COLLABORATIVE SUPPLY CHAIN MANAGEMENT OF NANOTECHNOLOGY INDUSTRY IN MALAYSIA

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ABSTRACT

Nanotechnology is becoming important in Malaysia and the supply chain management within this promising industry is obviously crucial for ensuring the sustainability of the industry to support the nation's economic growth. However, there is a lack of research focus on the supply chain management (SCM) between the industry players, namely the suppliers, research and development centres, and the commercialisation companies. This study examined the collaborative supply chain management within the nanotechnology industry context, with a more in-depth look into the wafer fabrication industry. Specifically, the research aimed to explore the current state of nanotechnology SCM and collaborative practices in Malaysia, the challenges for SCM in Malaysian nanotechnology, and finally to make recommendations to improve the collaboration within SCM based on specific projects. This study was cross-sectional in nature and used a qualitative approach in order to get a more insightful explanation. The use of triangulation approaches, which were interviews and document analysis, facilitated the research to meet the objectives. The key findings include issues highlighted in i) human resource, specifically on the need of nanotechnology education; ii) infrastructure, namely on the high start-up capital required; iii) organisational capabilities, focusing on the nature of nanotechnology which is equipment dependent; iv) process alignment, relating to involving more key players and champions; and v) collaborative supply chain management, which relies on various sources and technologies. In conclusion, this research identifies that there is a need of more knowledge in the area which can be supported by a solid education system for producing quality and qualified human capital; more political influence and government support for speeding up the process of research, development, and

commercialisation of nanotechnology in Malaysia; and more collaborative practices not only through collaborations with industry players within the country and abroad, but also using collaborative techniques, methodology, and applications. Ultimately, these enhancements to the nanotechnology supply chain are for achieving the national interest, organisational interest, and personal interest.

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LIST OF ABBREVIATIONS

A3G	Applied Algebra and Analysis Group
AMNL	Advanced Materials and Nanotechnology Laboratory
AMREC	Advanced Materials Research Centre
CNPAM	Centre for Nanotechnology, Precision and Advanced Materials
CST	Catalytic Science and Technology
IIS-UTM	Nanochem and Nanophys Lab
INEE	Institute of Nano Electronic Engineering
ISC	Industrial and Scientific Computation
MINE	Material Innovations and Nanoelectronics Research Group
MSIG	Mathematics Statistic Industrial Group
NAMBAR	Nano & Mesoporous Materials for Biological Applications
NANOCEN	Centre for Research in Nanotechnology and Catalysis
NNI	USA National Nanotechnology Initiative
NoMPTec	Novel Materials and Process Materials
PCAs	Program Component Areas
QuaSR	Quantum Nanostructures Research
SCM	Supply Chain Management
SCNI	Scientific Computational and Industrial
TCM	Theoretical and Computational Modeling for Complex Systems
UKM	Universiti Kebangsaan Malaysia
UM	Universiti Malaya
UPM	Universiti Putra Malaysia
USM	Universiti Sains Malaysia
UTP	Universiti Teknologi Petronas

CHAPTER ONE

RESEARCH BACKGROUND

1.1 Introduction

In the current competitive business environment, management should not only focus on the supply chain between organisations, but also the supply chain within the organisations as in the nanotechnology. Even though it has been discovered through the literature that SCM is a system that improves competitiveness of the organisations, there are still problems related to it, such as inventory shortage or excess, long supplier lead times, under-utilised warehouse and bottlenecks in the supply chain, which influence supply chain effectiveness (Anthony, 2000; Peterson et al., 2001). Nanotechnology organisations should be more flexible, productive and fast in producing the product, in light of changes in customers' demand behaviour. The evolution in nanotechnology, emphasis on quality philosophies and customer orientation are among the factors that influence the need for redesigning a supply chain.

Furthermore, competitiveness of these organisations is highly dependent on the level of effectiveness and efficiency of the SCM to cater for the changes and demands. As a result, nanotechnology organisations must prepare themselves through their SCM to be highly flexible and responsive to the changes in this competitive environment. The flexibility of the SCM mainly needs the organisation to adhere the processed-based approach (Hemani, 2004).

The emergence of collaborative computing inspired the effort of CSCM development (Silva et al., 2001). This collaborative environment facilitates communication among the nanotechnology work group, regardless of place and time. In addition, such an environment, allows work groups to work simultaneously in planning and designing nano-related products, forecasting and making decisions. However, Bechtel and Jayaram (1997) revealed that there is still a lack of effort in planning and developing an integrated or collaborative SCM. Integration across disciplines or functional areas is needed in order to resolve the complexity of linkages in the supply chain such as, information lost, process redundancy and asynchronous resources development. Moreover, nanotechnology organisations need to have a close relationship with their partners in the supply chain and this also needs to be applied to the functional areas within nanotechnology organisations in order to improve their performance and productivity. Humphreys et al. (2001) stressed that in buyer-supplier relationships, nanotechnology organisations should work closely as a way to reduce the complexity in supply chains pipelines, such as material overloading, warehouse overflow and congestion in the distribution channel, which incurs cost not only to customers or buyers, but also to suppliers.

There are several published articles in the area of improving the SCM such as collaborative planning (Stank et al., 1999), collaborative forecasting (Helms et al., 2000) and development of Collaborative Planning, Forecasting and Replenishment (CPFR) (Ireland & Bruce; 2000). However, comprehensive research, particularly in planning and designing a CSCM, has not yet been undertaken in the nanotechnology organisations, particularly in Malaysia. Research has shown interest in this area, for example Simatupang and Sridharan (2004), and Barrat (2004) have introduced the concept of supply chain collaboration. Simatupang and Sridharan (2004) in their work emphasised the development of a benchmarking scheme of supply chain collaboration, which helps the chain members to choose the performance metrics, which are most appropriate to the context of their collaborative arrangement. Meanwhile, Barrat (2004) has emphasised the issues of why, where, with whom, and what activities that relates to supply chain collaboration. These previous studies particularly related to the manufacturer not the nanotechnology organisations.

In order to meet these challenges, the rectified planning and designing of CSCM strategy is needed in order to develop a high performance supply chain in organisations. Previous studies showed that most of KBS application focused on the procurement activity such as supplier selection process (Vokurka et al., 1996; Kumaraswamy et al.,2000; Nwankwo et al.,2002) and make or buy decision (McIvor et al.,1997). The application of analytical approach also focused on the same activity (procurement activity) as done in previous studies by Barbarosogulu and Yazgac (1997), Masella and Rangone (2000), and Bhutta and Huq (2003). However, the utilisation of a hybrid methodology which comprises the Knowledge-Based (KB) and analytical approach such as AHP has never been done before in SCM development, and specifically, in planning and designing a CSCM as proposed in this research, which could add values and advantages to organisations in pursuing supply chain collaboration.

1.2 Background of Nanotechnology in Malaysia

Nanotechnology has becomes a new industrial revolution and many countries are investing heavily in this technology to maintain their market competitiveness. Since this is new yet growing and emerging, there is still a scarcity of research in this, particularly in developing countries like Malaysia. In term of investment amounts, the USA leads other countries by investing USD3.7 billion through its National Nanotechnology Initiative (NNI), followed by Japan with USD750 million and European Union with USD1.2 billion in investment (MIGHT Report, September 2006) and continuing to boost which extensively used in many areas and segments (MIGHT, 2008).

Nanotechnology has caused a stir in worldwide because of its potential. Big countries has invested in nanotechnology and taken a full concern over the development of nanotechnology. Malaysia has to have its own nanotechnology policies and initiative as well as strategic plan to manage the technology, as extensively stressed by the Deputy Prime Minister in his several meetings about this management of nanotechnology (for example: The News Straits Times, 20^{th} of June 2007). To sustain the technology, major agencies are also needed to guide the direction of nanotechnology management. Currently, Malaysia is lack behind in this aspect because of the technology is still new to the Malaysian expertise. The Ministry of Science, Technology and Innovation (MOSTI) oversees the nanotechnology development in this country, and particularly to develop policies, initiatives and strategic plans for nanotechnology.

According to Malaysia's S&T Policy for the 21st Century, to sustain technology support for Malaysian industries, there is a need to develop a secure knowledge base in key technology areas such as nanotechnology.

To this extend, the relatively small numbers of applications of nanotechnologies that have made it through the industrial application represent revolutionary rather than evolutionary advances (Kearns et al., 2005; Putranto et al., 2003). Current applications are mainly in the areas of determining the properties materials, the production of chemicals, precision manufacturing and computing. Food industry for instance, is also interested in nanotechnology such as Kraft Foods and Nestle in packaging, and food safety and processing and amongst others (Dunford, 2006). The application of nanotechnology such as precision farming and smart delivery system has major impact in the industry. Precision farming makes use of computers, global satellite positioning systems and remote sensing devices. It helps reduce agricultural waste and minimise the environmental pollution. Consequently, accurate and comprehensive management of nanotechnology at micro (organisational), semi micro (regulatory) and macro (economy) levels are virtually impossible, especially in high-tech regulated sectors and developing economies. However, based on the previous studies (Burgi & Pradeep, 2006; Hipkins, 2004) there is a need of research to look into the management aspects of nanotechnology in order to understand more about this area. Particularly, the collaborative SCM is to ensure a sustainable competitive advantage of the nanotechnology, particularly the efficiencies.

1.3 Problem Statement

A forward-looking approach to the key technologies of the future is crucial to sustain an active and competitive industrial economy. Government needs to provide a conducive environment for nanotechnology to growth, as it would benefits all (Burgi & Pradeep, 2006) and also other factors should be taken into perspective (Putranto et al., 2003). However, as mentioned earlier, Malaysia is considered at an infant stage of the development of nanotechnology. The scarcity of research and limited publication on the nanotechnology particularly in relating to collaborative supply chain weaken the efforts towards successful implementation of the nanotechnology in the future.

Many industries have applied the nanotechnology, as well as demonstrated the supply chain in their operations. The semiconductor industry has been one of the most important industries for the past three decades (Li et al., 2011). Owing to its critical position in modern industry, the research on the semiconductor industry is plentiful. It is expected that the industry more prone to apply nanotechnology due to its technology-intensive nature. Furthermore, the supply chain of the industry's development has also become prosperous and mature to some extent.

