NANOELECTRONICS TECHNOLOGY ROADMAP FOR MALAYSIA
-R&D Opportunities

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MALAYSIA

2008

PREAMBLE

This Roadmap is developed for Ministry of Science Technology & Innovation, Malaysia.

In preparing this Roadmap we have:

- Drawn related information from a report on National Nanotechnology Roadmap titled "Identification of Business and R&D Opportunities in the Application of Nanotechnology in Malaysia" prepared by MIGHT in 2007 for Economic Planning Unit, Prime Minister Department;
- Developed framework on the opportunities of Nanoelectronics technologies for Malaysia and shared with national players for feedback;
- Drawn information from a range of national and international research and policy reports;
- Incorporated comments from interested parties on an earlier framework of this Roadmap.

This is the first version of the Roadmap document. There will be updates from time to time as to incorporate new technology development and new strategic directions.

CONTENTS

Microelectronics has changed our world drastically: computers, mobile phones, digital television, DVD players, car navigation and security features, medical screening and health care equipment have all become essential parts of our everyday lives.

Nanoelectronics is just the next evolutionary step, as the number of transistors that can be integrated on a single chip reaches one billion, but it indeed represents a revolution marking a dramatic step forward.

- European Nanoelectronics Initiatives Advisory Council

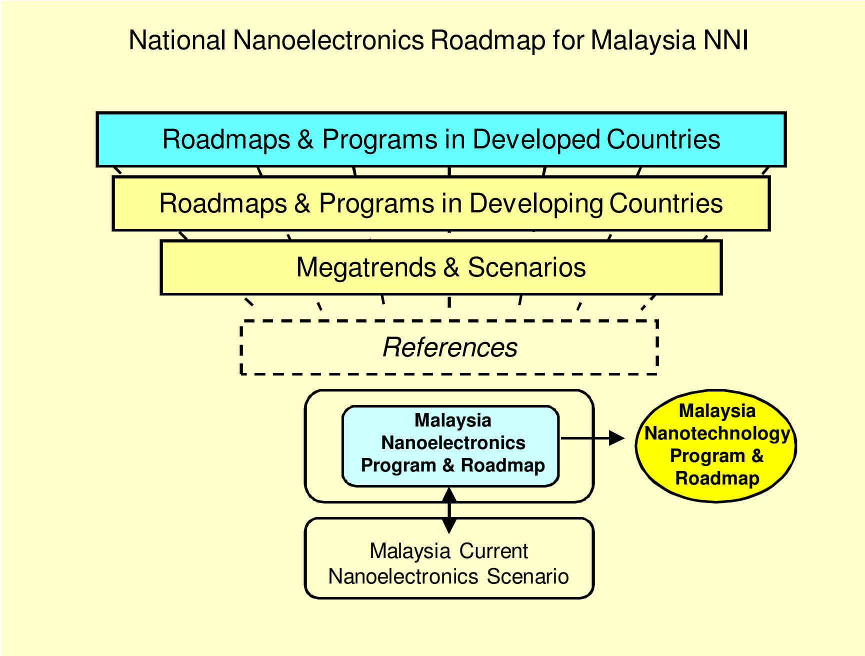
About the Roadmap

This document charts direction of Nanoelectronics technology, designed to guide Malaysia Nanoscience and Nanotechnology community towards a strategic development for the advancement of the technology in the country.

A National Roadmap is a type of strategy providing broad context and high level directions on a particular area, in this case nanoelectronics, from a Malaysia perspective. It represents the Government's position on the technology area, noting on how our Science & Technology capability should develop to best meet Malaysia's future needs. References on various countries' related initiatives and the status of the technology advancement and trends are useful in identifying areas of potentials. However, customization to national needs based on local scenarios is necessary to ensure that it can be implemented and applicable to most of the players and stakeholders.

This roadmap is to complement the National Nanotechnology Roadmap developed in 2007 by MIGHT under National Nanotechnology Initiative (NNI) with EPU sponsorship. In that initiative, the Roadmap has identified a number of focused products and technologies to be developed. Not to duplicate the identified areas, the Nanoelectronics Roadmap addresses the development of fundamental and applied electronics technologies for various applications enabled by nanotechnology that includes those identified in the NNI.

This is not a technological roadmap with milestones, targets & detailed research plans even though some rough timeline is indicated as general guideline. Those details need to be decided when actual projects are proposed.



By producing this Roadmap, and other Technology Roadmaps for Malaysia, the Ministry is ensuring that the strategic research investment goes to those areas that will make the most different for Malaysia over the long term.

The Roadmap also sets the scene for better co-ordination across related S&T community and the governing bodies to realize the target and mission of the initiatives. The directions in the Roadmap do not only highlight the areas we need to build but also the future skills that need to be developed.

How Nanoelectronics Roadmap complements Malaysia Nanotechnology Roadmap

National NANOELECTRONICS Roadmap

- Nanoelectronics Roadmap is to address ELECTRONICS Industry as another target to be developed under the Malaysia National Nanotechnology Initiative (NNI).
- Nanoelectronics Roadmap focuses on the engineering aspects of technologies to produce nano-scale electronics components and to apply it in micro- or nano-devices and systems for various technology/application platforms.
- Nanoelectronics Roadmap has identified almost the same target application industries where nano-scale electronics components & systems would be deployed. Thus the technologies and products to be developed under Nanoelectronics Roadmap would indirectly support or enhance the development of target products identified in Nanotechnology Roadmap.
- Nanoelectronics Centers of Excellence identified and established under this Roadmap could provide linkages between nanoscience community and nano-engineering community through project collaborations and resource sharing.

National NANOTECHNOLOGY Roadmap (2007)

Identified Target Industries Under NNI
BIOTECHNOLOGY
ENERGY
ENVIRONMENT
AGRICULTURE
MEDICINE

Target Products under NNI
BIOSENSOR
BIOCHIPS
MOLECULAR FARMING
DRUG DELIVERY SYSTEM
SOLAR
LITHIUM-ION

Technological position in a global context

- The term 'nanotechnology' is likely to be displaced by 'technology' in the coming years due to pervasiveness
- In the Nanotechnology domain, Nanoelectronics is a key market with several commercial products and more are expected in the coming years
- The U.S. is leading the world in regards to nanotechnology related investments, followed by Japan, EU and "Rest of World" including Asia Pacific, as being shown in both tables on the right
- Nanoelectronics is one of the key funding areas around the world by governments, industry and venture capitalists

The tables also show

- Increase in total investment, where 'Rest of World' contributed most of the increase and China joined the statistic in 2006
- Nanoelectronics remains one of the focus investment in each of the region

2005 Nanotech Investment by Region (US$ Millions)

Region	Government	Industry	Venture Capital	Total	Emphasis
U.S.	1,610	1,820	457	3,887	Fundamental nano science, bio/pharma, defense and consumer applications, and **nanoelectronics and nano manufacturing.**
Japan	1,100	1,430		2,535	**Nano materials and metrology, nanoelectronics (semiconductors and displays),** nano bio, energy and environment applications.
European Union	1,150	847	40	2,017	**Nanoelectronics: "More of Moore" and "More than Moore"**
Rest of World	714	450		1,179	Korea: **Nanoelectronics** and nano bio Taiwan: **Nanoelectronics**
Total	$4,574M	$4,547M	$497M	$9,618M	-------

2006 Nanotech Investment by Region (US$ Millions)

Region	Government	Industry	Venture Capital	Total	Emphasis
U.S.	1,780	1,930	650	4,340	Fundamental nano science, bio/pharma, defense and consumer applications, and **nanoelectronics and nano manufacturing.**
Japan	975	1,700	50	2,695	**Nano materials and metrology, nanoelectronics (semiconductors and displays),** nano bio, energy and environment applications.
European Union	883	700		1,603	**Nanoelectronics: "More of Moore" and "More than Moore"**
Rest of World	2,762	970		3,762	Korea: **Nanoelectronics** and nano bio Taiwan region: **Nanoelectronics** Mainland China: Construction materials, nano bio and other applications
Total	$6,400M	$5,300M	$700M	$12,400M	-------

Source: SEMI.ORG, 2007

USA	JAPAN	EU
• National Nanotechnology Initiative (NNI) and National Nanotechnology Coordinating Office (NNCO) are key government platforms • Government funding and industry investment has been increasing over the years • Nanotechnology research infrastructure has been in place • Has strong patent leadership with IBM and University of California being two of the top five nanotech patent holders in overall - Rice University, Hyperion Catalysis, Exxon and IBM are leading fullerene/carbon nanotube patent holders in overall - Hewlett Packard is in top five patent holders in overall for nanoelectronics • There is vibrant start-up environment, even though venture capital funding is in modest level • U.S. is leading nanotechnology commercialization and overall investment in nanotechnology	• Nano Business Creation Initiative (NBCI) is a key group of industry stakeholders advising government on nanotech strategy and roadmaps • Funding levels in is increasing trend with government investment declining but industry investment increasing • Has good national lab infrastructure where mostly are stemming from electronics • Has strong patent leadership with Canon, Hitachi and Olympus Opticalin are into top five nanotech patent holders overall - NEC is the 2nd fullerene/carbon nanotube patent holder overall • Japan has poor start-up climate with little venture capital money available -Only around 100-200 nanotech start ups in Japan out of 1000-1500 globally -Some government fundng is available while most of the investment is coming from companies	• European Nanoelectronics Initiative Advisory Council (ENIAC) is the European Technology Platform for Nanoelectronics. Among its roles are providing a strategic research agenda for the nanoelectronics sector in Europe with respect to R&D and set out strategies and roadmaps to achieve this vision through the Strategic Research Agenda and other associated documents. • ENIAC has a wide membership of various actors in the sector and with a Steering Group consisting in a core group of senior experts from semiconductor manufacturing companies, equipment and materials suppliers, application/system integrators, research organisations, academia, Member States, Regions, Eureka and other public authorities, financial organisations, etc. • Joint undertakings with industry associations (ARTEMIS/AENEAS) for a 10-year strategic programs (2007-2017

PAKISTAN	CHINA
• National Commission on Nano-Science and Technology (NCNST) is the driver • Funding of R&D projects on nanotechnology is by HEC and MoST • Several R&D organizations working on nanotechnology: COMSATS, KRL, PIEAS, PINSTECH, PCSIR, Universities • There is establishment of nanotechnology lab at PCSIR, Lahore	• Several centers on Nanotechnology include National R&D Centres: National Centre for NanoScience and Technology, National Engineering Centre for Nano Technology and its Applications • About 3000 S&T workers in 50 universities, 20 CAS institutes and 300 enterprises are working on nanoscience and technology
IRAN • The Special Office of Nanotechnology Development established in the Iran Presidency in 2003 • Iran developed ten year strategy of nanotechnology development (2005-2014) • ECO-NAN, ECO Nanotechnology Network was proposed by Iran in 2007	**TAIWAN** • Six year nanoscience and nanotechnology programme with US$ 700 million launched in January 2004 • National nanotechnology programme is centred at the Industrial Technology Institute • Taichung Science Park has been completed: A science-based industrial complex focusing on nanotechnology with 60 high-tech firms to invest US$ 5.78 billion, expected to create 40-50 thousand jobs
INDIA • Harnessing of technologies will help India achieve a Gross Domestic Product (GDP) of USD 2-3 trillion in the next 15 years, from the current USD 650 billion, according to [Reliance Industries Ltd Chairman and Managing Director, Mukesh D. Ambani] • During the fiscal year (2006-07), Rs 1.8 billion were budgeted to set up seven to eight nano-science and technology centers in the country.	**THAILAND** • National Nanotech Center (NANOTEC) established in 2003 by the Thai Cabinet's decree. NANOTEC's objectives among others are to set the agenda and lay out the nanotechnology roadmap for Thailand. • The nation's first nanotechnology roadmap include nanopolymers, nanocomposites, nanoparticles, nanoclay, nanofibers, nanotubes, nanoporous materials, nanocatalysts, solar cells, and nano-biosensors

Evolution of Technologies

Nanotechnology is in its growth stage, as depicted in a technology S-curve figure on the right, and is advancing as a very diverse technology. Regardless of the scale of the end products, Nanoelectronics can be defined as nanotechnology applied in the context of electronic circuits and systems [1]. This definition will be used as the context of the roadmap.

