronic application

Source: NanoMalaysia Strategic Report 2018

Penang may come to gain greater focus into the graphene technology in radio frequency (RF) electronics and conductive ink applications. This is because NanoMalaysia plans to extend collaborations under NGAP2020 to RF electronics, rubber additives and conductive ink applications. The RF electronics and conductive ink applications plans bode well for Penang-based companies that are presently advantageously involved in the semiconductor, semiconductor-related and E&E sectors.

Besides, the Institute of Nano Optoelectronics Research and Technology (INOR) at Universiti Sains Malaysia, is involved in the Gallium Nitride on Gallium Nitride or GaN on GaN (GoG) LED technology transfer programme. The Collaborative Research in Engineering, Science and Technology Centre (CREST) was assigned by MIDA to materialise this collaborative initiative. Other universities involved in this project include Universiti Malaya (UM), Universiti Malaysia Perlis (UniMAP), and Monash University Malaysia. Industry members involved in the GoG LED technology transfer programme are OSRAM, Penchem, Inari, and ItraMAS. The goal of this project is to produce high-efficiency, high-lumen white LEDs based on GoG technology. According to INOR's report, Malaysia is set to be at the forefront of GoG LED technology, which is expected to revolutionise the current technology that is based on GaN on sapphire. The GoG project has a target to position Malaysia among the top three LED solution providers in the world by 2020. As of 2018, Malaysia is the second largest exporter of the product under Harmonised System (HS) 854140, achieving an export value of USD4.5 billion (See Table 7), and with a significant contribution from companies in Penang. An overview of the GoG project is detailed in Box Article 1.

Facilitating SMEs to partake in nanotechnology

Small and medium enterprises (SMEs) are important stakeholders in existing and any new adjacent industrial opportunities, including in nanotechnology development and application. About 95.9% of the total manufacturing companies in Penang are SMEs[5]. NanoMalaysia is also supporting SMEs (including start-up companies) in the nanotechnology space through the iNanovation programme. The support and facilitation include provision of project investment funds via venture builder model, business partnerships, and technology expertise and support[6]. Under iNanovation, LED/optoelectronics applications continue to have significant attention in Penang. Hans Led Sdn. Bhd., for example, received assistance under iNanovation, and is in the activity of producing thermal substrate for LEDs (Table 4).

Table 3: Penang-based company under iNanovation and company assisted by NanoMalaysia under Advanced Materials Industrialisation

Company under iNanovation	***Nanotechnology products***	***Application***
Hans Led Sdn. Bhd.	Thermal substrate for LEDs	Production of Cu-CNT Substrates for LED applications
Company assisted by NanoMalaysia under Advanced Materials Industrialisation	*Nanotechnology Products*	
Eclimo Sdn. Bhd.	Battery management system for electric motorcycles	

Source: NanoMalaysia Strategic Report 2018

Alongside this, the NanoMalaysia's Advanced Materials Industrialisation Programme encourages the adoption of advanced materials for the purpose of product industrialisation. This programme helps local firms gain market advantage through the adoption of advanced materials in nanotechnology products and applications. One Penang-based company assisted under the Advanced Materials Industrialisation Programme is Eclimo Sdn. Bhd., whose nanotechnology product application is in the battery management system for electric motorcycles (Table 3).

[5] Penang Institute's calculation based on Economic Census, MyState Statistics, Penang, 2016 & Economic Census, Profile of Small and Medium Enterprises, 2016, Department of Statistics, Malaysia (Choy, Yeong and Yap, 2020).

[6]Other government/government-linked institutions offering financial and non-financial support for nanotechnology players (may not be limited for this industry only) include Malaysian Technology Development Corporation (MTDC), Kumpulan Modal Perdana (KMP), Malaysia Venture Capital Management Berhad (MAVCAP) and Malaysia Debt Ventures Berhad (MDV). At times, companies have also given feedback that there are too many different incentives and financing sources, and at the same time, there is a lack of a comprehensive database for ease of reference.

Box Article 1: Epitaxial technology catalyses the higher-value LED segment and beyond

In 2013, MIDA invited Professor Shuji Nakamura (recipient of 2014 Nobel Prize in Physics for inventing blue LEDs, shared the prize with Akasaki Isamu and Amano Hiroshi) from the University of California Santa Barbara (UCSB), to be a speaker at their conference. After his presentation at the conference, MIDA invited Nakamura to meet LED companies in Malaysia.