Hence, there is a need of research to investigate comprehensively on this aspect in order to the industries to get a sustainable competitive advantage. In specific guideline lists down by the Malaysia S&T policy, aggressive and strategic implementation of existing Technology Acquisition Programme under the smart partnership framework with Malaysian companies and government agencies is one of the ways to help boost Malaysia technology. Furthermore, there is a need to establish strong linkages with regional and international centres of excellence in collaborative SCM, also the R&D as well as co-development of technology to bridge our country in term of nanotechnology development. Therefore, realizing all the important factors should be taken seriously for investigation led this research to consider broader manner and comprehensive aspects of SCM of managing a nanotechnology to contribute to the body of knowledge in this emerging area.

1.4 Research Objectives

The research objectives for this research are:

1. to explore the current status of nanotechnology supply chain management and collaborative practices in Malaysia;
2. to identify the challenges for the supply chain management and collaborative practices in nanotechnology; and
3. to recommend collaborative SCM based on the assessment for specific industry, namely the semi-conductor industry.

1.5 Research Significance

The research hopes to make an important contribution to the supply chain area, by focusing on the nanotechnology in Malaysia. Finally, organisation need to ascertain on the status on nanotechnology in Malaysia and major factors on the collaborative supply chain management in order for them to evaluate how the industry can lead.

1.6 Research Limitations

The study is subject to the following limitations. Firstly, the use of semi-structured interviews which the established knowledge of its validity and reliability within the contexts of study. In order to manage this, the researcher has minimised the ambiguity by having triangulation of multiples sources.

Secondly, the research sample cannot be generalised to the total population. Contradict to the statistical research, which are used to consider whether the findings can be generalised from the sample to the universe, a “weak” form of generalisation often associated with case studies is “naturalistic generalisation” (Gomm, Hammersley, & Foster, 2000).

1.7 Organisation of Report

This report began with Chapter 1 which laid the background for this study where it described the research in terms of its problems, objectives, significance, and limitations. Chapter 2 then delves deeper into the literature to provide the foundation for this research. Next, Chapter 3 covers the approach taken by this research endeavour, while Chapter 4 presents the findings and discussion, which are the direct output from the previous chapters. Last but not least, Chapter 5 rounds up the report with a conclusion and recommendation for future research efforts.

CHAPTER TWO

LITERATURE REVIEW

2.1 Supply Chain Management

Since SCM has been originated from multi-disciplinary disciplines, there have been various definitions of SCM (Li et al., 2006). Most popular definitions came from the areas of purchasing and supply management, and transportation and logistics management (Li et al., 2006; Tan et al., 2002, Perumal & Zailani, 2011). From a purchasing and supply management perspective, Johnston (1995) defined SCM as the process of strategically managing the movement and storage of materials, parts and finished inventory from suppliers, through the firm and to customers. Similarly, Li et al. (2006) stated that SCM “is synonymous with the integration of the supply base that evolved from the traditional purchasing and materials functions”. Others who defined SCM from the purchasing perspective include Wisner and Tan (2000) and Fawcett et.al. (2008) and they stated that SCM is a basic strategic business process, rather than a specialised supporting function. From the perspective of transportation and logistics management however, SCM is synonymous with integrated logistics systems, and focuses on inventory reduction both within and across organisations in the supply chain (Danese & Romano, 2011). It is concerned with cost effective way of managing materials, information, and financial flows from the point of origin to the point of consumption to satisfy customer requirements (Narasimha & Roy,2007). Simchi-Levi et al. (2004) defined SCM as a set of approaches used to efficiently integrate suppliers, manufacturers, warehouses and stores so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time in order to minimise system wide costs while satisfying service-level requirements. Overall, SCM is widely been used in order to help company improve their capability level with the objective of being flexible and responsive to meet changing market requirements (Gunasekaran et al., 2004).

These two perspectives were eventually combined into the concept of integrated SCM that bring together all the activities along the whole supply chain (Li et al., 2006; Tan et al., 2002, Kim, 2006). These various definitions have proposed SCM can be extended to the achievement of a company-wide collaborative culture.

It is impossible for a company to cope with the challenges of the competitive market successfully by itself alone. The customer demands keep changing and the market structure have become more complicated. Hence, there has been growing understanding that SCM should be built around the integration of trading partners (Barratt & Oliveira, 2001). The companies not only rely on the physical logistics but they are dependent on information technologies. These technologies will act as the catalyst for further integration among the firms particularly creating an inter-dependence and shared destiny (Power, 2005). This advantage leads organisations to work closely with their suppliers, customers and competitors in a collaborative supply chain environment (Chong et al., 2009).

Collaborative been described as “firms collaborate in the sense of leveraging benefits to achieve common goals” (Bowersox et al., 2000) It occurs when 2 or more companies share the responsibility of exchanging common planning, management, execution and performance measurement information (Anthony, 2000). Similarly, Simatupang and Sridharan (2002) define collaborative SC as two or more independent companies (that) work jointly to plan and execute supply chain operations with greater success than when acting in isolation. Collaborative commerce enables companies to improve the way they manage their cross-enterprise value chains dramatically (Chen et al., 2007).

Supply chain integration characteristics (Ackermans `et al., 1999): cooperation, collaboration, information sharing, trust, partnerships, shared technology, and a fundamental shift away from managing individual functional processes to managing integrated chains of processes. According to Danese and Romano (2011), their findings reveal the need for firms to simultaneously pursue integration with customers and suppliers to improve efficiency performance. SC collaboration puts firms in a position of achieving better performance. All entities in the chain should make all necessary arrangements of collaborative practices, abide the rules, should have common objectives to achieve SCs performance benchmarks, and follow all ethical principles to make things work well. Building collaborative supply chains have always been a major focus for most companies as their initiatives for successful and sustainable business operations.

IT has played an enabling role in all these collaboration practices. The emergence of new technologies such as RFID, EDI, and CPFR (collaborative planning, forecasting and replenishment) has help to eliminate demand and supply uncertainty and enhance communications through the supply chain entity. According to Attaran and Attaran (2007), some of the important business benefits derived for the CPFR are:

1. enhanced relationship between partners,
2. increased sales revenue,
3. improved product offering,
4. reliable and accurate order forecasts,
5. reduction in inventories, and
6. improved technology return on investment.

Therefore, the current research highlights that the main components of collaborations are integration, automation, information and trust.

2.2 Background of Nanotechnology

Nanotechnology has become a buzzword for many years, to the point where industry players have predicted the nanotechnology business to be capable of rivalling the biotechnology industry and even perhaps forecasted to be at par with information communication technology (ICT) by 2014 (Hebert, 2004). It is said that nanotechnology is the next “disruptive technology”, meaning that it will influence across industries and affect our very lives, similar to previous technologies like “atomic” was for the 1950s, “micro” was for the 1980s, and “.com” was for the 1990s (Tan, 2010). Its forecasted impact is slowly blurring out the lines that separate reality with fantasy, whereby certain technologies that were only imaginary several decades ago, have now been physically demonstrated in laboratories today and even commercialised, such as spill proof clothing, golf balls that have less wobble and fly straighter, and air purifying pavements (Mongillo, 2007).

However, with the surrounding hype and champions of nanotechnology, what really is nanotechnology? The general public would view nanotechnology as a completely new area or field of study, but it is actually a question of studying the convergence of various fields at a nano scale. Burke (2009, p. 32) had stated nanotechnology to be “a general term for the ability to very specifically manipulate matter at the atomic and molecular scale and create products that were heretofore impossible”. Thus, this would give birth to a plethora of theoretically viable nanotechnology products and applications that could possibly exist sooner than expected. However, it must be pointed out here that although the research into the materials and applications of these materials is paramount to the growth of this promising industry, there must also be research into the management of this industry in order for it to flourish and aid in the betterment of mankind.

According to Thomas (2006), on the world scene, the European Union (EU), Japan, and the United States (US) are the leading investors of nanotechnology, while China comes second to the US in purchasing nanotechnology research. Thomas also reported that, at that time, about 60 countries have already initiated some form of national nanotechnology research programmes, half of which are located in Europe. The US has spent more than US$5 billion on research funding since 2001, and thus making it the next big publicly funded scientific endeavour since the Apollo Project moon-landing (ETC Group, 2005).

The ETC Group also reported that globally, both public and private sector nanotechnology investment was estimated at US$8.6 billion in 2004 alone.

2.3 Definition of Nanotechnology

The transdisciplinary nature of nanotechnology requires that scientists from differentiated disciplines (Lenhert, 2000a) are able to accurately communicate with precisely defined terminology (Siepmann, 1999). Most progress in nano-scale science and technology results from research involving various combinations of Biology, Chemistry, Physics, Engineering and Computer Science (Lenhert, 2000a).

Biology provides proof that the concept behind nanotechnology is realistic. The dis-assembly and re-assembly of biological systems into their individual components such as DNA, protein and phospholipids is common practice for the molecular biologist and has resulted in numerous advancements in biotechnology.

Chemistry is a well established method for dealing with atoms and molecules in very precise statistical sense. Nano-scale chemistry involves the study of single molecules, molecular assembly lines, nano-scale reaction vessels and more.

Physics has produced tools that can be used to directly interact with the nano-scale, namely Scanning Probe Microscopy (SPM). SPM technology was predicted in the 1950s by Feynman and its discovery in the 1980s could be considered the spark that started nanotechnology.

Engineering on the nano-scale involves the use of atomically precise components to design and build nano-scale devices. Simulation and fabrication of nanomachines, quantum computers and molecular electronics may soon become standard practice in the engineering community.

Computer Science is a field that may be the first to develop real nanotechnology. Rapidly shrinking computer chips and novel architectures require new chip fabrication methods and new software. Molecular simulation is an essential tool for nanotechnology.

Therefore, a basic understanding of each of these subjects is a valuable asset for a person engaged in interdisciplinary nanoscience. A diverse background will give a nanoscientist the ability to communicate with colleagues and find the appropriate methods for a particular project. While each of these subjects has a plethora of available information from a macroscale perspective, there is plenty of room for their development with respect to the nano-scale. With such a background established, a strong focus on the nano-scale intersection between two or more of these fields is a promising method for achieving success in the field of nanotechnology.

Furthermore complicating the situation is the fact that nanotechnology is not only science, but a real technology, which brings business/economics, social sciences (NSF, 2001), and even the (very) fine arts (Lenhert, 2000b) into the picture. The potential impact of nanotechnology on our everyday lives has been likened to the impact of electricity, illustrating the importance of being able to discuss nanotech-related concepts across and beyond scientific and industrial boundaries.