Nanotechnology advancement & progress can be viewed at different level of generations over a period of time as depicted in the figure at the bottom.

<u>1st. Generation: PASSIVE NANOSTRUCTURES</u>
- Examples include coatings, nanoparticles, bulk materials (nanostructured metals, polymers)

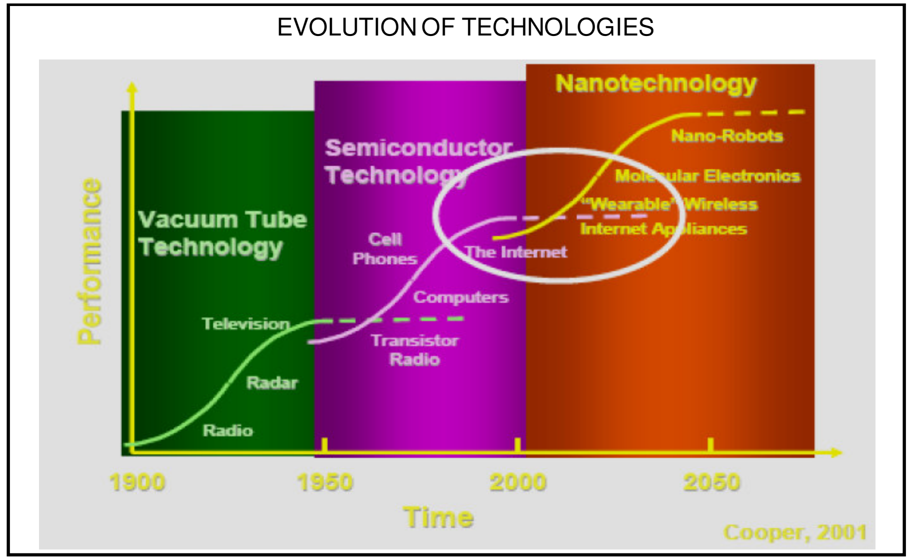
<u>2nd Generation: ACTIVE NANOSTRUCTURES</u>
- Examples include transistors, amplifiers, actuators, adaptive structures

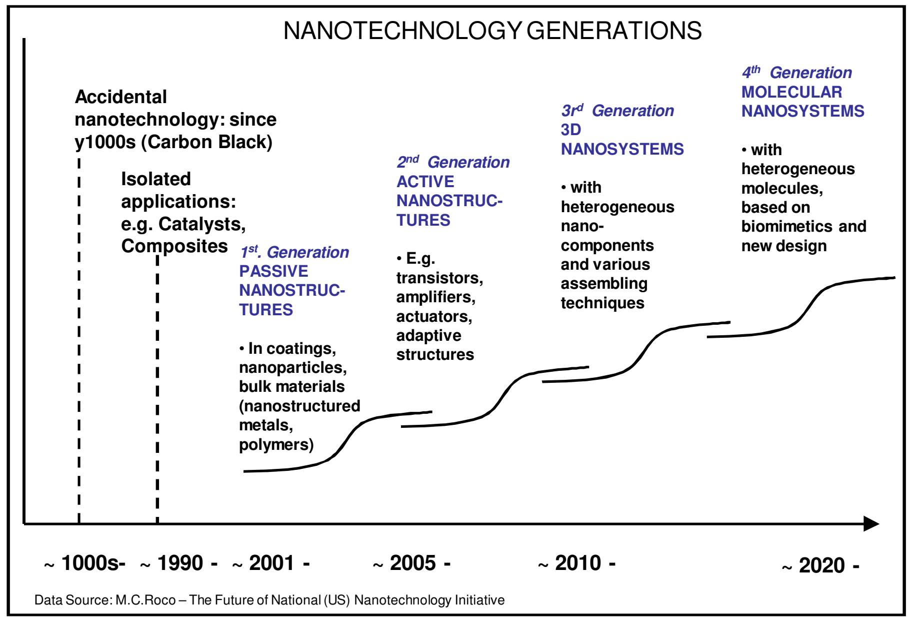
<u>3rd Generation: 3D NANOSYSTEMS</u>
- with heterogeneous nano-components and various assembling techniques

<u>4th Generation: MOLECULAR NANOSYSTEMS</u>
-with heterogeneous molecules, based on biomimetics and new design

The world is currently at 2nd Generation and moving towards 3rd Generation of 3D Nanosystems

[1]: Euro Training Project, 2008



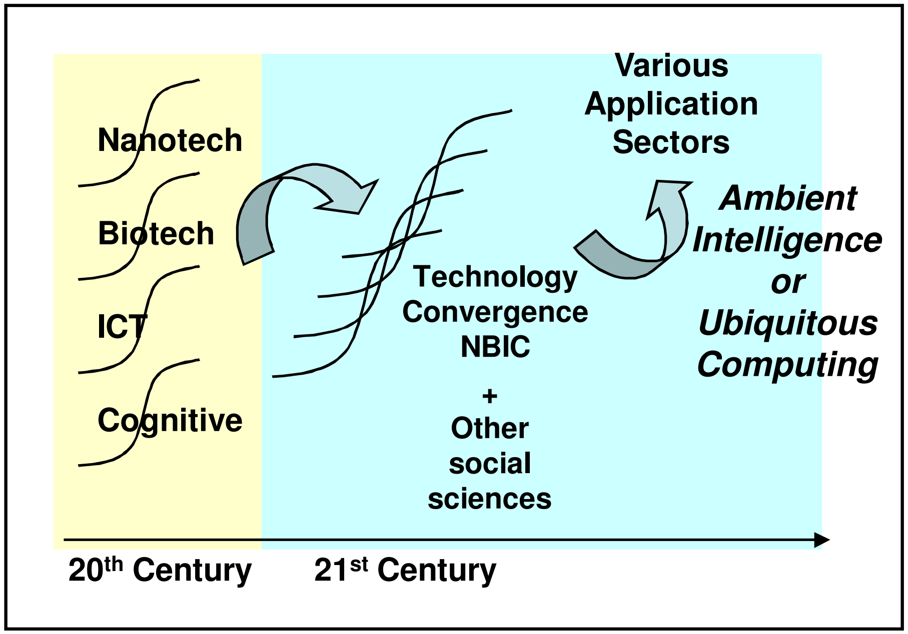


Technology Convergence: Nano-Bio-ICT-Cognitive

The trend on Technology Convergence (See figure on the right) is one of the driving factors for nanoelectronics.

In the 20th century, Nanotechnology, Biotechnology, Information and Communication technology are among the last major technology initiatives being pursued by many technology community & countries.

- Nanotechnology enables manipulation of individual atoms, development of improved materials and aims to miniaturization of just about everything.
- Biotechnological developments enables in-vitro process, genetic screening, more targeted pharmaceuticals and genetically modified crops
- ICT has prepared the ground for the computer, hand-held and mobile communicators, and the Internet.



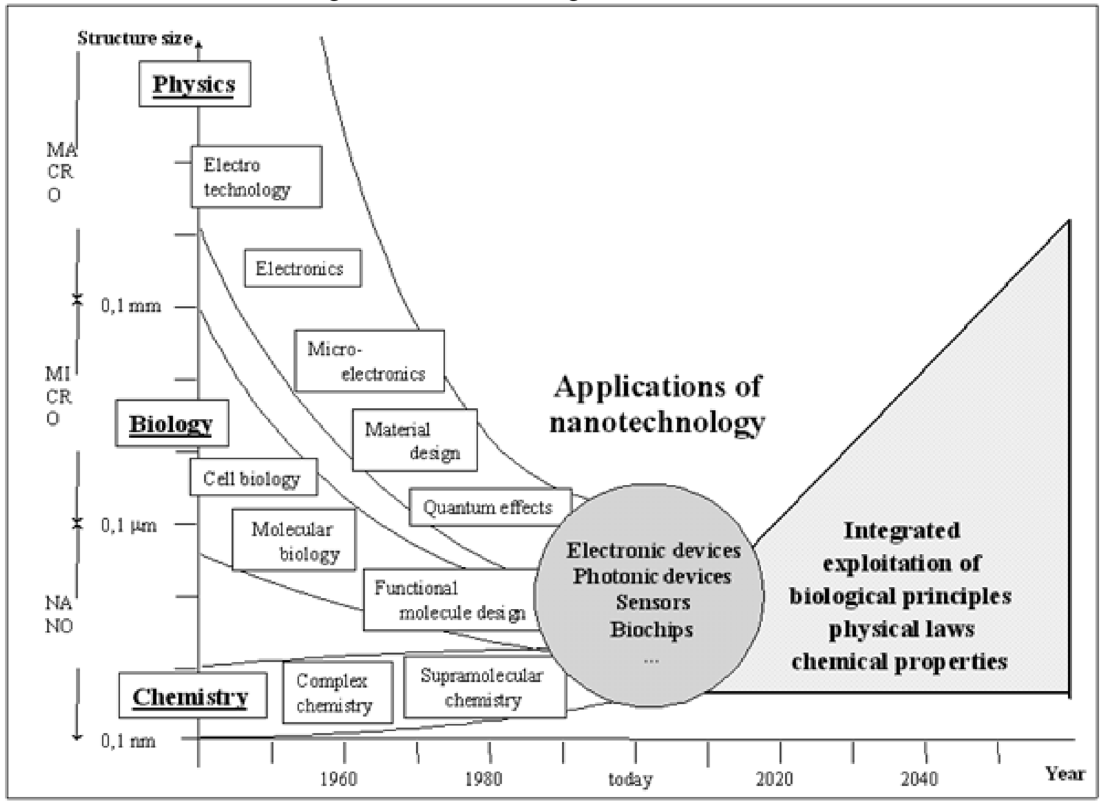
Along with the individual technology advancements, the 21st century sees the trend towards convergence of these enabling technologies. Nano-, Bio-, and ICT complement each other and have begun to join forces with cognitive science, social psychology and other social sciences. This convergence promises to transform every aspect of life through various application sectors, termed as Ambient Intelligence or Ubiquitous Computing.

Science Convergence: Physics-Biology-Chemistry

Figure on the right shows the convergence path that lead towards the scale range that defines nanotechnology area of today.

Over the years, researchers are working towards the integration of biological principles, physical laws and chemical properties to create novel solutions where nanotechnology can be applied into various fields for example electronic devices for consumer markets, photonic devices in communications, sensors for various sectors and biochips in medical.