During the conversation with the LED companies, it was suggested to Nakamura that the LED companies in Malaysia and UCSB could mutually benefit from collaboration with each other on epitaxial growth. Epitaxial technology refers to the growing of a thin layer on the surface of a crystal (substrate) so that the overlayer has the same structure as the underlying layer (Lim, 2018). Nakamura agreed that it was a good idea as Malaysia could gain from the front-end research at UCSB while the latter could gain from Malaysia's back-end industry's in-depth experience. Nakamura developed a proposal for a collaboration that will enable Malaysian companies and universities to send researchers to Nakamura's front-end research team at UCSB. Upon receipt of the proposal, MIDA assigned CREST to help materialise the collaborative initiative.

CREST organised a trip to visit Nakamura at UCSB together with representatives from Malaysia LED companies, MIDA and the Northern Corridor Implementation Authority (NCIA), as part of the proposal assessment. CREST's counter proposal was for Nakamura's team to consider replicating Nakamura's lab in Malaysia by sending UCSB researchers with specific knowledge of the lab to Malaysia for several months in order to replicate those conditions in Malaysian labs. This is similar to product technology transfers currently practised in the industry.

Initially, the government agreed to allocate RM80 million for the project. CREST however developed a proposal that detailed the collaborative research programme between industry and academia. Industry members would commit their research officers to the project, donate equipment, lab time and some know-how that was not proprietary to them, while universities would send their researchers, allocate lab space and provide lab equipment. With that, the total cost was estimated at RM120 million, covered collectively by government, industry and academia over a five-year period. GoG programme officially kicked off in August 2015.

Currently, each of the four universities involved have different capabilities – epitaxy technology (UM and USM), fabrication process (UM and USM), characterisation and testing (UniMAP), thin film and surface characterization (Monash University Malaysia and USM), and packaging (UniMAP). Some of the achievements of this project are:

- Completed the fab tools (ICP, E beam & RTA) installation in UM in August 2017.
- First GoG-packaged LED from UM epitaxial in Dec 2017.
- Completed the installation of 4" High Temp Metal-Organic Chemcal Vapour Deposition (MOCVD) at USM in March 2018.
- USM team lighted up their first growth GaN on Patterned Sapphire Substrate (PSS) and GoG in April 2018 and June 2018, respectively.

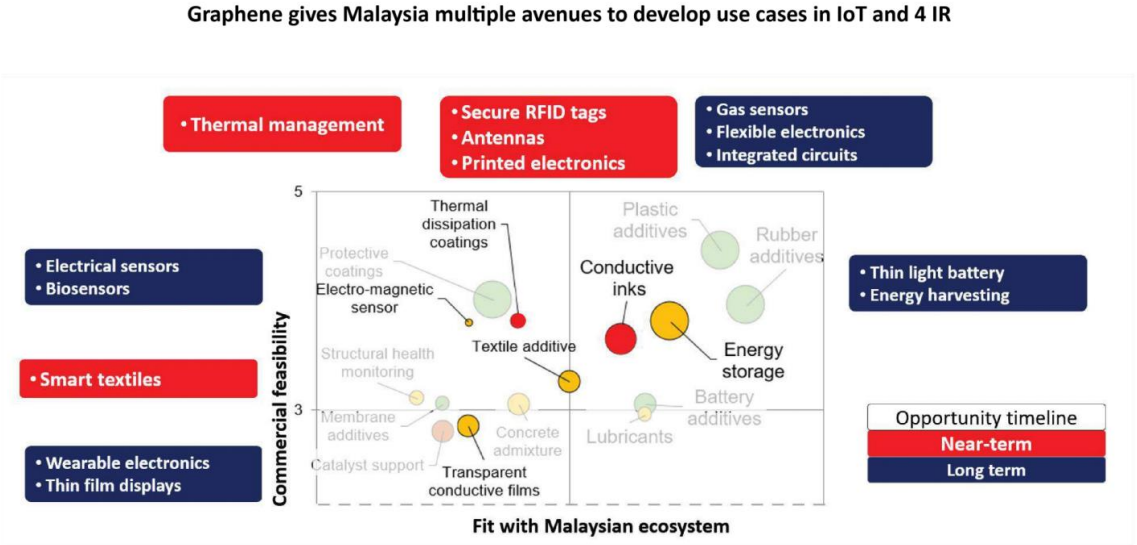
More outcomes are expected to be generated by this project, creating higher value jobs for Penang and Malaysia, with spillover effects for LED and its-related industries. Beyond LED, this programme is expected to contribute to the next phase of research and applications in GaN power devices, LiFi (light fidelity), ultraviolet (UV) LED applications and 'light recipe' for tissue culture and horticulture.