Nanotechnology has been one of the more difficult nanowords to detail out. Norio Taniguchi first used the term nanotechnology to describe the technology associated with production for obtaining higher accuracy and ultra fine dimensions, which refers to “the preciseness and fineness on the order of 1 nm (nanometer), 10^{-9} meter in length” (Taniguchi, 1974). The term has since evolved to mean everything from “the science of manipulating atoms and molecules”(Zyvex Glossary, n.d.) to “the synthesis of novel life forms” (Smalley, 2001). This variety has resulted in some entertaining debates between the haves and the have-nots (i.e. those who have nanotechnology - biologists & chemists, and those who do not - mechanical engineers). On the left side of the ring is the MNT community, planning to change the very nature of our existence by means of self-replicating nanorobots (Lenhert, 2001). On the right side of the ring are the heavyweight biotech and chemical industries (Whitesides, 2001) who continue to steadily and reliably improve our quality of life. Realising that a revolution of some sort is underway, quantum engineering and quantum biology would transcend their rhetoric.

Perhaps the most widely accepted definition of nanotechnology to date appears on the NASA website:

> “the creation of functional materials, devices and systems through control of matter on the nanometer length scale (1-100 nanometers), and exploitation of novel phenomena and properties (physical, chemical, biological, mechanical, electrical...) at that length scale.”(NASA, n.d.).

However, the terms novel and exploit in this definition seem ambiguous and superfluous. For instance, many nanotechnologies are neither new, e.g. nano-particles in ancient mesoamerican paint, (José-Yacamán, Luis, Arenas, & Mari Carmen, 1996), nor unique to the nano-scale, e.g. self-assembly can be carried out at a variety of scales (Gracias, Tien, Breen, Hsu, & Whitesides, 2000). Furthermore, a fish might 'exploit' fluid dynamics in order to swim, but that does not make swimming a technology.

To refine the definition of nanotechnology from the one given in the introduction, Borisenko and Ossicini (2007) defined nanotechnology as,

> a set of methods and techniques providing the fabrication of structures consisting of individual atoms, molecules or macromolecular blocks in the length scale of approximately 1–100 nm. It is applied to physical, chemical and biological systems in order to explore their novel and differentiating properties and functions arising at a critical length scale of matter typically under 100 nm (p. 287).

Several other authors also share the same or similar definition to the above, but with varying precision and information. For example, Allhoff and Lin (2008) mentioned nanotechnology as a new category of technology, but omitted the reference to biology, chemistry, and physics, whereas Bhushan (2004) included any technology that is performed at the nano-scale with applications in the real world, and also mentioned the three physical, chemical, and biological systems. Hornyak (2008) added that it was also the "understanding and control of matter ... [to] enable novel applications" (p. 10). However, after reviewing the various definitions in the literature, the following is considered by most as the latest definition by M. Meyyappan of Ames Labs,

> Nanotechnology is the creation of USEFUL/FUNCTIONAL materials, devices and systems through control of matter on the nanometer length scale and exploitation of novel phenomena and properties

> (physical, chemical, biological) at that length scale (Tilstra, Broughton, Tanke, Jelski, French, Zhang, Popov, Western, & George, 2008, p. 6).

Meyyappan distinctly added the useful/functional terms within the definition in order to reduce or play down the hype surrounding nanotechnology, or as he put it, “to distinguish from the science fiction scenarios popularised by novels and press articles” (Meyyappan, 2004, p. 311).

2.4 History and Development of Nanotechnology

This history of this promising technology which has wide implications on society can be summarised in the following timeline:

2.4.1 In the Beginning: 1959

The first description of ideas that formed the basis of nanotechnology was described by Feynman (1960) in his after-dinner talk describing molecular machines building with atomic precision. He described a field, in which little has been done, but in which an enormous amount can be done in principle. This field is not quite the same as the other fields in physics in that it will not contribute much of fundamental physics, but it is more like solid-state physics in the sense that it might tell much of great interest about strange phenomena that occur in complex situations. Furthermore, a point that is most important is that it would have an enormous number of technical applications in other fields. He further describes of the need to miniaturise components even further, which needs equipment capable of viewing and controlling these components at a very small scale. He also touched upon the biological system and other applications of nanotechnology, such as in lubrication and computing.

2.4.2 The Term Coined: 1974

Nanotechnology is one of the more difficult nanowords to pin down and define fully in order for it to be accepted by all. Taniguchi (1974) first used this term to refer to the "production technology to get the extra high accuracy and ultra fine dimensions, i.e. the preciseness and fineness on the order of 1 nm (nanometer), 10^-9 meter in length". His paper described the process of on ion-sputter machining.

2.4.3 The Official Start: 1977

Due to an outgrowth of studies of naturally-occurring molecular machines, Drexler (as an undergraduate student) originated the official and essential concept of nanotechnology at MIT. Being an undergraduate student with grand and controversial ideas, Drexler had faced strong criticisms and opposition by his peers in other fields, who viewed his idea as being impossible to implement. This field of opposition included Nobel Prize winner, which had made Drexler an eventual outcast as his idea was taken up by the more prominent scientists in the various scientific fields that had taken up the challenge of developing nanotechnology (Regis, 2004).

2.4.4 The Establishment: 1981

However, only in 1981 did he write his first technical paper on molecular nanotechnology engineering as an inspiration for building a machine using atomic precision (Drexler, 1981).His dream and vision were approaching closer to reality with the invention of STM (Scanning Tunneling Microscopy) by Gerd Binnig and Heinrich Rohrer in the same year, which was the first machine developed using nanotechnology in its construction (Binnig & Rohrer, 1986).

STM allows scientists to see and manipulate individual atoms. More specifically, it is widely used in both industrial and fundamental research to obtain atomic-scale images of metal surfaces. It provides a three-dimensional profile of the surface which is very useful for characterising surface roughness, observing surface defects, and determining the size and conformation of molecules and aggregates on the surface. Several other recently developed scanning microscopes also use the scanning technology developed for the STM. The STM inventors were then recognised for the efforts when they received the Nobel Prize in Physics in 1986. A precursor instrument, the topografiner, was invented by Russell Young and colleagues between 1965 and 1971 at the National Bureau of Standards (NBS) (currently the National Institute of Standards and Technology (NIST)).

2.4.5 The Buckyball Discovered: 1985

As narrated by Farnsworth, Fernandez, and Sabbatini (2007), Richard Smalley, Robert Curl, and Harold Kroto discovered fullerenes (also called buckyballs) in 1985, but the special properties of the buckyballs took a few years to prove and categorise. Although by 1996 no practical applications of buckyballs had been produced, scientists appreciated the direction this discovery based in organic chemistry had led scientific research, as well as its specific contributions to various other fields. The accidental discovery of fullerenes also emphasises the benefits and unexpected results which can arise when scientists with different backgrounds and research aims collaborate in the laboratory.

British chemist Harold W. Kroto at the University of Sussex was studying strange chains of carbon atoms found in space through microwave spectroscopy, a science that studies the absorption spectra of stellar particles billions of kilometres away to identify what compounds are found in space. This is possible because every element radiates a specific frequency of light that is unique to that element, which can observed using radiotelescopes. The elements can then be identified because a fundamental rule of matter stating that the intrinsic properties of elements apply throughout the universe, which means that the elements will emit the same frequency regardless of where they are found in the universe. Kroto took spectroscopic readings near carbon-rich red giants, or old stars with very large radii and relatively low surface temperatures, and compared them to spectrum lines of well-characterised substances. He identified the dust to be made of long alternating chains of carbon and nitrogen atoms known as cynopolyynes, which are also found in interstellar clouds. However Kroto believed that the chains were formed in the stellar atmospheres of red giants and not in interstellar clouds, but he had to study the particles more closely.

At the same time, Richard Smalley was doing research on cluster chemistry, at Rice University in Houston, Texas. “Clusters” are aggregates of atoms or molecules, between microscopic and macroscopic sizes, that exist briefly. Smalley had been studying clusters of metal atoms with the help of Robert Curl, using an apparatus Smalley had in his laboratory. This laser-supersonic cluster beam apparatus had the ability to vaporise nearly any known material into plasma using a laser, which is a highly concentrated beam of light with extremely high energy.

Through an acquaintance with Curl, Kroto contacted Smalley and discussed the possibility of using his apparatus to recreate the high-heat conditions of a red giant's atmosphere in order to study the clusters of carbon produced, which might give Kroto insight as to the formation of the carbon chains. Smalley conceded and Kroto arrived in Smalley's laboratory in Rice University on September 1, 1985 whom began working on the experiment along with graduate students J.R. Heath and S.C. O'Brien. Through this collaboration, these scientists were able to make one of the significant scientific discoveries in nanotechnology.

Buckyballs are giving scientists information about allotropes of carbon never before conceived. More importantly, these buckyballs allow engineers and doctors do what was never before possible, and some of the applications for buckyballs currently in research include medicine more specifically in drug treatments and scanning, and in engineering, through various applications in circuits, lubrication, superconductors, and as catalysts.

2.4.6 Initial Growth: 1986

In 1986, the beginnings of the nanotechnology movement were observed. The spectrum of development which was initially sparked off by Feynman had culminated in the first book ever being published by Drexler, titled "Engines of Creation: The Coming Era of Nanotechnology" (Drexler, 1986).

The field of nanotechnology was also being recognised as a major field that needs to be coordinated. This eventuated in the formation of the Foresight Institute, based in California, USA. This institute is a leading think tank and public interest organisation focused on transformative future technologies. Founded in 1986, its mission is to discover and promote the upsides, and help avoid the dangers, of nanotechnology, artificial intelligence, biotechnology, and similar life-changing developments.

In order to facilitate research and development in nanotechnology, scientists had invented the Atomic Force Microscopy (Blanchard, 1996). Extending from his previous work in STM, Greg Brinnig worked with Christoph Gerber and Calvin Quate had produced the AFM or scanning force microscopy (SFM), which is a very high-resolution type of scanning probe microscopy, with demonstrated resolution on the order of fractions of a nanometer, more than 1000 times better than the optical diffraction limit. The AFM uses a tiny needle made of diamond, tungsten, or silicon, much like those used in the STM. While the STM relies upon a subject's ability to conduct electricity through its needle, the AFM scans its subjects by actually lightly touching them with the needle. Like that of a phonograph record, the AFM's needle reads the bumps on the subject's surface, rising as it hits the peaks and dipping as it traces the valleys. Of course, the topography read by the AFM varies by only a few molecules up or down, so a very sensitive device must be used to detect the needle's rising and falling.