Integration & Convergence of Sciences



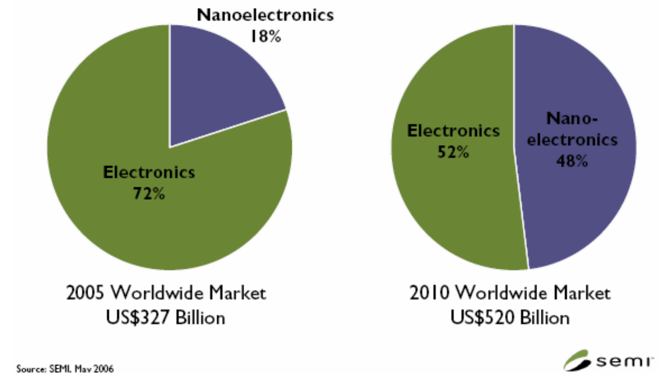
Source[1]: www.sigda.org/iwls/iwls2002/elena.ppt

[1] Farm, Petra et al. 2002. CAD problems in nanotechnology

Nanoelectronics Market Segment

- Nanoelectronics includes portions of semiconductor, display, storage, optoelectronics and Nano-Electro-Mechanical-System (NEMS)
- The worldwide market for nanoelectronics is forecasted to increase from 18% of total electronics market in 2005 to 40% in 2010
- Commercial nanoelectronic products include:
  - Semiconductors (90 nm and below)
  - Hard disk storage (perpendicular recording, etc.)
  - OLED
  - Alternative forms of memory (MRAM, FRAM, Phase Change RAM, NRAM)
  - CNT sensors
  - Atomic force microscope (AFM) tips
- Nanoelectronics products expected to be commercialized in next several years include:
  - Field emission displays, CNT backlight units, films
  - Thermal interface materials
  - Nano mechanical data storage
- Convergence and integration across traditional industry sectors is predicted to increase (e.g. electronics and biotechnology)

Market Forecast



Worldwide Market Sizes for Nano Tools for Electronics

Nano Tools and Equipment*	2010
Atomic Manipulation	100
Deposition	454
Etch	65
Ion Implantation	135
Inspection and Metrology	1,448
Lithography (includes direct write/e-beam, EUVL, nano imprint and 193 immersion)	815
Surface Conditioning	38
Thermal Processing	30
Total US$M	**$3,085**

* Excludes spare parts and service.

Worldwide Market Sizes for Nano Materials for Electronics

Nano Material*	2010
Catalysts	1
Coatings	171
Designer Molecules	679
Engineered Substrates	68
Fullerenes/Nanotubes	101
Nano Composites	1
Nano Particles	3
Nano Wires	1
Precursors	60
Slurries	50
Total US$M	**$1,135**

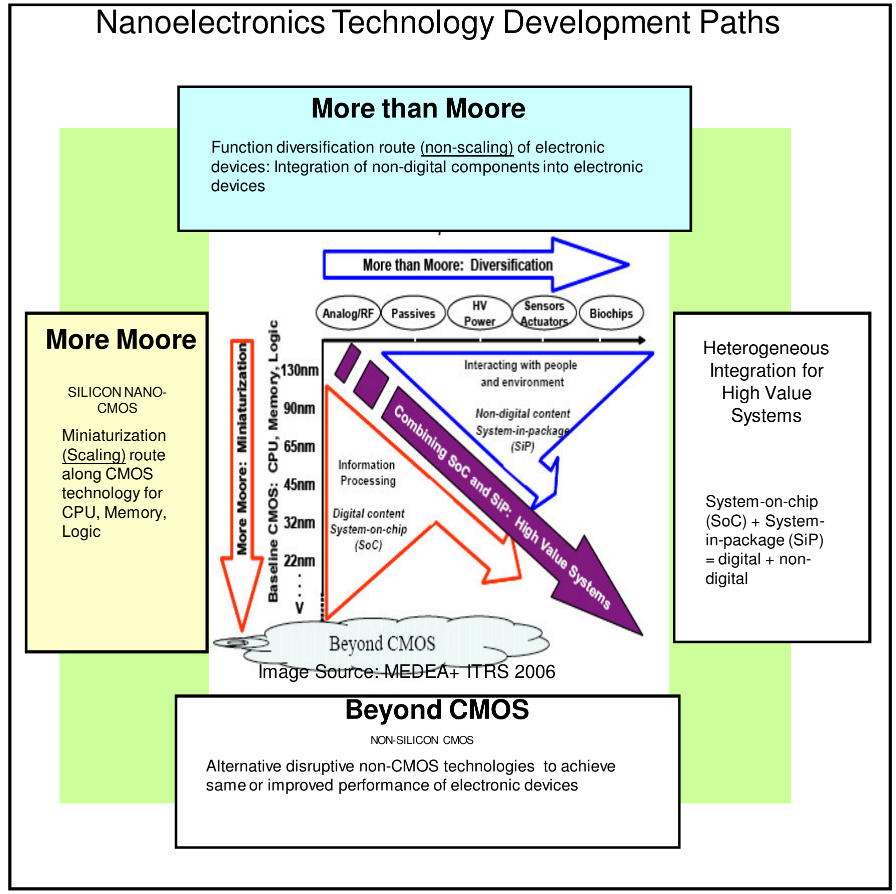
* Excludes license revenues.

Source: SEMI, Nov 2006

There are several perspectives to the concept of nanoelectronics, but the most accepted ones that reflect different paths of work (see figure on the right below) by different research groups worldwide are the following:

1. 'More Moore' domain of development is when nanoscale dimensions of nanoelectronic components allow development of systems of giga-scale complexity, measured in terms of component on a chip or in a package. This scaling feature and the road to giga-scale systems requires miniaturization and integration technologies.
2. 'More than Moore' domain of development – a concept that nanotechnology is very diverse and allows the integration of purely electronic devices with mechanical devices, bio-devices, chemical devices, etc. The technology fusion also can combine digital systems with analog/RF circuits.
3. A third is 'Beyond CMOS' development domain. The concept is that when traditional scaling limits in standard CMOS technology are reached during the next decade, there will be a need for fundamentally new nanoscale electronic devices. This path refers to development of new nanoelectronic components.

Ref: Euro Training Project, 2008



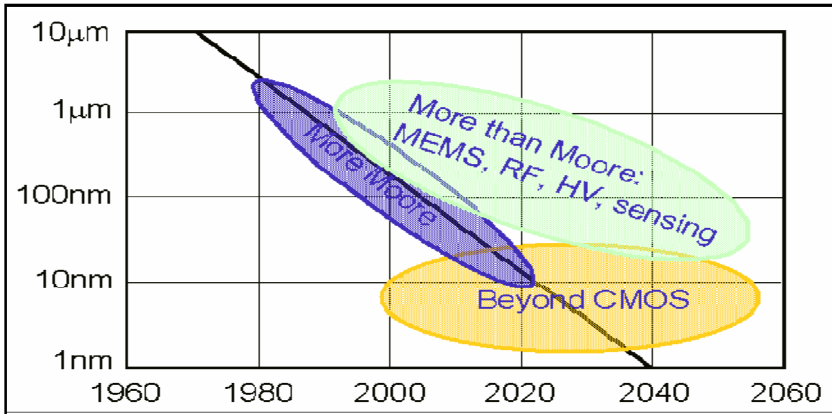
More Moore: Giga-systems

When systems are designed using nanoscale components the number of components in a system may reach gigascale orders. This imposes a number of challenges:

- The complexity scaling: how do we design utilizing such large numbers of components. In some systems it may be easy to utilize more components, e.g. in memory chips. In other systems, it is not so obvious what is the best way to utilize gigascale complexity.
- The scaling of electrical properties: when device dimensions scale, there is also a scaling of electrical properties such as power dissipation, supply voltage, speed, leakage currents. Design at the architectural level is required in order to overcome problems related to these scaling properties.

More than Moore: Technology fusion

Nanotechnology (in a broader sense than nanoelectronics) makes it possible to develop new components which may be used together with electronic components in system design. This includes for instance micromechanical systems, photonic systems, biochemical systems. Also, the combination of digital and analogue/RF circuits may call for combination of different technologies. Together with electronic components, such components open ways to the design of new integrated systems and applications, and research and education is needed concerning such technology fusion options.



Technology roadmap comparing the ‘More than Moore’ domain to the ‘More Moore’ domain and the ‘Beyond CMOS’ domain [2]

Beyond CMOS: New Nanoelectronic components

Planar CMOS technology has been the workhorse for electronic system design for several decades. It has been scaled according to Moore’s law, resulting in ever decreasing device sizes and in a number of technology nodes, the present one being the 45nm node. However, it is generally agreed that the scaling cannot go below approximately 10nm for MOS transistors and this limit is expected to be reached about 2015. Following the CMOS era, new nanoelectronic devices must be expected. It is yet to be seen which technologies and devices will be established as the workhorses for future nanoelectronics. Several candidates, including molecular devices, quantum devices, spintronics, etc., are present and future research topics. Not only the technology for such components must be developed but also models for such components so that they can in practice be employed by circuit and systems designers.

[2]: Medea+ Working Group: Towards and Beyond 2015: technology, devices, circuits and systems, 2007

Determining Factors	Assessment & Recommendation
Technology	
Technology Trends/Future Scenarios	- Technology Convergence & Fusion, Miniaturization, Giga-scale System & Ambient Intelligence or Ubiquitous Computing are key technology journey that the country should be ready to participate
Technology Challenges & Opportunities	- Because they are still in emerging stage with lots of challenges to solve, R&D opportunities should be granted in all of the following: Bottom-up Process, Integration Technologies, Packaging Technologies, Tools, Metrology & Standards. Besides, lack of expertise in the areas would require a concerted effort on capability building for, among others, transition from MEMS to NEMS at the system designs & applications development
Marketability & Potential Return	
Market Potential	- Markets for nanomaterials & nanoparticles for various application including to enhance electronics devices has been increasing and market for nanoelectronics in various application sectors is predicted to rise due to technology trends and future living scenarios.
IP generation Potential	- Potential is high in the 'More than Moore' (technology diversification & fusion) direction, Integration & Packaging technologies, Tools & Metrology. Strategic program/projects at national level should be planned involving parties of multidisciplinary backgrounds.
Technology Investment Risks	- Investment on 'More Moore' especially on manufacturing cost is getting higher for every generation while the output is getting more uncertain. There are established global players in this area, and Malaysia would not be in a good position to compete.
Target Application Sectors	
Application Sectors to be Developed	- R&D activities are to be targeted for Application sectors where there are still a lot of improvement and new innovation to be explored. Target Application Sectors are identified based on global socioeconomic needs and reference to other countries' initiatives. However, their applicability to Malaysia, a developing country, is important.
Technology-Application Matching	- Technology solutions will be driven by application platforms identified to develop the target sectors. For some areas of applications, mix of technology paths (More Moore & More than Moore) are required.
Country Position	
Current Competencies on Related Technologies	- There are 2 main groups working on nano-scale devices – one from engineering and one from sciences, with most of work are surrounding the creation & characterization of nanomaterials, nanowires, nanoparticles, etc. Only a handful of groups are working on electronics components s.a. SET, FET, QD. The roadmap should cover both sides of technology development to benefit all.
National Other Technology Initiatives, Policy & Coordination	- Nanoelectronics Roadmap is to align with National Nanotechnology Roadmap. The Nanotechnology Roadmap has identified areas to be developed based on selected target products. Some level of coordination will also need to be carried out on common activities, project collaboration, Center of Excellence formation, etc.