Source: Interviews with CREST and INOR, USM; Lim (2018)

Prevailing and potential opportunities

Diagram 1 shows use cases opportunities in Internet of Things (IoT) and Fourth Industrial Revolution using graphene for Malaysia by NanoMalaysia, in the near-term and long-term time periods. In line with Penang's industrial strength, some suggested shortlisted sectors in the short-term are thermal management, secure RFID tags, antennas, and printed electronics. Meanwhile, long-term opportunities are seen in wearable electronics, thin film displays, electrical sensors, biosensors, gas sensors, flexible electronics, integrated circuits, and thin light battery.

Diagram 1: Use cases opportunities in IoT and Fourth Industrial Revolution using graphene by NanoMalaysia



Source: Adapted from NanoMalaysia Strategic Report 2019

The established ecosystem in Penang allows for more collaboration and joint efforts in nanotechnology and nanotechnology-based industries. Policymakers should therefore also encourage the adjacent collaboration or development of nanotechnology applications by companies that already have a presence in Penang. Based on an analysis of data from StatNano, Nanowerk, and The Nanodatabase, a list of companies with presence in Penang whose parent companies/related units have a footprint in nanotechnology applications, is detailed in Table 4.

Many of these companies already have a significant presence in Penang, and are industry leaders within their respective business segments. Promising industries include electronics, medical-related and nanotechnology materials. Some of these companies have also funded nanotechnology-related university research projects and consultancy such as by Malaysia Toray Science Foundation and ItraMAS Corporation in INOR projects.

Table 4: Companies with presence in Penang whose parent companies have nanotechnology products, in a broad range of industrial applications

Electronics		
Sensor	*Processor*	*Integrated Circuits*
• Amphenol Corporation • Analog Devices	• Advanced Micro Devices • Intel	• Analog Devices
Unspecified electronics		
• Advantest • Agilent Technologies • Benchmark Technologies • Bruker • Honeywell • Keysight Technologies • Osram		
Medical		
Medical Supplies		
• B. Braun • Bactiguard • Smith+Nephew (announced investment in Penang)		
Nanotechnology materials		
• Toray Industries		

Note: Non-exhaustive list. See StatNano, Nanowerk, and The Nanodatabase for full compilation, and database information.
Source: Author's compilation based on data from StatNano, Nanowerk, and The Nanodatabase

Key challenges and proposed solutions: Re-focus exploration for nanotechnology in Penang

Key issues, challenges and proposed solutions for the nanotechnology and nanotechnology-related sphere are summarised in Table 6. The main issues concerning the nanotechnology and nanotechnology applications sphere in Penang are:

(1) obstacles in development and commercialisation process,
(2) willingness of multinational corporations (MNCs) to collaborate,
(3) SMEs and local companies access to ongoing projects,
(4) slower rate of adoption of nanotechnology applications products in the market, and
(5) continued funding for the development of nanotechnology applications and materials.

Table 5: Key issues, challenges and proposed solutions for the nanotechnology and nanotechnology-related sphere

Issues	Challenges	Proposed solutions
Problems in nanotechnology development and in the commercialisation process	According to an interview with NanoMalaysia (in September 2020), nanotechnology actively began in the academic research domain. Common feedbacks in the nanotechnology field are found in the product development and commercialisation process. Some also agree that many research projects in this field tend to remain in research institutions, and there are often complications in commercialisation. This may be due to market irrelevance or to low market readiness stemming from R&D-Market disconnect, mismatch in expectations during negotiations to commercialise, and less clear expectations from different players in the licensing process.	While there has been progress in bridging the gap between the academic community and the industry, efforts to address real industry problems need to be intensified. With INOR in Penang, policymakers may also continue to encourage more collaboration between INOR with industry members. Increased efforts to link researchers to the problems in the industry (such as currently being coordinated and improved by NanoMalaysia) may also provide impetus to commercialise more nanotechnology innovations and applications.
MNCs may not be willing to share their technology roadmap, and the extent of each company opening up their technology and collaborative ventures differs	Some identified companies with a presence in Penang whose parent companies/related units have a footprint in nanotechnology applications are listed in Table 6. However, a main challenge is that some MNCs may not be willing to share their technology roadmap, and the extent of each company opening up their technology and taking on collaborative ventures differs. Oftentimes, closed innovation is more common than open innovation. There are also expected difficulties in encouraging co-operation (joint venture/localization of innovations) of new applications in nanotechnology.	It is suggested that a more enhanced environment that encourages (1) partnership, (2) localisation of innovations, or (3) generating new innovations for nanotechnology and nanotechnology applications. This includes tax holidays, tax deduction, matching grants, and enhancement to the intellectual property (IP) protection.
SMEs and local companies find it difficult to locate the different innovations in nanotechnology	It was also gathered that SMEs and local companies think it difficult to locate the different innovations in this field taking place among different actors. There are increasingly more companies interested in adopting different innovations for commercialisation, but the difficulty to gather information on such innovations makes it difficult for companies to explore such opportunities.	It is suggested that a database on the different innovations taking place be established to ensure that companies that are willing to explore the licensing opportunities and to take nanotechnology innovations for scalable productions or to synergise with their existing products, will be able to do so.
Slower rate of adoption of nanotechnology applications products in the	Some literature continues to highlight that the cost of products with nanotechnology applications are usually at a premium compared to conventional products, and this may hamper the demand and adoption	On balance, the addition of nanomaterials into a product is usually low (i.e. less than 10%) and is not disruptive to production lines; such is the case for at least