2.4.7 Disseminating Information: 1987

Hundreds of members of the MIT community were introduced to the concept of nanotechnology at a Symposium held on January 20. Sponsored by the Departments of Applied Biological Sciences, Materials Science and Engineering, Political Science, and the Artificial Intelligence Laboratory, the event was organised by the MIT Nanotechnology Study Group. Entitled "Exploring Nanotechnology", the Symposium's all-day format enabled participants to probe technical, political, economic, and social aspects of the technology. The first presentation, "Overview of Nanotechnology", was given by Eric Drexler, a Visiting Scholar at Stanford University and Research Affiliate with MIT's Artificial Intelligence Lab. Drexler made the basic case for technical feasibility, sketched several possible development paths, and outlined some applications.

Meanwhile in "Materials Science and Protein Engineering," Dr. Kevin Ulmer summarised the state-of-the-art in protein design. Protein engineering is seen as one development path or "enabling technology" for nanotechnology. Ulmer is pursuing this path, currently as the Director of the Centre for Advanced Research in Biotechnology. This was also the year that witnessed the first engineered protein developed as a result of nanotechnology based research.

2.4.8 Formal Education: 1988

About fifty students attended the ten-week course on "Nanotechnology and Exploratory Engineering" taught by Foresight Institute's president Eric Drexler at Stanford during the spring quarter. The main body of the course was highly technical, drawing from the disciplines of physics, chemistry, computation, and engineering. Later sessions addressed applications in space development, warfare, and medicine, along with policy issues and an analysis of where we are today in developing the technology.

Next is a list of the major events occurring throughout the decades until today.

1989

- IBM logo spelled in individual atoms
- First national conference

1990

- First nanotechnology journal
- Japan’s STA begins funding nanotech projects

2.4.9 Extending the Buckyballs: 1991

The discovery of nano-tubes in 1991 by S. Iijima has been by far the buckyball’s most significant contribution to current research. Nano-tubes, both single- and multi-walled, can be thought of as sheets of graphite rolled into cylinders and sometimes capped with half-fullerenes. Nano-tubes, like fullerenes, possess some very unique properties, such as high electrical and thermal conductivity, high mechanical strength, and high surface area. In fact, carbon nano-tubes provide a clear example of the special properties inherent at the quantum level because they can act as either semi-conductors or metals, unlike macroscopic quantities of carbon molecules. These properties make nano-tubes extremely interesting to researchers and companies, who are already developing many potentially revolutionary uses for them.

1. Japan’s MITI announces bottom-up “atom factory”
2. IBM endorses bottom-up path
3. Japan’s MITI commits $200 million

1992

1. First textbook published
2. First Congressional testimony

1993

1. First Feynman Prize in Nanotechnology awarded for modeling a hydrogen abstraction tool useful in nanotechnology
2. First coverage of nanotech from White House
3. “Engines of Creation” book given to Rice administration, stimulating first university nanotech centre

1994

1. Nano-systems textbook used in first university course
2. US Science Advisor advocates nanotechnology

1995

1. First think tank report
2. First industry analysis of military applications
3. Feynman Prize in Nanotechnology awarded for synthesis of complex three-dimensional structures with DNA molecules

1996

1. $250,000 Feynman Grand Prize announced
2. First European conference
3. NASA begins work in computational nanotech
4. First nanobio conference

1997

1. First company founded: Zyvex
2. First design of nanorobotic system
3. Feynman Prize in Nanotechnology awarded for work in computational nanotechnology and using scanning probe microscopes to manipulate molecules

1998

1. First NSF forum, held in conjunction with Foresight Conference
2. First DNA-based nanomechanical device
3. Feynman Prize in Nanotechnology awarded for computational modeling of molecular tools for atomically-precise chemical reactions and for building molecular structures through the use of self-organisation

1999

1. First Nanomedicine book published
2. First safety guidelines
3. Congressional hearings on proposed National Nanotechnology Initiative
4. Feynman Prize in Nanotechnology awarded for development of carbon nano-tubes for potential computing device applications and for modeling the operation of molecular machine designs

2000

1. President Clinton announces U.S. National Nanotechnology Initiative
2. First state research initiative: $100 million in California

3. Feynman Prize in Nanotechnology awarded for computational materials science for nanostructures and for building a molecular switch

2001

1. First report on nanotech industry
2. U.S. announces first centre for military applications
3. Feynman Prize in Nanotechnology awarded for theory of nanometer-scale electronic devices and for synthesis and characterisation of carbon nano-tubes and nanowires

2002

1. First nanotech industry conference
2. Regional nanotech efforts multiply
3. Feynman Prize in Nanotechnology awarded for using DNA to enable the self-assembly of new structures and for advancing our ability to model molecular machine systems

2003

1. Congressional hearings on societal implications
2. Call for balancing NNI research portfolio
3. Drexler/Smalley debate is published in Chemical & Engineering News
4. Feynman Prize in Nanotechnology awarded for modeling the molecular and electronic structures of new materials and for integrating single molecule biological motors with nano-scale silicon devices

2004

1. First policy conference on advanced nanotech
2. First centre for nanomechanical systems
3. Feynman Prize in Nanotechnology awarded for designing stable protein structures and for constructing a novel enzyme with an altered function

2005

1. At Nanoethics meeting, Roco announces nanomachine/nano-system project count has reached 300
2. Feynman Prize in Nanotechnology awarded for designing a wide variety of single molecular functional nanomachines and for synthesizing macromolecules of intermediate sizes with designed shapes and functions

2006

1. National Academies nanotechnology report calls for experimentation toward molecular manufacturing
2. Feynman Prize in Nanotechnology awarded for work in molecular computation and algorithmic self-assembly, and for producing complex two-dimensional arrays of DNA nanostructures

2007

1. Feynman Prize in Nanotechnology awarded for construction of molecular machine systems that function in the realm of Brownian motion, and molecular machines based upon two-state mechanically interlocked compounds

2008

1. Technology Roadmap for Productive Nano-systems released
2. Protein catalysts designed for non-natural chemical reactions
3. Feynman Prize in Nanotechnology awarded for work in molecular electronics and the synthesis of molecular motors and nanocars, and for theoretical contributions to nanofabrication and sensing

2009

1. An improved walking DNA nanorobot
2. Structural DNA nanotechnology arrays devices to capture molecular building blocks
3. Design 'from scratch' of a small protein that performed the function performed by natural globin proteins
4. Organising functional components on addressable DNA scaffolds
5. Feynman Prize in Nanotechnology awarded for experimental demonstrations of mechanosynthesis using AFM to manipulate single atoms, and for computational analysis of molecular tools to build complex molecular structures

2010

1. DNA-based 'robotic' assembly begins
2. Feynman Prize in Nanotechnology awarded for work in single atom manipulations and atomic switches, and for development of quantum mechanical methods for theoretical predictions of molecules and solids

2011

1. First programmable nanowire circuits for nanoprocessors
2. DNA molecular robots learn to walk in any direction along a branched track
3. Mechanical manipulation of silicon dimers on a silicon surface

2.4.10 Trends in the United States of America

Very recently, the U.S. House of Representatives, together with the Committee on Science, Space, and Technology and Subcommittee on Research and Science Education held a hearing charter regarding the progress of nanotechnology since their National Nanotechnology Initiative (NNI) was launched in 2001, as well as the possible and most viable future directions that the nanotechnology industry can take (CSST, 2011a).

The hearing had revealed much about the current progress of the USA in the field of nanotechnology and what stance the USA government is currently taking. "Nanotechnology represents a great deal of promise for the future of the U.S. economy, both in terms of leaps and bounds in the scientific knowledge base and in terms of potential products and employment opportunities as the technology continues to mature," said Subcommittee Chairman Mo Brooks (R-AL). "Many believe it has the potential to be the next industrial revolution leading to significant social and economic impact. In these difficult budget times, Congress needs to be sure that all Federal investments will work to strengthen the economy, including our investments in nanotechnology" (CSST, 2011b).

A common discussion was the impact of an emerging nanotechnology industry on U.S. employment. A recent study funded by the National Science Foundation (NSF) projects that 6 million nanotechnology workers will be needed worldwide by 2020, with 2 million of those jobs in the United States. Discussing the potential economic benefits of the emerging industry, Dr. Clayton Teague, Director of the National Nanotechnology Coordination Office, told the Committee, “This funding has a remarkable return on investment when viewed in terms of expected job creation and the potential for significant economic growth.”

Teague also discussed how the nanotechnology industry would employ a broad cross section of varying educational backgrounds, where “Nanotechnology will continue to create many jobs requiring college degrees and higher education, but it also will create jobs that can be filled through training and vocational programs, including community colleges and 2-year degrees”.

Echoing these potential benefits, Dr. Seth Rudnick, Chairman of the Board at Liquidia Technologies, said that “nanotechnology has the undeniable potential to create entirely new industries and products that will positively impact our environment as well improve the quality of life and prevent disease. But we cannot just innovate, we need to scale our inventions to realise this potential, creating jobs and economic prosperity”.

In the three years since the Science, Space, and Technology Committee last held a nanotechnology focused hearing; there have been several new developments and advances in the field. Witnesses today discussed these developments, as well as the coordination, planning, and review mechanisms necessary to ensure that the involved agencies are effectively supporting program and government goals.

The hearing had briefly highlighted the inner workings of the USA NNI effort, outlining the budget as well as the key research areas and strategies. This will be described in the following sections.

2.4.11 The USA National Nanotechnology Initiative (NNI)

The USA National Nanotechnology Initiative (NNI) is a multi-agency research and development (R&D) program. The goals of the NNI, which was initiated in 2001, are to maintain a world-class research and development program; to facilitate technology transfer; to develop educational resources, a skilled workforce, and the infrastructure and tools to support the advancement of nanotechnology; and to support responsible development of nanotechnology.

Currently, 15 Federal agencies have ongoing programs in nanotechnology R&D. Additionally, 10 other agencies, such as the Food and Drug Administration, the U.S. Patent and Trademark Office, and the Department of Transportation, participate in the coordination and planning work associated with the NNI (see Table 2.1).