Role of Technology	Values		
As enabling technology to continue improve current technologies & products	• Miniaturization of CMOS devices (Transistors & IC) for better computing performance • Value added Electronic Products (with functionalities & capabilities)	Nanotechnologies will further enable electronics with increased functionalities & capabilities. Note: But it will not replace the fundamental technologies (e.g. Silicon CMOS	**Make Electronics** **FASTER** **CHEAPER** **SMALLER** **LAST LONGER**
Enable exploration & creation of new process and building blocks as alternatives to current semiconductor technologies (when by itself is not strictly nanotechnology)	• New tools (e.g. inspection, manipulation & metrology) • New building blocks for electronic systems (e.g. OLEDs enabled by nanoparticles) • New circuit platform (e.g. plastic IC enabled by metal nanoparticles sprayed on substrate by inkjet printers to create electronic circuits)	New building blocks to offer alternative technologies for CMOS that are reaching its performance limit. A group of nanomaterials, nanostructures and nanodevices are manipulated and functionalized in many different ways to develop e.g. Carbon nanotubes, nanoparticles, quantum dots, nanowires, catalysts, coatings and designer molecules	

To increase functionalities & capabilities

Image Source: LUX Report, 2004

Nano-enabled Components	Adopters
Processors	Intel; AMD
DRAM/SRAM; Flash; NAND/NOR	Samsung; Hynix; Intel; Powerchip
MRAM	Freescale
Phase change memory (PCRAM)	Ovionics; Samsung; Intel
Ferroelectric RAM (FeRAM)	Texas Instrument
Magnetic Storage device	IBM; Seagate; Toshiba; Hitachi; Western Digital
Optical storage device	Sony; Toshiba
Holographic optical storage	Colossal Storage corporation; Optware; InPhase; Aprilisc
Millipede	IBM
LCD	Sharp; Samsung; Philips; LG; AUoptronics; Chi Mei Optoelectronics
Plasma	Panasonic; Samsung; Philips; LG
Organic Light Emiting Diode (OLED)	Kodak

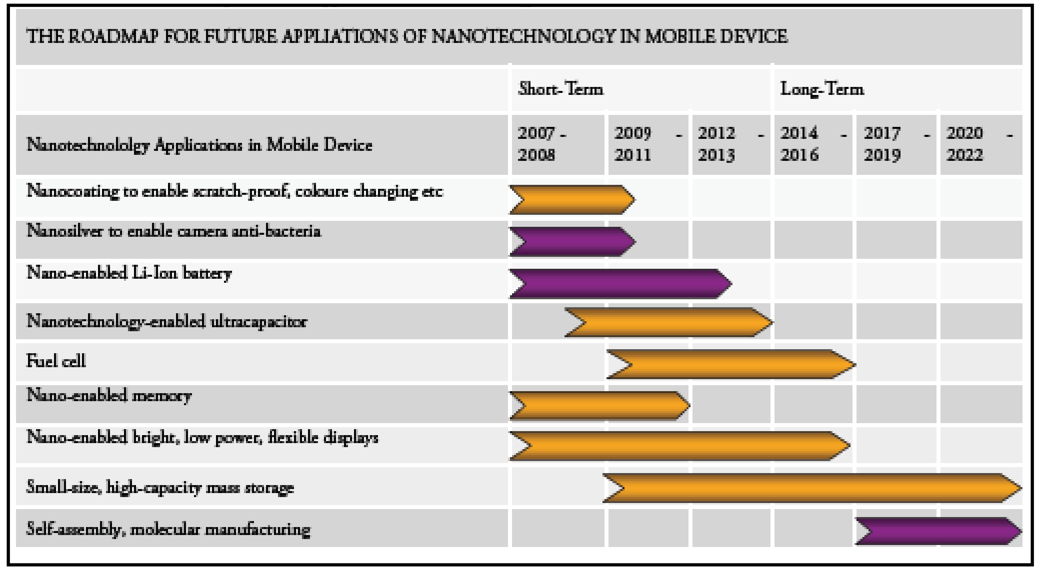
Nano-enabled Components	Adopters
Field Emission Displays (FEDs)	Samsung
Surface Emitting Display (SED)	Toshiba; Cannon
Flexible Display	Xerox; Fujitsu; Polymer Vision; Plastic Logic
New Li-Ion battery	Toshiba; Sony; NEC; A123Systems
Multiple battery	mPhase; Bell Lab
Ultracapacitor	MIT
Nano mechanical sensors	Nanotechnica
Nano electrochemical sensors	Dai Group at Stanford University; Pennsylvania State University; SentechBiomed Corporation; Applied Nanotech Inc ; Lieber Group at Harvard University; Tel Aviv University
Nano optical sensors	Nanosphere; Quantum Dot Corp; MIT

Nanotechnology in Mobile Devices

Figure on the right forecasts the development timeline of nanotechnology-enabled applications in Mobile Devices through various improvement in functions and features.

Table below lists the technology used for each application areas and how they value add them.

Data & Image Source: Cientifica, 2007



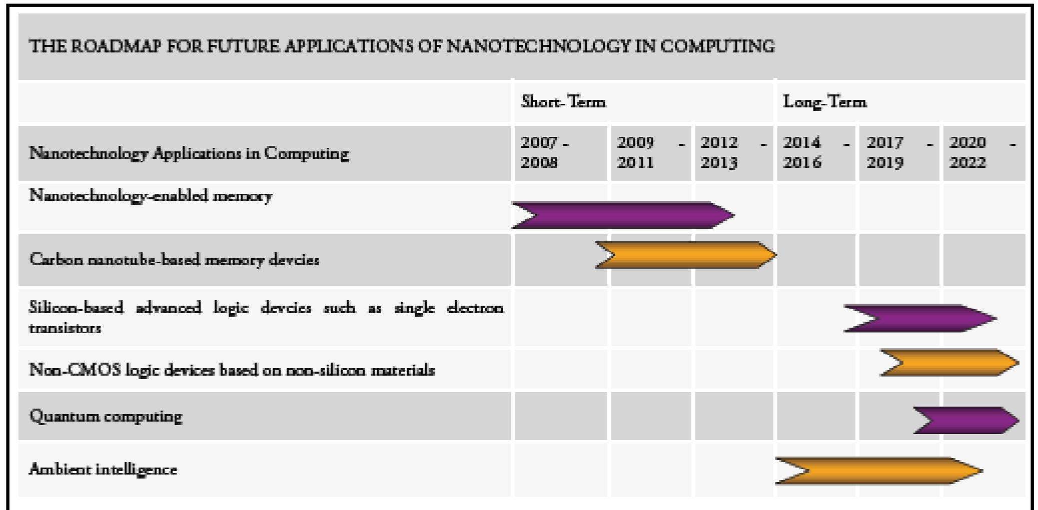
Applications	Technology Used	Added Values	Adopters
New Li-Ion Batteries	Nanostructured electrode; Nanocomposite polymer electrolytes	Increase battery energy and power density; Long life cycle	Toshiba, Nokia, Samsung, NEC
Ultra-Capacitors	Carbon Nanotube	Higher energy storage density, Many recharge cycles	MIT
Low-power, ultra-density nanomemory	Carbon Nanotube, Nanowire	Combines the high storage and low cost of DRAM; High speed of SRAM; The non-volatility of flash memory	Nantero; LSI Logic; Imperial College London; Durham University; University of Sheffield
Nano Emissive Displays	Carbon Nanotube	Energy-efficient; High-definition; Long lifetime; Potentially low cost	Motorola
Anti-bacterial mobile phone	Nano silver	Anti-bacterial	NEC; Samsung; LG
Scratch resistive mobile phone	Nanoparticles & nano-coating	Scratch resistive	Nokia
Self-cleaning surface	Nanomaterials	Water/oil/stain repellent; Deodorant; Antibiotic & antisoiling	Nokia

Nanotechnology in Computing

Figure on the right forecasts the development timeline of nanotechnology-enabled applications in Computing through expected improvement in memories, logic devices (Silicon and non-silicon materials), quantum computing and a concept of ambient intelligence.

Table below lists the technology used for each application areas and how they value add them.

Data & Image Source: Cientifica, 2007



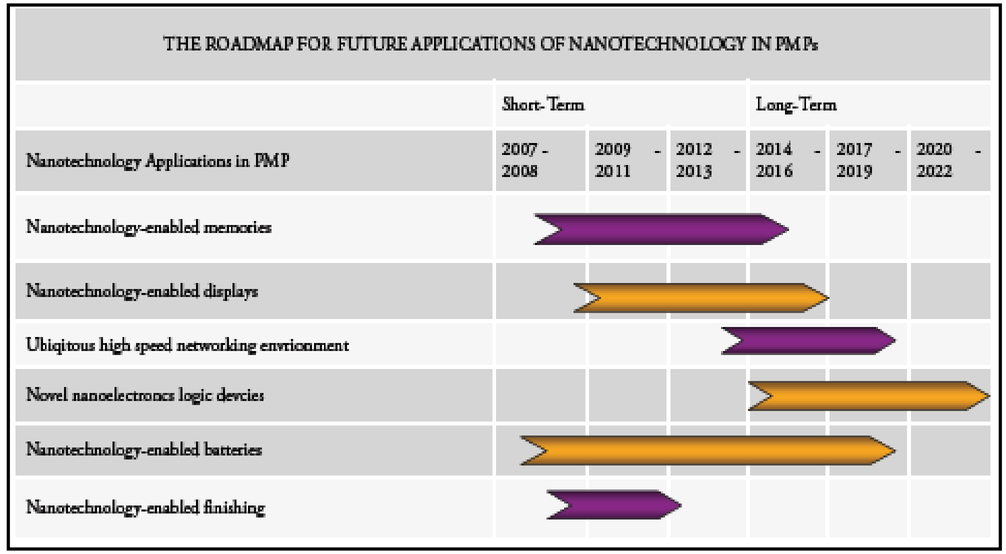
Applications	Technology Used	Added Values	Adopters
Higher density processor	CMOS-based sub-100 nm chip making process	More powerful processors while consuming less energy	Intel; AMD; IBM
Novel nanoelectronics devices	Nanowire (cross bar architecture)	More powerful processors while consuming less energy	HP
Low power, ultra high density nanomemory	NRAM; MRAM; FERAM	Higher storage capacity at lower energy consumption	Nanotero; Samsung
High capacity data storage	Nanoscale patterned media fabricated with nanoimprint technologies; Self-organized particle media using self-assembling FePt nanoparticles; Nanoscale optical antenna; Nanograting; Atomic holographic optical data storage; Milipede	Delivery and storage of high definition games, high definition movies	Collosal Storage corporation; Optware; Inphase; Aprilic; IBM Seagate; Toshiba; Hitachi; Western Digital; Sony; Toshiba
New Li-Ion batteries	Nanostructureed electrode; Nanocomposite polymer electrolytes; Nano-ceramic separators	Increase battery energy and power density; Long lifetime	Toshiba; Nokia; Samsung; NEC; Sony
Display	Carbon nanotubes; E-ink; polymer substrate; OLED/PLED	Higher quality display (higher resolution, contrast ratio and response time) whilst consuming less energy ; Portability; Rollable display	Samsung; Polymer vision; Cambridge Display Technology
Ubiquitous Computing	Nano-enabled sensors	Ubiquity	Xerox

Nanotechnology in Portable Multimedia Players

Figure on the right forecasts the development timeline of nanotechnology-enabled applications in Computing through expected improvement in memories, networking environment, logic devices, batteries & finishing of the products.