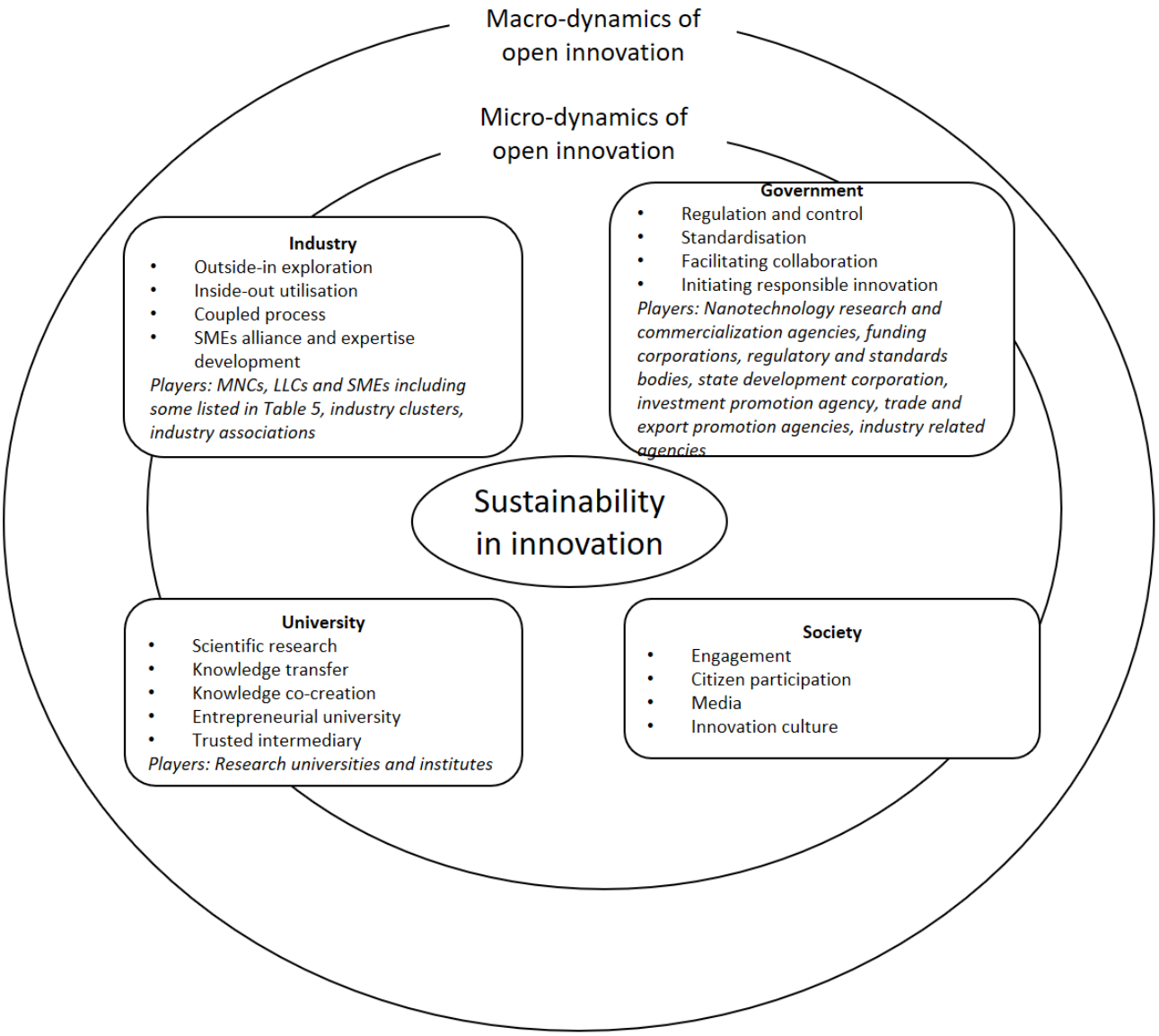
market	of nanotechnology applications products on the market.	many products. Furthermore, as new products are released, it may also be part of a business strategy or a corporate decision to price the product at a premium, and need not necessarily be seen as a weakness in the commercialisation of nanotechnology products.
Funding for the development of nanotechnology applications and materials	NanoMalaysia has been granted RM75 million over five years by the Economic Planning Unit to advance the nanotechnology agenda under the 11th Malaysia Plan (2016 – 2020). There should be continued funding for the development of nanotechnology applications and materials in Penang and Malaysia.	As Malaysia leaps towards a new decade in 2021, it is suggested that such funding for development and commercialisation of nanotechnology products be improved in order to benefit a greater pool of companies and industry members. This would also translate into more job creation and upgrading in the industry, and an overall strengthening of the existing industry ecosystem.