The potential contributions of nano-scale science and technology to future U.S. economic growth were first raised to the level of a Federal initiative, known as NNI, in the FY01 budget request to Congress. Legislatively, the NNI was originally authorised in 2003, through the 21st Century National

Table 2.1. List of organisations participating in the USA NNI.

Federal agencies with budgets dedicated to nanotechnology research and development	
1.	Consumer Product Safety Commission (CPSC)
2.	Department of Defence (DOD)
3.	Department of Energy (DOE)
4.	Department of Homeland Security (DHS)
5.	Department of Justice (DOJ)
6.	Department of Transportation (DOT, including the Federal Highway Administration, FHWA)
7.	Environmental Protection Agency (EPA)
8.	Food and Drug Administration (FDA, Department of Health and Human Services)
9.	Forest Service (FS, Department of Agriculture)
10.	National Aeronautics and Space Administration (NASA)
11.	National Institute for Occupational Safety and Health (NIOSH, Department of Health and Human Services/Centres for Disease Control and Prevention)
12.	National Institute of Food and Agriculture (NIFA, Department of Agriculture)
13.	National Institute of Standards and Technology (NIST, Department of Commerce)
14.	National Institutes of Health (NIH, Department of Health and Human Services)
15.	National Science Foundation (NSF)
Other participating agencies	
16.	Bureau of Industry and Security (BIS, Department of Commerce)
17.	Department of Education (DOEd)
18.	Department of Labour (DOL, including the Occupational Safety and Health Administration, OSHA)
19.	Department of State (DOS)
20.	Department of the Treasury (DOTreas)
21.	Director of National Intelligence (DNI)
22.	Nuclear Regulatory Commission (NRC)
23.	U.S. Geological Survey (USGS, Department of the Interior)
24.	U.S. International Trade Commission (USITC)
25.	U.S. Patent and Trademark Office (USPTO, Department of Commerce)

Nanotechnology Research and Development Act (P.L. 108-153). The Act adds oversight mechanisms to provide for planning, management, and coordination of the program; encourages partnerships between academia and industry; encourages expanded nanotechnology research and education and training programs; and emphasises the importance of research into societal concerns related to nanotechnology to understand the impact of new products on health and the environment.

The Act authorised appropriations for nanotechnology research and development (R&D) activities through FY08. While the programs and funding in the Act were only authorised through 2008 they have continued to receive funding through the annual Appropriations process. As is the case with numerous Federal programs, in order to maintain program integrity the Federal government continues to provide funding while the reauthorisation process takes place.

The management structure for the NNI is as follows:

1. The National Nanotechnology Initiative is managed within the framework of the National Science and Technology Council (NSTC), the Cabinet-level council by which the President coordinates science and technology policy across the Federal Government.
2. The Nano-scale Science, Engineering, and Technology (NSET) Subcommittee of the NSTC's Committee on Technology coordinates planning, budgeting, program implementation, and review of the initiative.
3. The NSET Subcommittee is composed of representatives from agencies participating in the NNI.
4. The National Nanotechnology Coordination Office (NNCO) provides technical and administrative support to the NSET Subcommittee, serves as a central point of contact for Federal nanotechnology R&D activities, and engages in public outreach on behalf of the NNI. The NNCO also serves as a liaison to academia, industry, professional societies, foreign organisations, and others to exchange technical and programmatic information. Additionally, the NNCO coordinates preparation and

publication of NNI interagency planning, budget, and assessment documents.

The NNI has also established eight program component areas (PCAs) that provide an organisational framework for categorising NNI activities (see Table 2.2).

Table 2.2. List of programme component areas identified.

No.	PCA Title	Description
1	Fundamental Nano-scale Phenomena and Processes	Discovery and development of fundamental knowledge pertaining to new phenomena in the physical, biological, and engineering sciences that occur at the nano-scale. Elucidation of scientific and engineering principles related to nano-scale structures, processes, and mechanisms.
2	Nano-materials	Research aimed at the discovery of novel nano-scale and nanostructured materials and at a comprehensive understanding of the properties of nano-materials (ranging across length scales, and including interface interactions). R&D leading to the ability to design and synthesise, in a controlled manner, nanostructured materials with targeted properties.
3	Nano-scale Devices and Systems	R&D that applies the principles of nano-scale science and engineering to create novel, or to improve existing, devices and systems. Includes the incorporation of nano-scale or nanostructured materials to achieve improved performance or new functionality. To meet this definition, the enabling science and technology must be at the nano-scale, but the systems and devices themselves are not restricted to that size.
4	Instrumentation, Research, Metrology, and Standards for Nanotechnology	R&D pertaining to the tools needed to advance nanotechnology research and commercialisation, including next-generation instrumentation for characterisation, measurement, synthesis, and design of materials, structures, devices, and systems. Also includes R&D and other activities related to development of standards for nomenclature, materials characterisations and testing, and manufacture.
5	Nanomanufacturing	R&D aimed at enabling scaled-up, reliable, and cost-effective manufacturing of nano-scale materials, structures, devices, and systems. Includes R&D and integration of ultra-miniaturised top-down processes and increasingly complex bottom-up or self-assembly processes.

6	Major Research Facilities and Instrumentation Acquisition	Establishment of user facilities, acquisition of major instrumentation, and other activities that develop, support, or enhance the nation's scientific infrastructure for the conduct of nano-scale science, engineering, and technology R&D. Includes ongoing operation of user facilities and networks.
7	Environment, Health and Safety	Research primarily directed at understanding the environmental, health, and safety impacts of nanotechnology development and corresponding risk assessment, risk management, and methods for risk mitigation.
8	Education and Societal Dimensions	Education-related activities such as development of materials for schools, undergraduate programs, technical training, and public communication, including outreach and engagement. Research directed at identifying and quantifying the broad implications of nanotechnology for society, including social, economic, workforce, educational, ethical, and legal implications.

2.4.12 USA NNI FY12 Budget Request

In February 2011, the NNI released a supplement to the President's FY12 budget request. This supplement identifies the total amount of nanotechnology-related funding requested by each NNI participating agency.

The FY12 budget request for NNI is $2.1 billion, an increase of $216 million or 11.3 percent over the FY10 actual levels. The Administration's budget request includes funding for three signature initiatives: Nanoelectronics for 2020 and Beyond; Sustainable Manufacturing: Creating the Industries of the Future; and Nanotechnology for Solar Energy Collection and Conversion. The DOE contribution will increase to $611 million, a $237 million or 63 percent increase. Likewise, NASA sees a 64 percent increase, EPA an 11.9 percent increase, NSF a 6.3 percent increase, HHS a five percent increase, and NIST a one percent increase. All other agency funding is reduced by a total of $88 million.

Each of the 25 participating agencies creates its own annual budget request, including its request for nanotechnology-related funding. "The NNI is an interagency budget crosscut in which participating agencies work closely with each other to create an integrated program." Of the 25 participating agencies, only 15 have funding dedicated to nanotechnology-related fields (see Table 2.3).

Table 2.3. NNI Budget by Agency from 2010 to 2012.

	Fiscal Year (USD in millions)		
Agency	**FY10 Actual**	**FY11 CR***	**FY12 Proposed**
DOE**	373.8	380.8	610.6
HHS/NIH	456.8	456.8	464.8
NSF	428.7	412.1	455.9
DOD***	439.6	415.4	368.2
DOC/NIST	114.7	95.9	115.7
NASA	19.7	20.1	32.3
EPA	17.7	17.6	19.8
HHS/NIOSH	8.5	9.5	16.5
HHS/FDA	7.3	7.3	15
USDA/NIFA	13.2	13.2	11.6
DHS	21.9	12.3	10.2
USDA/FS	7.1	5	5
CPSC	0.5	2.2	2
DOT/FHWA	3.2	2	2
DOJ	0.2	0	0
TOTAL:	**1912.8**	**1850.3**	**2129.6**

Note: * 2011 levels reflect the annualised amounts provided by the continuing resolution (CR) that extended through March 4, 2011.
** Funding levels for DOE include the combined budgets of the Office of Science, the Office of Energy Efficiency and Renewable Energy (EERE), the Office of Fossil Energy, and the Advanced Research Projects Agency for Energy (ARPA-E).
*** The 2010 DOD figures include $75 million in congressionally directed funding that is outside the NNI plans.

The FY12 budget request states the NNI's continued support for the Federal role in basic research, infrastructure development, and technology transfer, while renewing an emphasis on accelerating the transition from basic R&D into innovations that support sustainable energy technologies, healthcare and environmental protection. To achieve this, Advanced Research Projects Agency for Energy (ARPA-E) at the Department of Energy, the Environmental

Protection Agency, and the National Institutes of Health each receive significant funding increases through the request. Furthermore, environmental, health and safety (EHS) research remains a priority as identified by funding increases in the FY12 budget request. NNI EHS funding for the Food and Drug Administration is increased over 100 percent, and the Consumer Product Safety Administration requests a 300 percent increase. Additionally, agencies like the Occupational Safety and Health Administration are strengthening their role in the NNI and EHS research.

2.4.13 PCAST Third Assessment of the USA NNI

The 21st Century National Nanotechnology Research and Development Act required that a National Nanotechnology Advisory Panel (NNAP) biennially report to Congress on trends and developments in nanotechnology science and engineering and on recommendations for improving the NNI. The President's Council of Advisors on Science and Technology (PCAST) acts as the NNAP, and as such conducts the biennial assessments. The latest assessment by PCAST was released in March 2010.

2.4.14 USA NNI Strategic Plan

The National Nanotechnology Initiative Strategic Plan is the framework that underpins the nanotechnology work of the NNI member agencies. Its purpose is to facilitate the achievement of the NNI vision by laying out guidance for agency leaders, program managers, and the research community regarding planning and implementation of nanotechnology R&D investments and activities.

Released in February 2011, the NNI strategic plan is used by participating agencies to guide coordination of nanotechnology-related research, training programs and resources. The strategic plan builds on the four NNI goals by creating objectives to support each goal.

Goal 1: Advance a world-class nanotechnology research and development program.

Objective 1: Continue to support R&D at the frontiers and intersections of scientific disciplines in the form of intramural and extramural programs targeting single investigators, multi-investigator and multidisciplinary research teams, and centres for focused research.

Objective 2: Develop at least five broad interdisciplinary nanotechnology initiatives that are each supported by three or more NNI member agencies and support significant national priorities.