Table below lists the technology used for each application areas and how they value add them.

Data & Image Source: Cientifica, 2007



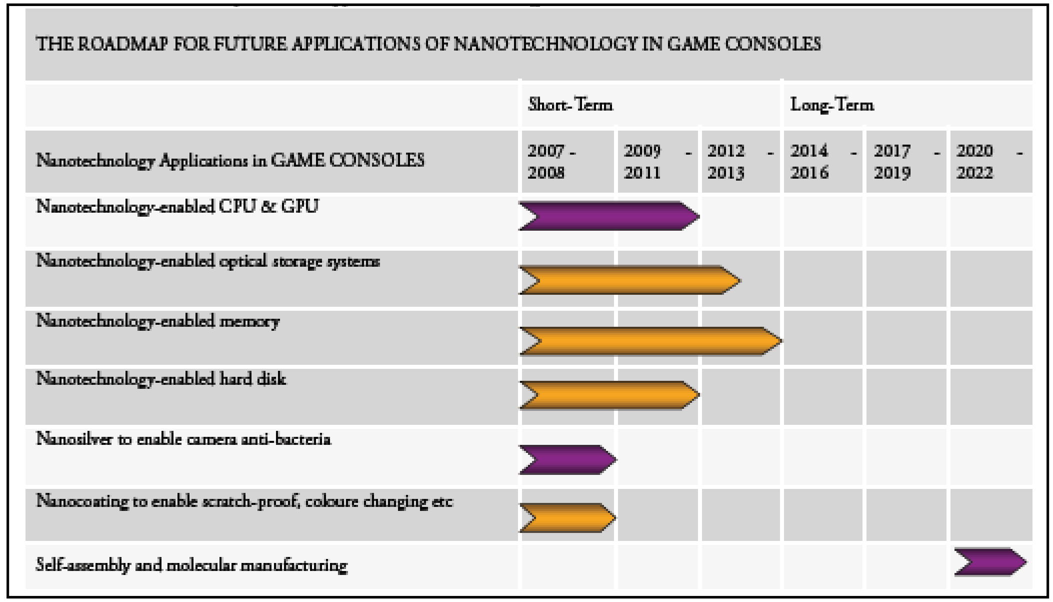
Applications	Technology Used	Added Values	Adopters
Low power, ultra high density nanomemory	NRAM; MRAM; FERAM; PCRAM; SONOS	Higher storage capacity at lower energy consumption (non-volatile memory)	Nanotero; Samsung
High capacity data storage	Nanoscale patterned media fabricated with nanoimprint technologies; Self-organized particle media using self-assembling FePt nanoparticles; Nanoscale optical antenna; Nanograting; Atomic holographic optical data storage; Milipede	Delivery and storage of high definition games, high definition movies	Collosal Storage corporation; Optware; Inphase; Aprilic; IBM Seagate; Toshiba; Hitachi; Western Digital; Sony; Toshiba
New Li-Ion batteries	Nanostructureed electrode; Nanocomposite polymer electrolytes; Nano-ceramic separators	Increase battery energy and power density; Long lifetime	Toshiba; Nokia; Samsung; NEC; Sony
Display	Carbon nanotubes; E-ink; polymer substrate; OLED/PLED	Higher quality display (higher resolution, contrast ratio and response time) whilst consuming less energy ; Portability; Rollable display	Samsung; Polymer vision; Cambridge Display Technology

Nanotechnology in Game Consoles

Figure on the right forecasts the development timeline of nanotechnology-enabled applications in Game Consoles through expected improvement in CPU & GPU, storage system (optical), memories, hard disk, camera & finishing of the consoles.

Table below lists the technology used for each application areas and how they value add them.

Data & Image Source: Cientifica, 2007



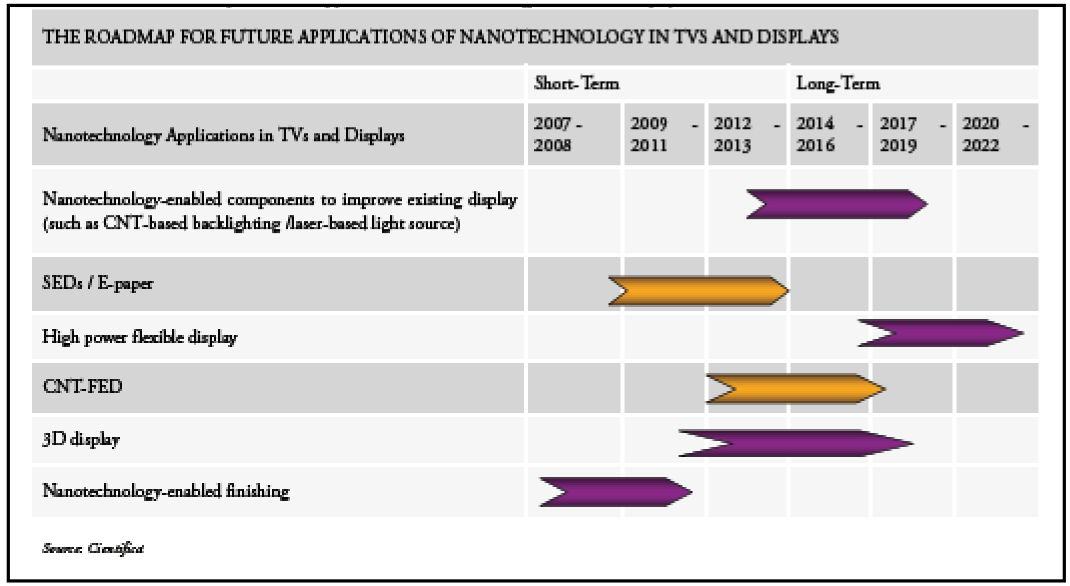
Applications	Technology Used	Added Values	Adopters
High density, low power consumption memory	NRAM; MRAM; FERAM; PCRAM; SONOS	Speed processing; Lifelike gaming experience	Nantero; Samsung
More processing & graphical power	Nanofabrication (nanolithography; nanoimprint; SPM, self-assembly); Nanoelectronics(SET, RTD, Quantum Computing molecular electronics, spintronics); Carbon Nanotube; Nanowire	More processing and graphical power; Low power consumption; Lifelike gaming experience	Intel; AMD; TI; HP; IBM
High resolution, low power display	Carbon Nanotubes, E-ink; Polymer substrate; OLED/PLED	Higher quality display (higher resolution, contract ratio and response time) whilst consuming less energy; Portability; Rollable display	Samsung; Polymer vision; Cambridge Display Technology
High capacity data storage	Nanoscale patterned media fabricated with nanoimprint technologies; Self-organized particle media using self-assembling FePt nanoparticles; Nanoscale optical antenna; Nanograting; Atomic holographic optical data storage; Milipede	Delivery and storage of high definition games, high definition movies	Collosal Storage corporation; Optware; Inphase; Aprilic; IBM Seagate; Toshiba; Hitachi; Western Digital; Sony; Toshiba

Nanotechnology in TVs and Displays

Figure on the right forecasts the development timeline of nanotechnology-enabled applications in TVs and Displays through expected improvement in the displays, image output and finishing of the products.

Table below lists the technology used for each application areas and how they value add them.

Data & Image Source: Cientifica, 2007



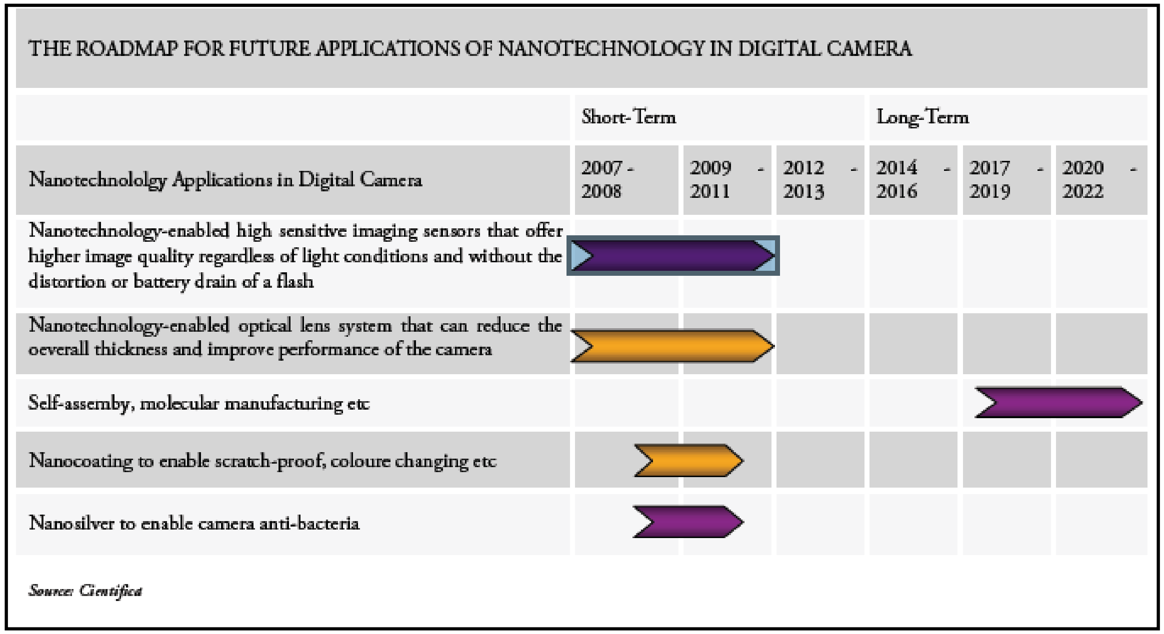
Applicationsba; Canon	Technology Used	Added Values	Adopters
SED (surface-conduction electron-emitter display)	Nanodot	Have the brightness and contrast of CRT displays, but use one-third less power than of plasma TVs	Toshiba; Cannon
CNT-FED (**Field Emission Display**)	Carbon Nanotube - grid of carbon nanotubes working within a vacumn like a CRT which phosphors, but it is a much thinner profile display, similar toOLED	Very thin, low power consumption, energy-efficient, super-sharp, high definition image, ultra wide angle of vision, short response time, easier to manufacturer than the latest OLED displays at this point in time. FED uses much less power than a plasma display	Samsung; Motorola; Sony
Flexible Display	Flexible substrate	Portability	Plastic Logic; Fujitsu; Xerox
Replacing light source with Carbon Nanotube	Carbon Nanotubes; LED	Energy saving	Samsung
Rollable Display	E-ink	Portability	Polymer vision; E-ink

Nanotechnology in Digital Camera

Figure on the right forecasts the development timeline of nanotechnology-enabled applications in Digital Cameras through expected improvement in imaging sensors, optical lens systems for better performance and finishing of the products.

Table below lists the technology used for each application areas and how they value add them.