The Quadruple-Helix model in Penang's nanotechnology context

This section proposes the Quadruple-Helix model, adapted from Yun and Liu (2019), in Penang's nanotechnology context. The Quadruple-Helix model mainly encompasses the industry, government, university and society in the dynamics of open innovation. At the core of this is *innovation*, where each player has interactive roles to play in the macro- and micro-dynamics of open innovation.

There is already rather robust interaction between the different participants in the nanotechnology industry in Penang and Malaysia (as discussed in earlier sections). The proposed modified model and suggested players in Diagram 2 are aimed at capturing the attention of a larger pool of players, old and new, in the nanotechnology and nanotechnology-related sectors. An interactive and continually evolving relationship in initiation, development and collaboration is envisioned between the different stakeholders.

Diagram 2: Proposed Quadruple-Helix model in Penang's nanotechnology context



Source: Adapted and modified from Yun and Li (2019)

Within the industry group (which covers MNCs, LLCs, SMEs, industry clusters and associations), this is usually where real-world problems take place, and solutions are required. Large firms, especially those with a centre of excellence and in-house research and development, may already have resources to work with, while SMEs are able to show more of their expertise on open platforms (Yun and Liu, 2019; Chesbrough, 2003). The role of universities for research and education continually evolves as the major functions expand into knowledge transfer, knowledge co-creation, their role as entrepreneurial mentors, and being a trusted intermediary. This is even more important in nanotechnology where things usually begin in the academic research domain, and the development and commercialisation processes require linkages to external parties (especially industry members).

Next, the government's role includes regulation and control, standardisation, collaborations facilitation and responsible innovation initiation. Notably, NanoMalaysia and its related subsidiaries have taken up many of these roles within the nanotechnology industry ecosystem in Malaysia. Interestingly, NanoMalaysia has expanded its triple-helix based 11th Malaysian Plan Nanotechnology Commercialization Programme to the quadruple-helix version namely REVOLUTIoNT for the 12th Malaysia Plan. Other governments and government-related research agencies in the graphene ecosystem include SIRIM Advance Material Research Centre (AMREC), MIMOS Berhad, CREST and Malaysian Rubber Board (NanoMalaysia and Agensi Inovasi Malaysia, n.d.)

This study further suggests that additional linkages be built by other related corporations, including those at the state level. This may include the state economic development corporation, investment promotion agency and promoted industry promotion agency. Finally, society itself forms an integral part of any innovation. It gives feedback via engagement sessions, citizen participation and gains knowledge from the media. The cultivation of an innovation culture in society may also give rise to more uses for nanotechnology applications.

Concluding Remarks

Nanotechnology and nanotechnology applications cut across different spheres of industries and technological applications. This paper proposes that Penang aligns nanotechnology and nanotechnology applications with focus especially on the electronics devices and systems segment, while at the same time penetrating further into the national key jumpstart sectors through capitalising on the state's industrial cumulative experience and technical expertise strength.