Objective 3: Identify and support goal-oriented nano-scale science and technology research aimed at national priorities informed by active engagement with academia, industry, and other stakeholders.

Objective 4: Develop quantitative measures to assess the performance of the U.S. nanotechnology R&D program relative to that of other major economies, in coordination with broader efforts to develop metrics for innovation.

Goal 2: Foster the transfer of new technologies into products for commercial and public benefit.

Objective 1: Develop robust, scalable nanomanufacturing methods necessary to facilitate commercialisation by doubling the share of the NNI investment in nanomanufacturing research over the next five years.

Objective 2: Increase focus on nanotechnology-based commercialisation and related support for public-private partnerships.

Objective 3: Establish and/or sustain national user facilities, cooperative research centres, and regional initiatives with the goal of accelerating the transfer of nano-scale science from discovery to commercial products.

Objective 4: Assist the nanotechnology-based business community, including small- and medium-sized enterprises, in understanding the Federal Government's R&D funding and regulatory environment.

Objective 5: Increase international engagement to facilitate the responsible and sustainable commercialisation, technology transfer, innovation, and trade related to nanotechnology-enabled products and processes.

Goal 3: Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology.

Objective 1: Initiate, develop, support, and sustain programs for educating, training, and maintaining a skilled nanotechnology workforce.

Objective 2: Initiate outreach and informal education programs and publish related information to foster a student population, workforce, and public that are well informed about the opportunities in nanotechnology-related industries and the potential impacts of environmental, health, and safety (EHS) and ethical, legal, and societal implications (ELSI) of nanotechnology.

Objective 3: Provide, facilitate that sharing of, and sustain the physical R&D infrastructure for nano-scale fabrication, synthesis, characterisation, modelling, design, computation, and hands-on training for use by industry, academia, non-profit organisations, and state and Federal agencies.

Goal 4: Support responsible development of nanotechnology.

Objective 1: Incorporate safety evaluation of nano-materials into the product life cycle, foster responsible development, and where appropriate, sustainability across the nanotechnology pipeline.

Objective 2: Develop tools and procedures for domestic and international outreach and engagement to assist stakeholders in developing best practices for communicating and managing risk.

Objective 3: Identify and manage the ethical, legal, and societal implications (ELSI) of research leading to nanotechnology-enabled products and processes.

Objective 4: Employ nanotechnology and sustainable best practices to protect and improve human health and the environment.

It can be concluded that the developed nations, lead by the USA, is lending continual as well as increasing support for the nanotechnology industry. They are at the stage of focusing on key areas for research and development that will facilitate the growth of this industry which will ultimately improve their quality of life even more. The NNI strategic plan looks forward over the next ten years for areas to induce greater agency collaboration, such as the nanotechnology Signature Initiatives: Nanotechnology for Solar Energy Conversion; Sustainable Nanomanufacturing; and Nanoelectronics for 2020 and beyond. The strategic plan also calls for leveraging collaborative interagency opportunities and building an internet-based “one-stop shop” access point for nanotechnology information. Moving into the next decade, meaningful engagement with stakeholders and ongoing external assessments will strengthen the efforts of the NNI as the participating agencies move toward realising the four NNI goals.

2.5 The Impact of Nanotechnology on SCM

Whacker (2008) reported that nanotechnology is no longer new and novel, where a study recently released by the National Centre for Manufacturing Sciences covering 600 executives shows the increased significance of nanotechnology to both traditional and emerging fields in the last five years. In 2000, one could identify only a handful of companies with nanotechnology programs. In 2005, 18% of the surveyed industries were already marketing products, about 80% expect to commercialise nano-products by 2010, and almost everyone expressed confidence their organisations will be involved with nanotechnology in the future. Products containing nano-particles already pass unnoticed through the supply chain of many businesses.

However, the current uses of nanotechnology are still in the first or early second of four stages as defined by the Joint Economic Committee of Congress. In a report titled, “Nanotechnology: The Future is Coming Sooner Than You Think” (Saxton, 2007), those stages were defined as 2000-2005: passive nanostructures, 2005-2010: active nanostructures; 2010-2015: systems of nano-systems (2010-2015) and 2015-2020: molecular nano-systems.

Whacker (2008) further described the impact and implications of nanotechnology on the supply chain, which he categorised into the Mild, Wild, and Way-Out-There Waves. He explained that the early implementation of nanotechnology can be classed as the Mild Wave, where it is characterised by utilising nanotechnology to improve existing capabilities. For the supply chain one result will be packages and packaging that ensure the quality of products from initial packaging through transport to ultimate consumption. Some of the developments in this area include:

1. Ultra-strong materials resist tearing or even bending (carbon nano-tubes are 400 times stronger than steel)
2. Ultra-light materials reduce added weight (Aerogel are solids with the feel of Styrofoam but are nearly as light as air)
3. Ultra-efficient materials provide superior insulation and protection from chemical or UV effects (Polymer nano-composites show significant improvement over conventional materials)
4. Ultra-clean materials battle microbiological effects (25nm silver particle antibacterial and anti fungal coatings are being used on some cell phones)

5. Designer packaging that meets specific requirements of manufacturers and transporters will have a major impact on the supply chain.

A second area of impact is the use of nanotechnology to provide protection from counterfeiting. According to Industry Week, the cost of counterfeiting and piracy to the world economy is anywhere from US$500 to $650 billion. Nano-tags built into unit products can be used to verify authenticity. NanobarcodesTM are being developed for paper, plastic, metal and textiles that allow for trillions of unique codes. Surface enhanced Raman (SERS) nano-tags give a unique fingerprint when interrogated by lasers. Pharmaceutical companies are particularly interested in these capabilities because their products are highly targeted for counterfeiting.

Next, the Wild Wave of nanotechnology moves beyond enhancements to the creation of new capabilities for the supply chain. Some of the most interesting will require active and systems of nano-systems capabilities that will emerge over the next 5-10 years.

One of these capabilities is the creation of Nanoelectromechanical Systems (NEMS). NEMS devices are part electronic and part mechanical allowing for the creation of ultra-small, ultra-efficient sensors. NEMS sensors will sample the quality, temperature, and other characteristics of products throughout the supply journey and signal for action should any degradation occur. A primary difference with today’s sensors, aside from their ultra-low size and cost, will be their ability to be parasitic powered by harnessing the energy in motion, ambient temperature or even radio waves in the atmosphere.

Another element of this Wild Wave will use nanotechnology to enable the economic creation of high capability robots. In other words, it will move robots from isolated usage into nearly every aspect of the supply chain. One primary difference in these robots is that they will have capabilities similar to human beings. These robots will have artificial muscles powered by chemical sources, similar to human muscles fuelled by glucose and oxygen in our blood. They will utilise NEMS sensors mentioned above and will be controlled by computers built ultra-capable with nanotechnology as well.

Finally the Way-Out-There Wave highlights the creative limits and imaginations of nanotechnologists who strive to make their flights of fancy a reality which can benefit everyone. Clark (1961) coined as one of his three laws, “any sufficiently advanced technology is indistinguishable from magic.” Indeed scientists and engineers are now seriously pursuing capabilities that we would consider magical, or at least the stuff of science fiction. If built, the Space Elevator would expand the supply chain to off-of-this-world products as materials glide up to and down from earth orbit on a 24 inch ribbon. Contemplated nano-movers, with ultra-smooth surfaces lubricated by adaptive nanites may move cargo from one location to another without friction. But the ultimate and most controversial potential application of nanotechnology is the elimination of finished goods from the supply chain. Nano-factories, facilitated by nano-assemblers, would assemble molecules of raw materials into finished products on demand. However, how about the impact of SCM on nanotechnology? This is the focus of this current research.

2.6 Nanotechnology R&D Roadmap Overseas

Looking to other countries, it can be observed that the focus is not just on the R&D of nanotechnology that is pertinent, but other facets are also paramount in facilitating and eventually sustaining this industry. The New Zealand Ministry Research, Science and Technology (MRST, 2006) has produced a nanotechnology and nanoscience roadmap which also highlights nine directions which all stakeholders should take into consideration. Of these directions the development of bio-nano capabilities is highlighted, which of course covers bio-nano-sensors. The first three directions is basically the initiation of a nanotechnology initiative, while the rest are intertwined to initiate certain actions:

1. focus on basic research,
2. increase focus on relevance to existing industries,
3. increase focus on transformative applications,
4. build capabilities in bio-nano,
5. link to industries and sectors,
6. develop tools and skills,
7. link with social research,
8. support public engagement, and
9. build robust regulatory processes.

These directions will give rise to actions to start in providing education and utilising resource, collaboration between organisations and bodies, solidifying policy coordination, and forming strong international linkages.

Also from this, it can be observed that social science activities play an important role in supporting the pure scientific research activities. Some of the supportive roles by identifying key areas for improvement through social science research, some of which include creating and promoting public awareness of nanotechnology by identifying levels of public understanding, identifying gaps in skill levels of human resource for developing a capable workforce, confirming policy enhancements through use of up-to-date information from the industry, providing closer industry-academic ties through bridging the gap from the perspectives of perceptions and expectations, collating information to attract foreign direct investment into the country, to name but a few. Some of the actions that can be supported by social science research from the report are as follows (MRST, 2006):

- Research funding and investment agents to support both:
    - social research that informs the nanoscience research and policy communities on the public values and priorities for science and technology, including integration of social and nanoscience research in joint programmes; and
    - research that investigates effective means for the public to engage with science and technology issues.
- Research organisations to recognise and support researchers' public engagement activities.
- Workshops are to be convened for nanotech researchers, social scientists, policy makers and other interested groups to identify particular research questions and approaches that facilitate responsible development of nanoscience and nanotechnologies.

- On-going discussions are to be coordinated across governments on policy issues associated with national and international developments in nanoscience and nanotechnologies.

From the above observations, it is clear that there is a need to perform more social science research in the field of nanotechnology in general, more specifically in bio-nanotechnology, because of its importance and the potential positive impact it has on other industries which will eventually facilitate the sustainability and longevity of the industry and thus drive the growth of the nation's economy, quality of life, and standard of living.

2.7 Summary of Nanotechnology Development in Other Countries

While the U.S. still leads the world in nanotech innovation by virtue of its size, Japan, Germany, and South Korea are doing a better job of bringing technology to market, according to a report released by Luxresearchinc.com (2010) recently.