Data & Image Source: Cientifica, 2007



Applications	Technology Used	Added Values	Adopters
More sensitive imaging sensor system	SMPD (Single carrier Modulation Photo Detector) , nanoscience	Enable picture taking in near total darkness; Low power consumption; High resolution	Planet82 Inc.
Extremely thin functional layers	Nano-optical lens; Integrating nanostructured gratings and thin film interface layers into a multi-component optical structure	High resoluiton; Ultra-thin cameras	NanoOpto

Research & Development	Commercialization	Impacts in Market Sectors
Extensive research on nano-materials has unveiled many interesting and promising material properties for novel applications in electronics and photonics. But in order to benefit mankind for such discoveries, it is necessary to cross the chasm between nano-materials and nano-devices and their applications. This effort will require a multi-disciplinary approach combining research in material design, processing, modeling, characterization and metrology. The commercialization of nanotechnology is also important to fuel future research. But what are the paths between fundamental research and potential electronic and photonic applications. Potential areas include: New developments, New concepts, New practices, Investigating future research needs. Source: IEEE Nanoelectronics Conference 2008	The commercialization of nanoelectronics devices remained patchy in 2007, without the breakthrough that players and researchers had expected in some segments From signs during year 2007, 2008 should herald more commercialization of nanoelectronic devices Materials development remains a key driver in nanoelectronics, In 2008 we saw growth in segments such as ultracapacitors and advanced batteries, which showed them benefiting from new nanomaterials as functional layers. Source: SRI BIC (2008)	After 10 years of R&D, the highly developed supply chain and stability of commercially available nanomaterials is finally enabling higher value-added applications. Recently the number of producers of nanomaterials has decreased as consolidation has increased and multinational chemical companies now dominate the market. Today, most of the nanomaterials heralded just a few years back as new high-value materials are quickly taking on a bulk commodity stature. While this commoditization and consolidation means that little money remains to be made by producing nanomaterials, the ability of these nanomaterials to enable higher-value products will lead to a US$1.5 trillion market by 2015. The market for products enabled by nanotech will reach US265 billion by 2012 and US1.5 trillion by 2015. The highest growth rates will be in the healthcare and pharmaceutical sector although many niche applications have the potential to grow into very significant markets and the additional attraction that less international research attention has been paid to some of these until now. Source: Cientifica (2008)

Table on the right summarizes potential level of the challenges & opportunities for Malaysia, on the following:

Top-down processing techniques, Bottom-up processing techniques, Design and Technology, Device Packaging, IC and Characterization Tools

Assessment is being done against local competencies, technological scale and potential markets for near to middle term targets.

The recommended domain areas having medium to high potentials level are:

1. Bottom-up processing techniques
2. Design & Technology
3. Device Packaging
4. Top-down processing

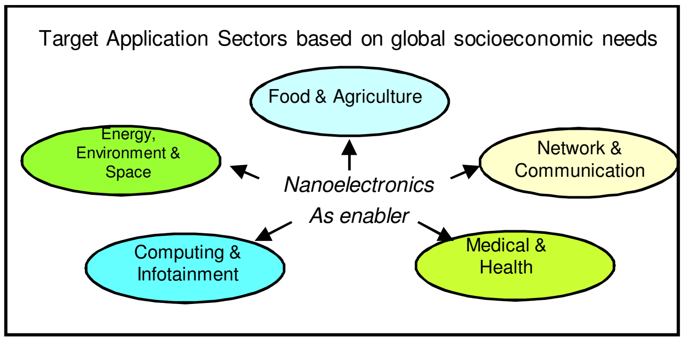
The potential areas for R&D within each domain are as listed in the table.

For domain areas rated as having low potentials could also be pursued for long term targets.

CHALLENGES & OPPORTUNITIES	R&D OPPORTUNITIES For MALAYSIA	
	Potential Level	**Areas**
1. Top-Down Processing Techniques	**Medium**	Nano-Electromechanical Devices (Bio & RF NEMS) – Rotors, Actuators, Valves, Switches, Resonators, Phase Shifters. Tunable Devices – Circuits, Antennas, Capacitors, Inductors.
2. Bottom-Up Processing Techniques	**High**	Material and Substrate Engineering – New Packaging Materials, Ultra-thin Substrates, Nano-Phosphor for LEDs, Carbon Nanotubes, Metallic and Silicon Nano-Wires. Sensors, OLEDs, Flexible Solar Cells, Nano-Structured Batteries.
3. Design and Technology	**High**	Simulation Tools– New Software Creation/Upgrades. Devices Integration – Sensors of Precision Agriculture, Fishery, Environment and Healthcare.
4. Device Packaging	**High**	New Packaging Materials – Composites to Enhance Strength of Packaging Materials, Nano-Paint, Microawave Absorbers, Thermal Insulation, Corrosion Shielding.
5 . IC	**Low**	Lithographic Tools – Beyond EUV, Computing – DNA Computing, Nano-Transistors, Quantum Dots, Memory.
6. Characterization Tools	**Low**	Nano-Probes for Atomic Force Microscopes, Super-Lenses for Microscopes.

Target Applications Domains

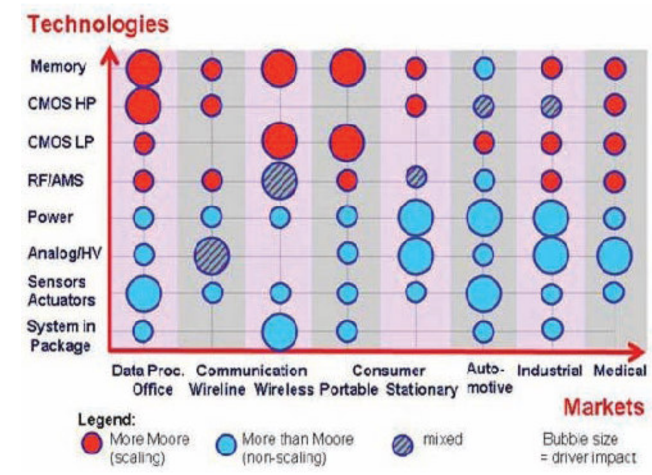
The target application domains as depicted in the diagram below are chosen based on the society needs to achieve a total quality of living in the current social, economic and technology trends towards future world scenarios. Some universal needs include improvement in medical & health, cheap and easy communication, easy access to rich information and entertainment, quality food and sustainable supply, affordable energy and clean environment.



Technology-Application Matching

Matching technology to intended application is very important to strategically plan and implement a technology roadmap and to ensure quality return of investment while minimizing risk. Diagrams on the right shows that different application domains use different types of technology for their development.

Based on the current technology, R&D on CMOS scaling (More Moore) requires very high investment, continuous advancement in the semiconductor process and involves a very high risk business. Established players in the world have been on track and will continue to pursue the trends in the nano-CMOS.



Source: ITRS/STMicroelectronics

Source: ENIAC

Based on current capability and activities of local semiconductor R&D and E&E industry, Malaysia will have more potential in the field of More than Moore where there are still a lot of opportunities to be explored.

WHICH NANOELECTRONICS PATH IS FOR MALAYSIA?

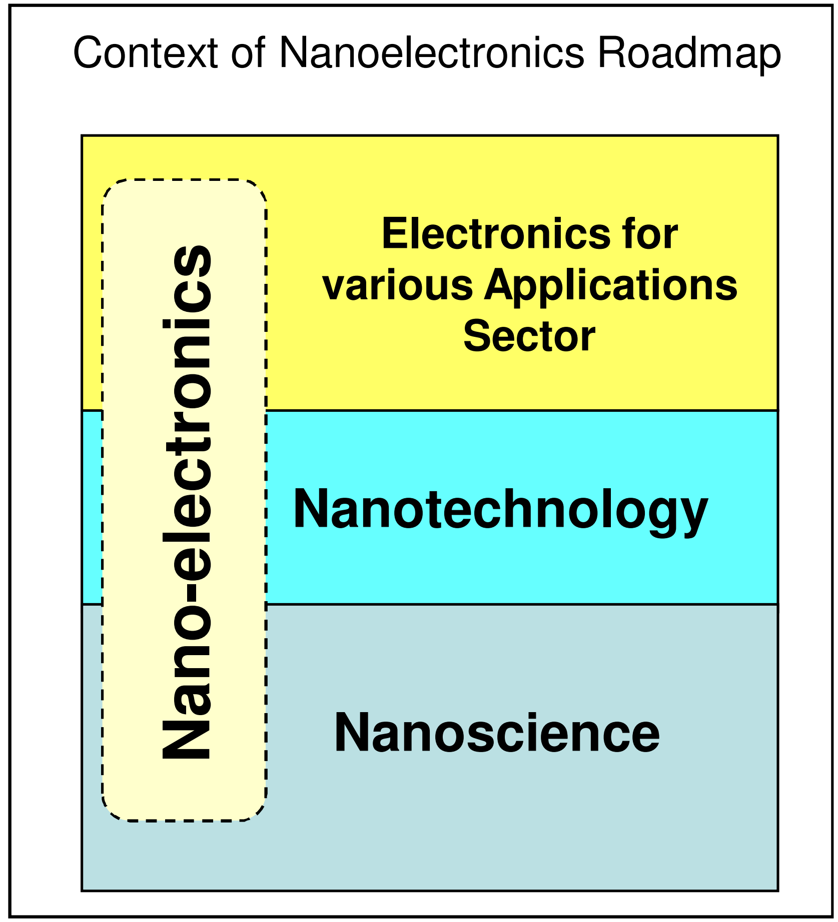
MIXED PATHS

While not limiting national efforts on any particular path on nanoelectronics, the roadmap

a. is charting the development of electronics technology that could be applied to enhance the deliverables of Malaysia NNI target products and create nanoelectronics cluster of excellences for Malaysia.

b. addresses the interest of different groups in Malaysia that are involved in nano-scale electronics R&D. i) From engineering group who are mostly still using top-down process and ii) science group who are researching bottom-up process to prepare various materials to enhance electronics applications.

c. is aligning the target application platforms towards several sectors that are most viable for Malaysia as a developing country but also preparing the nation towards a world trend scenario on Ambient Intelligence or Ubiquitous Computing.