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Appendix

Box Article 2: NanoMalaysia's role in nanotechnology energising in Malaysia

NanoMalaysia Berhad (NanoMalaysia) is the lead agency responsible for the commercialisation of nanotechnology in the country. NanoMalaysia was incorporated by the Government of Malaysia in 2011, as the special purpose vehicle to spearhead the growth of the national nanotechnology sector. Nanotechnology was identified under the New Economic Model (2011 – 2020), as a crucial new growth engine and a key enabler to drive innovations across all technology-based sectors.

NanoMalaysia's role is to provide support for commercial entities within the nanotechnology industry, to achieve targeted outcomes in moving towards an innovation-driven economy. Support by NanoMalaysia ecosystem includes global marketing activities, helping build sectoral talent, providing financial and infrastructure resources, assisting with technology and knowledge transfers, and catalyzing product innovations leveraging on nanotechnology.

Among its roles are:

- Commercialisation of nanotechnology research and development
- Industrialisation of nanotechnology
- Facilitating investments in nanotechnology
- Furthering human capital skills development in nanotechnology.

There are three main companies with specific functions under NanoMalaysia: NanoVerify (which is a consultation and verification company); NanoCommerce (a business and commercial company), and; Nanovation Ventures (an investment facilitation company). NanoVerify has been delegated to operate Malaysia's first and only nano certification programme, known as the NANOVerify Programme.

Table 6: Penang's approved manufacturing investments by industries, 2017-2019

Industries	2017		2018		2019	
	RM million	% share	RM million	% share	RM million	% share
Electronics and electrical products	6,710.1	62%	1,483.3	26%	9,895.1	59%
Scientific and measuring equipment	1,769.3	16%	214.7	4%	2,453.2	15%
Machinery and equipment	423.9	4%	1,277.5	22%	2,394.3	14%
Non-metallic mineral products	0.0	0%	82.1	1%	442.8	3%
Chemical and chemical products	796.0	7%	58.6	1%	431.9	3%
Fabricated metal products	225.5	2%	317.3	5%	361.3	2%
Plastic products	125.4	1%	408.1	7%	248.4	1%
Transport equipment	173.0	2%	457.6	8%	221.6	1%
Others	588.70	5%	1,481.80	26%	406.80	2%
Total investment	10,811.9	100%	5,781.0	100%	16,855.4	100%

Source: Malaysian Investment Development Authority

Table 7: Export of HS854140 in USD billion

	2015	2016	2017	2018
China	22,831.27	16,923.15	16,469.24	18,218.69
Malaysia	3,944.38	4,397.12	4,043.88	4,514.49
Japan	4,031.92	3,912.77	3,882.19	3,955.82
South Korea	3,633.22	4,164.39	4,613.56	4,308.27
Hong Kong	2,885.41	2,882.96	3,272.59	3,622.25
Netherlands	1,720.70	1,756.81	2,145.96	2,371.05
Viet Nam	551.22	1,617.76	2,325.30	2,000.07
Germany	3,150.11	2,832.47	2,731.73	2,644.34
United States of America	2,425.60	2,310.20	2,405.32	2,570.60
Taiwan	5,929.63	5,082.89	4,412.01	3,115.61
Singapore	2,360.78	2,606.58	2,337.71	1,696.56
Thailand	327.91	986.55	1,469.26	1,202.60
France	387.04	378.43	392.39	557.64
Philippines	1,640.27	1,319.61	379.21	212.28
Italy	353.13	357.75	343.99	329.68
India	144.42	126.72	138.49	115.65
Portugal	18.08	16.60	17.27	17.69
Belgium	247.99	156.26	134.02	132.04
United Kingdom	160.99	167.71	205.95	191.62
Canada	320.97	286.85	250.27	185.48
Others	2,541.75	2,249.38	1,656.18	1,446.59
Total	59,606.77	54,532.95	53,626.52	53,409.02

Note: Some data may be derived from import mirror data
Source: International Trade Centre (ITC)

Analytical Framework

The main sources of information for this brief include information from NanoMalaysia (various reports), National Economic Model report, INOR report, nanotechnology and nanotechnology-related databases – StatNano, Nanowerk, and The Nanodatabase, and various company websites. Filtering of companies from the databases to obtain companies that have a presence in Penang is by the author, and is based on InvestPenang, the Malaysian Investment Development Authority (MIDA), and International Trade Centre (ITC) directories. Interviews with industry stakeholders were also conducted. See reference for the complete list of work referred to by the author.

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