In terms of sheer volume, the U.S. dominated the rest of the world in nanotech funding and new patents last year, as U.S. government funding, corporate spending, and venture-capital investment in nanotech collectively reached $6.4 billion in 2009. However, according to the new report, countries such as China and Russia launched new challenges to U.S. dominance in 2009, while smaller players such as Japan, Germany and South Korea surpassed the United States in terms of commercialising nanotechnology and products.

The report, titled “Ranking the Nations on Nanotech: Hidden Havens and False Threats,” compares nanotech innovation and technology development in 19 countries in order to provide government policymakers, corporate leaders and investors a detailed map of the nanotech’s international development landscape. Overall, the report found global investment in nanotech held steady through the recent financial crisis, drawing $17.6 billion from governments, corporations and investors in 2009, a 1% increase over 2008’s $17.5 billion. Only venture capitalists dialled back their support, cutting investments by 43% relative to 2008.

To uncover the most fertile environments for technology developers, buyers, and investors, Lux Research mapped the nanotech ecosystems of select nations, building on earlier reports published from 2005 through 2008. In addition to tracking fundamentals, such as the number of nanotech publications and patents issued, the report also inventoried direct and indirect spending on nanotech from government, corporate and venture sources. Among its key observations:

- The U.S. continues to dominate in nanotech development… for now. Last year saw the U.S. lead all other countries in terms of government funding, corporate spending, VC investment, and patent issuances. But its capacity to commercialise those technologies and leverage them to grow the economy is comparatively mediocre. U.S. competitiveness in long-term innovation is also at risk, as the relative number of science and engineering graduates in its population is significantly lower than it is in other countries.

- Other countries stand to get more bang for their nanotech buck. Japan, Germany, and South Korea continued their impressive trajectories from 2008, earning top spots in publications, patents, government funding, and corporate spending. Compared to the U.S., all three also remain more focused on nanotech and appear more adept at commercialising new technology. The relative magnitude of the technology manufacturing sectors in these three countries are the world's highest, meaning their economies stand to benefit the most from nanotech commercialisation.
- Russian and Chinese investment in nanotech yields slow progress. While both governments launched generous nanotech investment programs last year, the technology hasn't gained momentum in either country's private sector, both of which have a history of skimping on R&D. The relative lack of momentum was further underscored by the abysmal number of new nanotech patents for either country last year.

Several developing countries have also launched nanotechnology initiatives in their respective countries in order to strengthen their capacity and sustain economic growth (Court, Daar, Martin, Acharya, & Singer, 2004). India's Department of Science and Technology will invest $20 million over the next five years (2004–2009) for their Nano-materials Science and Technology Initiative. Panacea Biotec (http://www.panacea-biotec.com/products/products.htm) (New Delhi, India) is conducting novel drug delivery research using muco-adhesive nano-particles, and Dabur Research Foundation (Ghaziabad, India) is participating in Phase-1 clinical trials of nanoparticle delivery of the anti-cancer drug paclitaxel (Bapsy et al., 2004). The number of nanotechnology patent applications from China ranks third in the world behind the United States and

Japan (Investorideas.com, 2003). In Brazil, the projected budget for nanoscience during the 2004 to 2007 period is about $25 million, and three institutes, four networks, and approximately 300 scientists are working in nanotechnology (Salamanca-Buentello, Persad, Court, Martin, Daar, & Singer, 2005). The South African Nanotechnology Initiative (http://www.sani.org.za) is a national network of academic researchers involved in areas such as nanophase catalysts, nanofiltration, nanowires, nano-tubes, and quantum dots. Other developing countries, such as Thailand, the Philippines, Chile, Argentina, and Mexico, are also pursuing nanotechnology (Court et al., 2004).

Science and technology alone are not the answer to sustainable development challenges. Like any other science and technology waves, nanoscience and nanotechnology are not "silver bullets" that will magically solve all the problems of developing countries; the social context of these countries must always be considered. Nevertheless, science and technology are a critical component of development (Sachs, 2002). The 2010 Human Development Report (UNDP, 2010) of the UN Development Program clearly illustrates the important roles of science and technology in reducing mortality rates and improving life expectancy in the period 1960–1990, but it did not emphasise nanotechnology specifically. In a report released in early 2005 (Juma & Yee-Cheong, 2005), the UN Task Force on Science, Technology and Innovation (part of the process designed to assist UN agencies in achieving the UN Millennium Development Goals) addresses the potential of nanotechnology for sustainable development. The report provided a snapshot of the nanotechnology progress of some developing countries, which is shown in Table 2.4.

The report had concluded that even though technology presents a vast array of opportunities for improving the human condition, many challenges lie ahead in harnessing its power. There needs to be a concentrated effort in developing the infrastructure in general and technological innovation in particular. Technical competence in various fields needs to be increased through the development of a capable workforce through a comprehensive human resource development programme. The powers in place also need to provide an improved environment so that it fosters entrepreneurship and the commercialisation and wider diffusion of technologies. The capacity to participate effectively in the global trading as well as in the global knowledge system needs to also be increased. And the overall policy environment needed to promote the application of science, technology, and innovation to the goals needs to be improved.

Table 2.4. Research and development on nanotechnology in selected developing countries.

Status	Countries	Nanotechnology Activity	Example
Frontrunner	China, India, Republic of Korea	• National government- funded nanotechnology program • Nanotechnology-related patents • Commercial products on the market or in development	China • National Centre for Nanoscience and Nanotechnology • Clinical trials of nanotechnology bone scaffold India • Nano-materials Science and Technology Initiative • Commercialisation of nanoparticle drug delivery Republic of Korea • Nanotechnology Development Program • World's first carbon nanotube field emission display

Middle ground	Brazil, Chile, Philippines, South Africa, Thailand	• Development of national government-funded nanotechnology program • Some government support (research grants) • Limited industry involvement • Numerous research institutions	Brazil • Institute of Nanoscience, Federal University of Minas Gerais Chile • Nanotechnology Group, Pontificia Universidad Católica de Chile Philippines • University of the Philippines/Intel Technology Philippines optoelectronics project South Africa • South African Nanotechnology Initiative Thailand • Centre of Nanoscience and Nanotechnology, Mahidol University
Up and comer	Argentina, Mexico	• Organised government funding not yet established • Industry not yet involved • Research groups funded through various science, technology, and innovation institutions	Argentina • Nanoscience research group, Centro Atómico Bariloche and Instituto Balseiro Mexico • Department of Advanced materials, Instituto Potosino de Investigación Científica y Tecnológica

2.8 Nanotechnology Trends in Malaysia

Nanotechnology is globally recognised as a high-priority emerging technology that brings dramatic benefits. As such, there has been increasing funding granted by the government in order to support the nanotechnology development in Malaysia (Table 2.5).

It started when the Malaysian government had funded some pioneering work in nanotechnology during the Seventh Malaysia Plan which span the years 1996 to 2000 (National Nanotechnology Initiative - NNI, 2010). Further reinforcement was of this nanotechnology research drive was seen with the emphasis of nanotechnology being one of 14 priority research areas in the Intensification of Priority Research Areas (IRPA), which was governed by the Malaysian Ministry of Science, Technology, and Innovation (MOSTI).

Table 2.5. Allocation of government R&D grants.

Malaysia Plan	Government Grants			
	Intensification of Research in Priority Areas (IRPA)	Industry Research and Development Grant Scheme (IGS)	Multimedia Super Corridor Research and Development Grant Scheme (MGS)	Demonstrator Application Grant Scheme (DAGS)
Fifth	RM400 million	-	-	-
Sixth	RM600 million	-	-	-
Seventh	RM708 million	RM100 million	RM65 million	RM30 million
Eighth	RM833 million	RM230 million	RM100 million	RM90 million

Source: ATIP (2006)

Furthermore, NNI (2010) had stated the short term strategy for Malaysia was, geared towards identifying researchers in various areas of nanotechnology with specific expertise; upgrading and equipping nanotechnology laboratories with state-of-the-art facilities; and to prepare a comprehensive human resource development programme for producing nanotechnologists.

This is further reinforced by the National Science and Technology Policy II (Ministry of Science, Technology, and Innovation - MOSTI, n.d.) which, specifically with regard to nanotechnology, desires to position Malaysia as a technology provider in the key strategic areas of nanotechnology; to ensure the widespread diffusion and application of nanotechnology, leading to enhanced market-driven research and development (R&D) to adapt and improve technologies by undertaking a detailed scrutiny of the industry; and to build competence for specialisation in key emerging technologies by developing a secure knowledge base in nanotechnology to sustain technology support for the Malaysian industry (MOSTI, n.d.).

Hashim, Nadia, and Salleh (2009) had provided the current outlook of the nanotechnology industry in Malaysia through their research. The study had concluded that the Malaysian scenario required much work in the management of such high technology. Some of the highlighted problems within the nanotechnology industry include lack of linkages between various projects, no central facility, there is no definitive plan to realise and develop the nanotechnology industry, there is no clear overall road-map for nanotechnology research, and lack of effort in promoting awareness of nanotechnology.

Furthermore, Hashim et al. (2009) also revealed a Strength, Weakness, Opportunity, and Threat (SWOT) analysis of the nanotechnology industry in Malaysia, as formulated by the Malaysian Industry-Government Group for High Technology (MIGHT), which is placed under the supervision of the Economic Planning Unit (EPU) of the Malaysian Prime Minister's Department. Some of the weaknesses identified were, no dedicated policy for nanotechnology, need for human resource planning, lack of private sector investment and participation, lack of facilities, and lack of world-class companies to raise the standard.

The report by the Asian Technology Information Program (ATIP) had identified the infrastructure components for supporting the nanotechnology industry, namely R&D infrastructure, human resource, industry infrastructure, and industry readiness (ATIP, 2006). From the comparison performed in 2006, it was highlighted that the Malaysian nanotechnology industry still requires more development in R&D infrastructure and human resource development, as compared to the other ANF countries; ANF being a network organisation that is supported by 13 countries, including Australia, China, Hong Kong, India, Indonesia, Korea, Japan, Malaysia, New Zealand, Singapore, Taiwan, Thailand, and Vietnam.