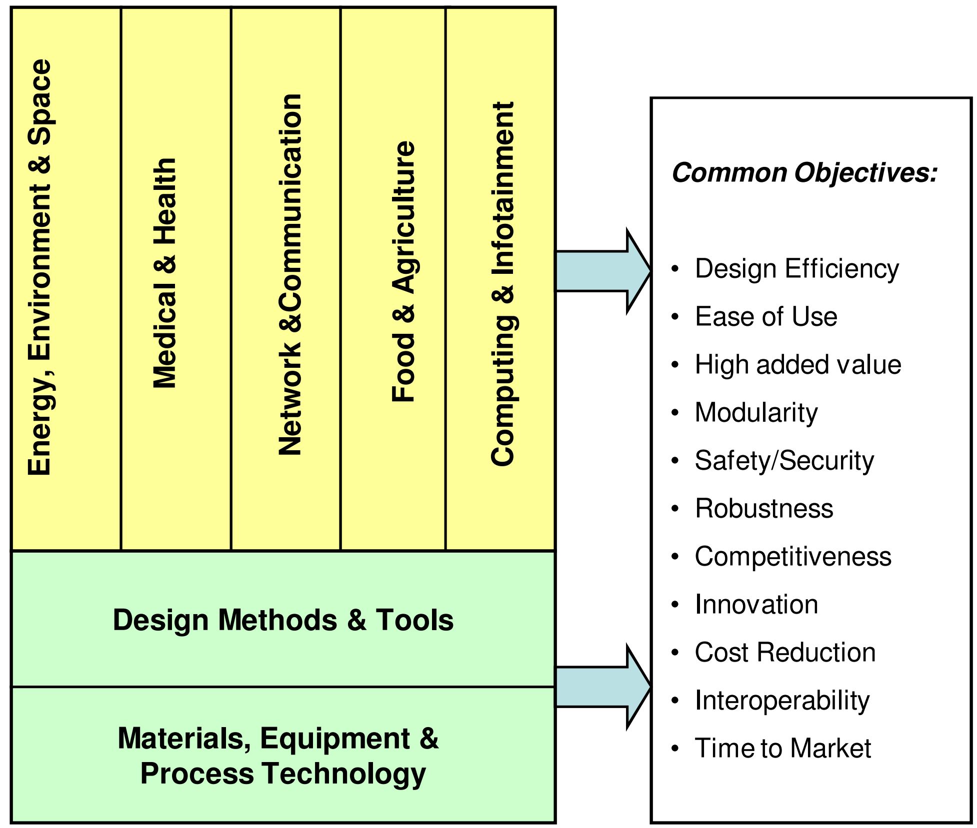


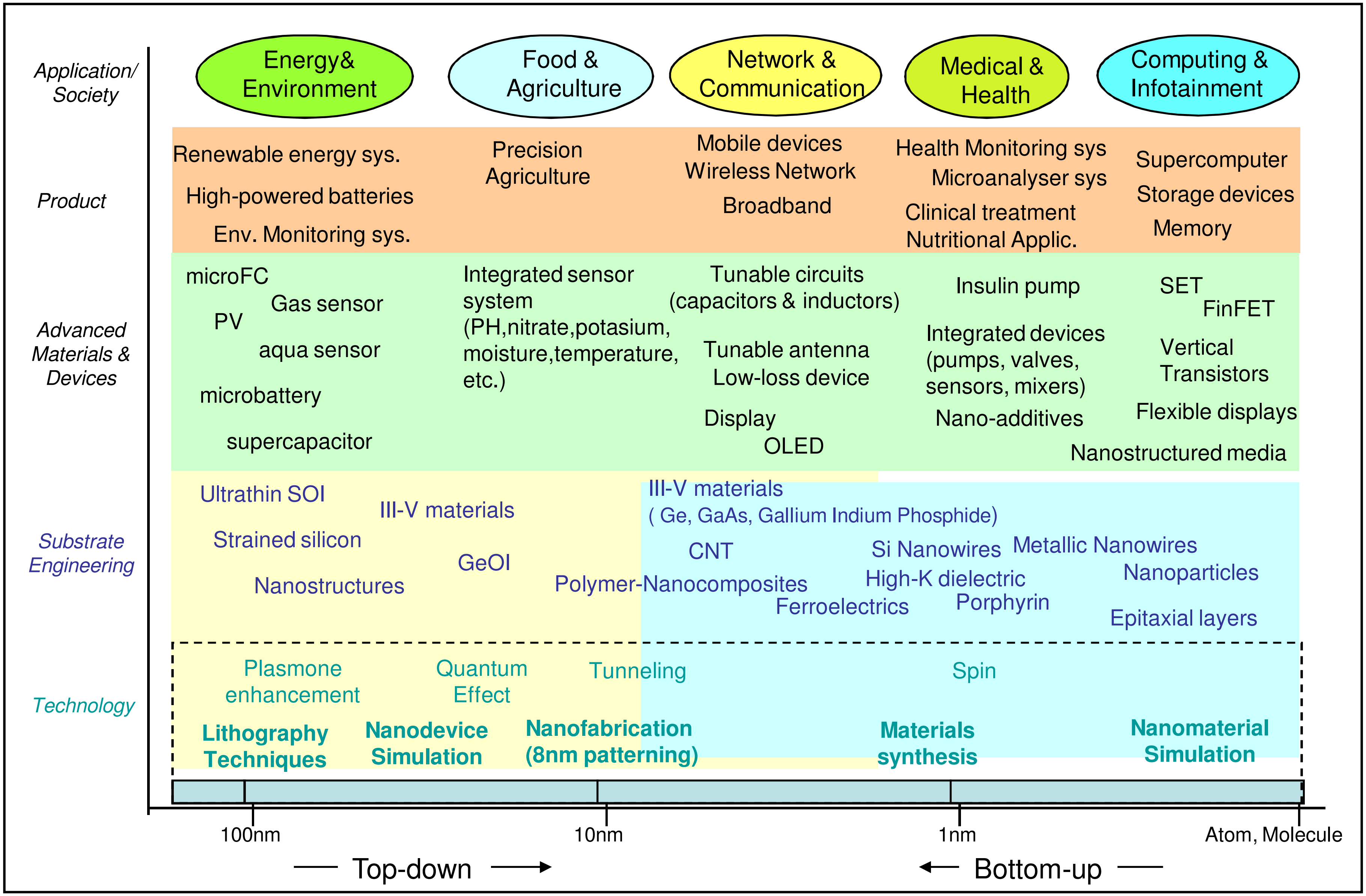
Target Applications Domains:

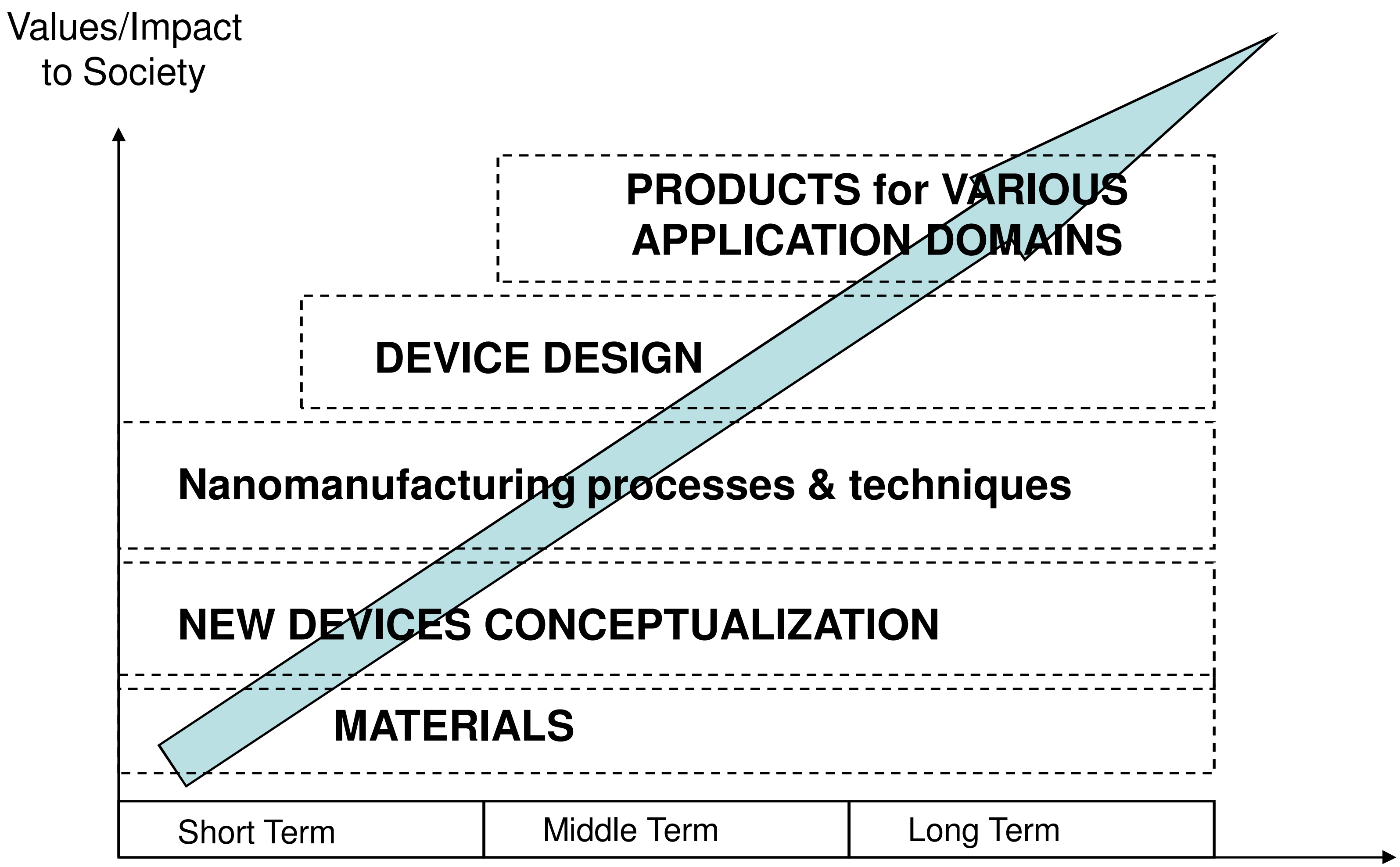
1. Energy, Environment & Space
2. Medical & Health
3. Network & Communication
4. Food & Agriculture
5. Computing & Infotainment

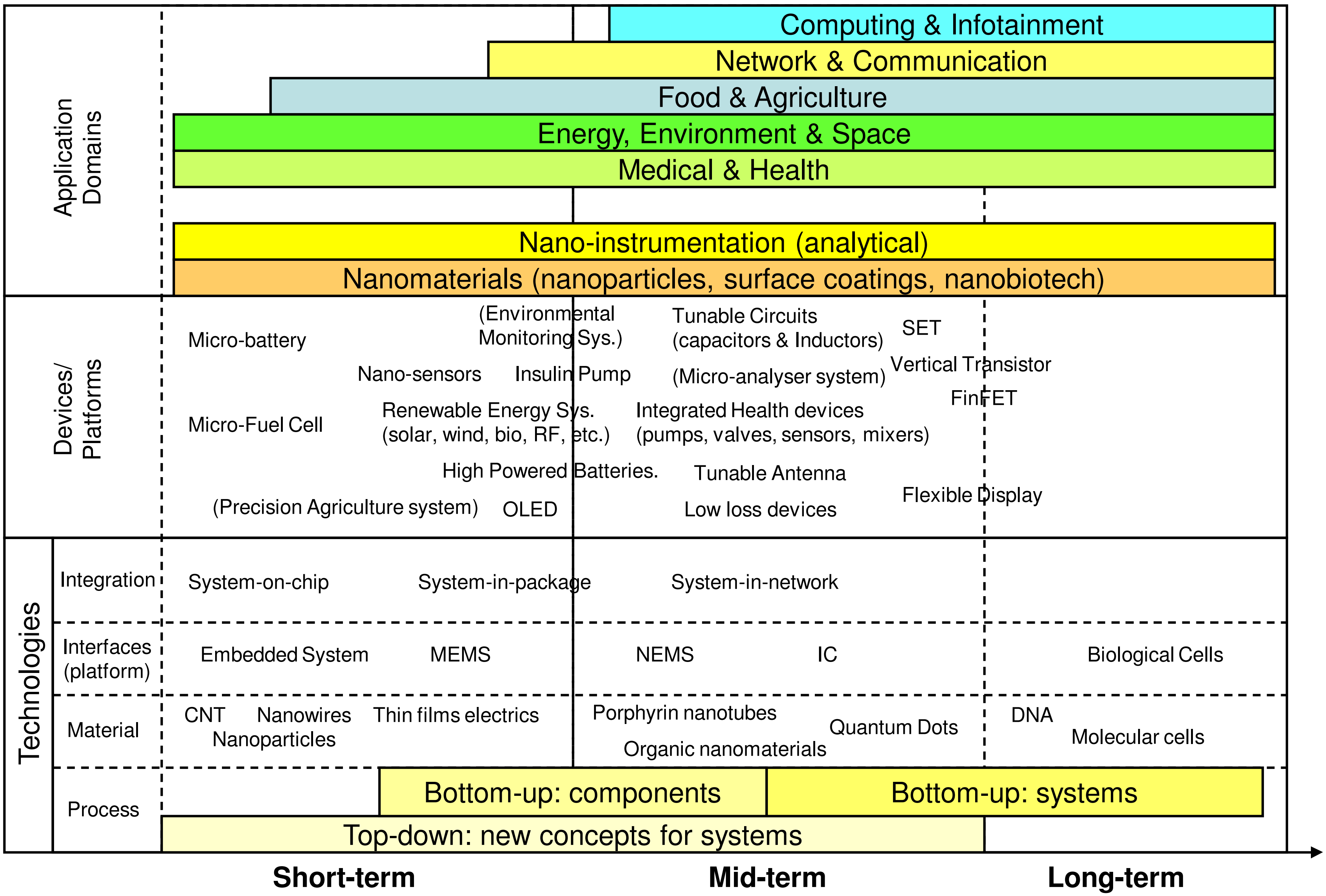
Two technology domains with cross-applications aspects:

1. Design Methods & Tools
2. Materials, Equipment & Process Technology




Application/ Society
Energy& Environment
Food & Agriculture
Network & Communication
Medical & Health
Computing & Infotainment
Product
Renewable energy sys.
High-powered batteries
Env. Monitoring sys.
Precision Agriculture
Mobile devices
Wireless Network
Broadband
Health Monitoring sys
Microanalyser sys
Clinical treatment
Nutritional Applic.
Supercomputer
Storage devices
Memory
Advanced Materials & Devices
microFC
Gas sensor
PV
aqua sensor
microbattery
supercapacitor
Integrated sensor system (PH,nitrate,potasium, moisture,temperature, etc.)
Tunable circuits (capacitors & inductors)
Tunable antenna
Low-loss device
Display
OLED
Insulin pump
Integrated devices (pumps, valves, sensors, mixers)
Nano-additives
SET
FinFET
Vertical Transistors
Flexible displays
Nanostructured media
Substrate Engineering
Ultrathin SOI
III-V materials
Strained silicon
GeOI
Nanostructures
Polymer-Nanocomposites
III-V materials
(Ge, GaAs, Gallium Indium Phosphide)
CNT
Si Nanowires
Metallic Nanowires
High-K dielectric
Nanoparticles
Ferroelectrics
Porphyrin
Epitaxial layers
Technology
Plasmone enhancement
Quantum Effect
Tunneling
Spin
Lithography Techniques
Nanodevice Simulation
Nanofabrication (8nm patterning)
Materials synthesis
Nanomaterial Simulation
100nm
10nm
1nm
Atom, Molecule
Top-down
Bottom-up


Values/Impact
to Society
PRODUCTS for VARIOUS
APPLICATION DOMAINS
DEVICE DESIGN
Nanomanufacturing processes & techniques
NEW DEVICES CONCEPTUALIZATION
MATERIALS
Short Term
Middle Term
Long Term


Application Domains
Computing & Infotainment
Network & Communication
Food & Agriculture
Energy, Environment & Space
Medical & Health
Nano-instrumentation (analytical)
Nanomaterials (nanoparticles, surface coatings, nanobiotech)
Devices/ Platforms
Micro-battery
(Environmental Monitoring Sys.)
Tunable Circuits (capacitors & Inductors)
SET
Nano-sensors
Insulin Pump
(Micro-analyser system)
Vertical Transistor
FinFET
Micro-Fuel Cell
Renewable Energy Sys. (solar, wind, bio, RF, etc.)
Integrated Health devices (pumps, valves, sensors, mixers)
High Powered Batteries.
Tunable Antenna
Flexible Display
(Precision Agriculture system)
OLED
Low loss devices
Technologies
Integration
System-on-chip
System-in-package
System-in-network
Interfaces (platform)
Embedded System
MEMS
NEMS
IC
Biological Cells
Material
CNT
Nanowires
Nanoparticles
Thin films electrics
Porphyrin nanotubes
Organic nanomaterials
Quantum Dots
DNA
Molecular cells
Process
Bottom-up: components
Bottom-up: systems
Top-down: new concepts for systems
Short-term
Mid-term
Long-term

Participation:

- Participation of all Malaysia nanoelectronics value chain players (Universities, Research Institutes, Industries)
- Based on agreed collaboration models with clear definition and mutual recognition of roles and strengths of participating parties

Center of Excellence:

- Formation of Centers of Excellences (CoE) to carry out specific research areas based on existing strength of the research bodies
- Specialization of CoEs to avoid duplication of efforts towards a bigger national impact

Partnership Model:

- Flexibility in terms of partnerships and fast decision making are essential because technology cycles are too short
- Collaboration projects based on clusters to achieve greater impacts

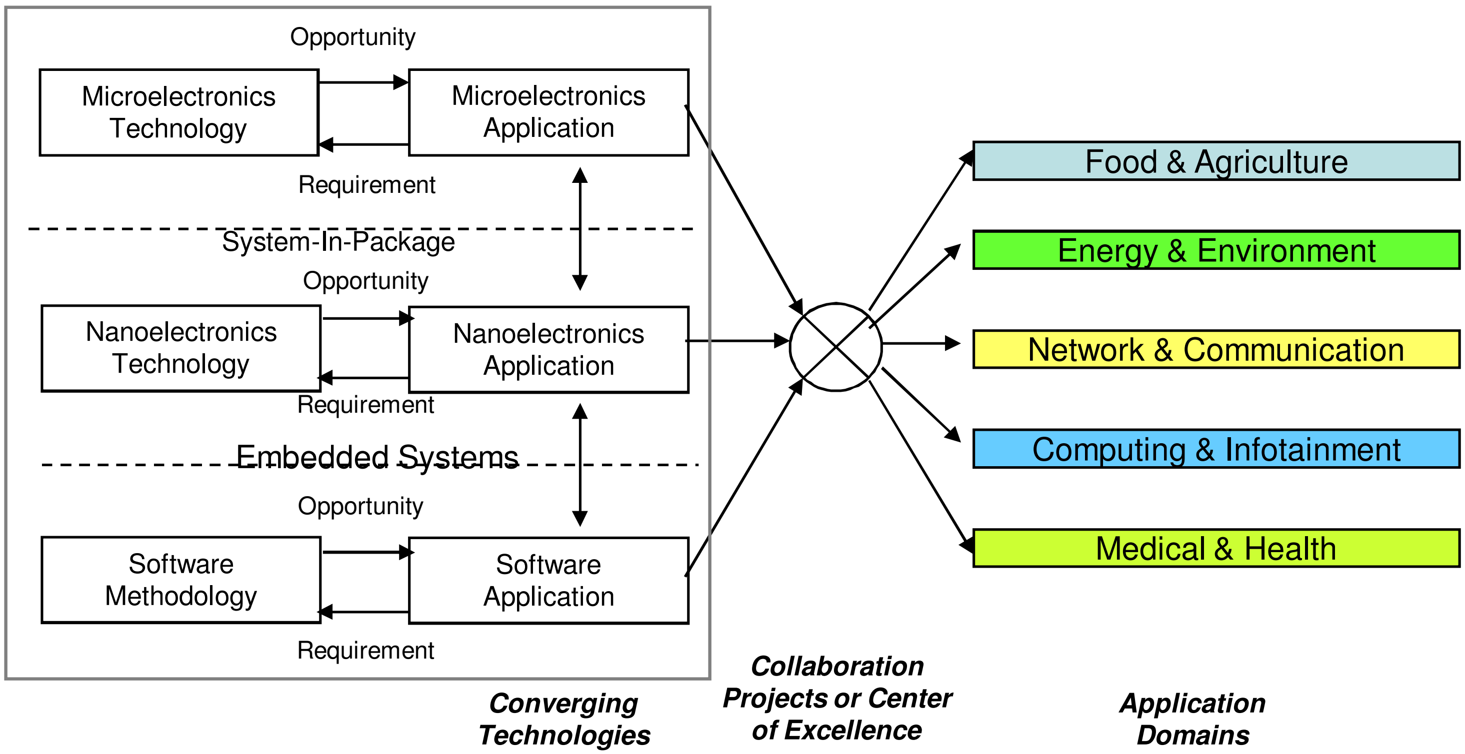
International Involvement:

- Participation in Standards development initiatives on areas related to Nanotechnology and Nanoelectronics

R&D Alignment:

- Through down-stream R&D: driven by industry needs along identified target APPLICATION DOMAINS that have high potentials to address society needs in current and future scenarios and at the same time provide economic opportunities to the country
- Technology development along identified core technology areas will be tailored to solve APPLICATIONS & SOLUTIONS identified to address society needs according to the application domains
- Choice of technologies to be developed (along core technology areas) are open to allow innovations and creativity. The aims would be PLATFORM TECHNOLOGY development that could be applied in various vertical applications while at the same time contribute to the advancement in nanoelectronics technology field. Upstream technology development on the related fields would be supported as part of the CORE TECHNOLOGY advancement effort and to increase core competencies in nanoelectronics. COMMON TECHNOLOGY areas to be developed would also be identified for cross-function applications
- Based on the needs for MULTI-DISCIPLINARY solutions in applications development, collaborative projects are encouraged

MICROELECTRONICS + NANOELECTRONICS to ensure smooth transition and applicability



Adapted from: CATRENE Whitebook

APPENDIX

National Nanotechnology Roadmap

Reference is made to National NANOTECHNOLOGY ROADMAP to ensure non-duplication of efforts at national program

The Study for Malaysia Nanotechnology Roadmap (2007) has identified 5 industries to benefit from Nanotechnology development namely:

- Biotechnology
- Energy
- Environment
- Agriculture
- Medicine

After screening all the potential nanotechnolgy-based products under each industry, the Study further selected 6 target products that could bring most impact to the identified industries and the country. Each has its own roadmap to help guide the implementation plan . They are:

- Biosensors
- Biochips
- Molecular Farming
- Drug Delivery System
- Solar
- Lithium-Ion

Table on the right lists potential applications that could be developed using the identified products & technologies.

Source: Malaysia NNI Roadmap Report, 2007

Target Products	Identified Applications
BIOSENSOR	• Clinical diagnostic • Home diagnostic • Real-time alert sensor & detector for pathogen infection caused by bacteria, fungi & viruses • Real-time detection of contamination • Food production & agricultural diagnostic kit
BIOCHIPS	• Whole genome arrays • Pathogen (HIV, bacteria, fungus) detection chips • Real-time monitoring of chemical substance • Portable lab-on-chip devices
MOLECULAR FARMING	• Mass producible therapeutic medical proteins • Low cost enzymes for industrial use • Mass producible vaccines • Plant/animal vaccines for agriculture/ livestock • Biosensor/biochip for agricultural diagnostics
DRUG DELIVERY SYSTEM	• Clinical treatment • Topical & cosmetics • Nutritional applications • Veterinary and agricultural application
SOLAR	• Higher efficiency and lower cost solar panels • Flexible/robust solar panels for outdoor applications • Dye-sensitized solar panels
LITHIUM-ION	• Li-ion batteries for hybrid electric vehicle (HEV) • Li-polymer batteries • Industrial application (i.e. robotic systems)