Thus, based on the preliminary review of material, there is a need to look into the technology management aspects of nanotechnology (Burgi & Pradeep, 2006; Hipkin, 2004; Ghazinoory & Farazkish, 2010) in order to manage the development of this potentially viable industry to become more focused and successful by identifying the factors which may be of influence in facilitating the growth of this industry.

2.8.1 Malaysian Government Support/Initiative

Not wishing to take the wait-and-see approach, the Malaysian government has taken up the challenge of exploring the vast potentials of nanotechnology by launching its own National Nanotechnology Initiative on 4 July 2005 in Johor Bahru, Malaysia (Asia Pacific Nanotech Weekly, 2005). In order to remain competitive, Malaysia has to have its own nanotechnology policies, as well as strategic plan to manage this viable technology, as extensively stressed by the then Deputy Prime Minister, now the Prime Minister, in several of his public appearances regarding the research and management of nanotechnology.

In order to enhance Malaysia's competitiveness and to be part of this nanotechnology revolution, Malaysia has developed its own technology policies and initiatives as well as strategic plan (Hashim et al., 2009) Nanotechnology R&D started by the Malaysian government in 2001 and categorised as a Strategic Research (SR) program under IRPA in the Eight Malaysia Plan (8MP) which spans from 2001 to 2005. The Malaysia's National Budget 2006 unveiled the allocation of RM868 million to be provided under MOSTI and R&D. The focus will be biotechnology, nanotechnology, advanced manufacturing, advanced materials, ICT, and alternative source of energy including solar, to encourage innovation among local companies and developing new products.

Later, the initiatives have been continued in the 9th Malaysia Plan (2006-2010) where the government first thrust is to move the economy up the value chain. The Government aims to increase the value added of existing economic sectors. In addition, the manufacturing sector is expected to shift into high technology and generate new knowledge-intensive activities with high value added content in various industries, especially involving electrical and electronics, petrochemicals, biotechnology, machinery and equipment, aerospace and maritime. The Government has prepared prepare specific incentives to attract investments, including high quality FDI for manufacturing sector activities that are being promoted.

Furthermore, small and medium enterprises (SMEs) with high innovation capabilities have been encouraged to become part of the global supply chain. Some of the projects that have been implemented to enhance the manufacturing sector include the expansion of Kulim High Technology Park, the establishment of Sarawak Technology Park and Perak Technology Park, the development of 20 industrial and SME parks throughout the country, and infrastructural improvements to existing industrial areas. To improve access to sources of finance, the Government has created several funds such as the Strategic Investment Fund, the Automotive Development Fund, the Industrial Restructuring Fund, the Automation Fund, and specific funds for biotechnology products.

2.8.2 Nanotechnology R&D Roadmap in Malaysia

In the context of steering the direction of the nanotechnology industry toward a more sustainable future, here, a roadmap is designed to guide the industry's science and research activity by highlighting a strategy that provides the broad context and high level directions from the Malaysian perspective. Roadmaps may represent the governing body's stance or position on the science of nanotechnology, emphasising on how the industry efforts should be developed in order to best meet Malaysia's future needs. This roadmap is not one filled with detailed milestones, targets, or research plan, since all of these particulars need to be decided by those with the responsibility for funding particular pieces of research in conjunction with the end-users of the research, which consequently, will build toward clarifying the overall picture that is being presented by this roadmap.

The Malaysian Government has produced a National Nanotechnology Roadmap, titled “Malaysia NNI Roadmap Report” in 2007 (MIMOS Berhad, 2008), which was based on a study that identified five industries that would benefit from the development of nanotechnology, namely:

1. Biotechnology,
2. Energy,
3. Environment,
4. Agriculture, and
5. Medicine.

After a screening process of all the potential nanotechnology-based products in the industry was performed, six target products were identified as being able to bring the most impact to the above identified industries directly, and consequently the development of the country. These products include biosensors as being on the top of this list, as follows:

1. Biosensors,
2. Biochips,
3. Molecular farming,
4. Drug delivery system,
5. Solar, and
6. Lithium-ion.

This shows how important nanotechnology has become in impacting other industries. Focusing on the promising field of nano-biosensor, some specific identified applications of the biosensor in other industries include diagnostic kits for clinical and homes uses, real-time applications such as alert sensor and detector for pathogen infection caused by bacteria, fungi, and viruses during outbreaks and detection of contamination, and food production and agricultural diagnostic kits to aid in production. Furthermore, biosensors also assist in facilitating the usage and production of the above mentioned products, such as in molecular farming where biosensors are used in agricultural diagnostics, and in biochips and drug delivery system, where biosensors can be applied as monitoring and controlling devices.

Furthermore, other countries have observed the potential of biosensors even earlier. For example, Thailand has established the National Nanotech Centre (NANOTEC) 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. That nation's first nanotechnology roadmap includes nano-biosensors, as well as nanopolymers, nano-composites, nano-particles, nanoclay, nanofibers, nano-tubes, nanoporous materials, nanocatalysts, and solar cells (MIMOS Berhad, 2008).

Even though currently there is no clear and detailed roadmap for nanotechnology specifically on research and development (Hashim et al., 2009) let alone a specific roadmap for the nano-biosensor industry, because of the importance of such a promising industry, certain bodies have attempted to produce roadmaps in line with countries from overseas. For example, relating to the nanoelectronics industry, MIMOS Berhad (2008) had developed a roadmap for the Malaysian Ministry of Science, Technology, and Innovation. In this roadmap, it was highlighted that sensors play an important role in supporting other industries, of which includes the role played by nano-biosensors in energy and environment, food and agriculture, and medical and health.

2.9 Research Dimensions

2.9.1 Human Resource

Human resource management involves the planning, implementation and monitoring of the organisation's labour force. Another way of looking at the organisation's human resources is in terms of "human capital," which refers to the knowledge and skills of the labour force. Clearly, the human resources of any organisation are its most valuable assets. In the view of many top-level executives, employees are the key source of an organisation's competitive advantage (Brown &Kraft, 1998; Chilton, 1994).

Critically important to effective human resource management is to develop and instil core values throughout the organisation (Down, Mardis, Connolly, &Johnson, 1997). These values include integrity and honesty, commitment to the organisational mission, accountability for and pride in one's work, commitment to excellence, and building trust. They form the basis for developing cohesiveness and teamwork, as well as for developing policies, procedures and programs that focus on meeting the needs of customers or clients.

The human resources management function is charged with planning and controlling human resources to make sure that people's needs are met so they can work to achieve organisational goals. Commitment to meeting employees' needs is not merely an altruistic function—it is highly likely that staff who are reasonably comfortable with working conditions, and stimulated by the environment, will be productive (Miron, Leichtman, & Atkins, 1993).

In traditional government bureaucracies, many human resource functions are centralised in a ministry and often not in the control of individual organisational bureaucracies. Increasingly, however, as part of overall public sector reforms, government ministries and agencies are taking control of some of these functions. From an organisational perspective, control over human resources is critical to hold managers accountable for organisational performance.

Nevertheless, progress in this area has been slow. The following sections examine five aspects of human resources management: planning, staffing, developing, assessing and rewarding, and maintaining effective relations.

2.9.1.1 Human Resources Planning

Human resource planning involves forecasting the human resources needs of the organisation, and planning the steps necessary to meet these needs. This planning is the first step in any effective human resources management function. Human resources planning should be closely linked to the organisation's strategic objectives and mission. Even in regions of the world with a plentiful, well-educated workforce, such planning is a challenge because the needs of the organisation are constantly changing and sometimes do not converge (Cockerill, Hunt, & Schroder, 1995). The challenge is even greater if the pool of people from which the organisation recruits is limited by such factors as brain drain, or because labour market wages in the private sector are more attractive (Colvard, 1994). Forecasting in these environments is quite difficult.

2.9.1.2 Staffing Human Resources

An important step in implementing a human resources plan is to recruit and train new people to carry out the work of the organisation. Staffing an organisation means searching for, selecting and orienting individuals who have the appropriate range of knowledge, skills, behaviour and values to meet the organisation's needs.

Staffing also means responding to trends in the labour pools and helping people adjust to the environment within which the organisation is operating. Staffing capacity relates to the ability of an organisation to identify the kinds of human resources that it needs to perform well (McNerney, 1995). It does this through a variety of techniques involved in job and needs assessments, review of core competencies, organisational human resource competency analysis, and so forth. An organisation must find new organisational members who cannot only meet the present demand for human resource services, but also future needs. It is a sobering thought to think that in many government organisations the people being hired today could very well be the workers 20 to 30 years from now. While there are no guarantees with respect to how people will mature in their organisational role, initial selection and training play an important role in assuring good long-term performance.

2.9.1.3 Developing Human Resources

Building human resource skills, knowledge and attitudes is becoming an increasingly important part of the work of an organisation. In a period of rapid change, the staff members of an organisation need to adapt to changing conditions (Bennett, 1993). For example, public servants today need to know how to work with a wide variety of stakeholders. In the manufacturing sector, new technologies have revolutionised the production of goods. In almost every aspect of work today, employees need to adapt, change and learn. This is the human resource development function of an organisation.

Developing human resources in an organisation means improving employee performance by increasing or improving their skills, knowledge and attitudes. This allows the organisation to remove or prevent performance deficiencies, makes employees more flexible and adaptable, and increases staff commitment to the organisation. Developing human resources can take several forms, such as job training, training for the role inside the organisation, or training for a career. This can include career development, succession planning, or organisational development activities. Having the right people skills in place at the right time is an important aspect of the human resource development system.

An effective and popular approach to develop human capital is staff training and development programs (Harrison, 1997). The basic purpose of such programs is to enable employees to acquire the requisite knowledge and skills that will upgrade their job performance. Management training and development programs can facilitate the development of skills and communication among staff by providing a common language, building employee networks, and establishing a common vision for the firm. These programs promote cohesion by helping employees socialise, instilling in them a common set of core values, and improving employee skills critical to the organisation's key operations and its core and distinctive competencies (Hagen, Hassan, & Amin, 1998).

Historically in development work, there has been a great deal of investment in training. In many development projects, training as part of technical assistance is perceived as a panacea for poor individual performance. It is easy to disburse for training activities and it is also easy to obtain visible outputs. As such, it is a fairly safe tactic. Unfortunately, training may not be the most appropriate intervention for improving employee productivity and, hence, organisational performance. Many observers doubt that training is an effective way to improve performance in developing countries because it is often isolated and not linked to infrastructure, job requirements, incentive structures or evaluation procedures. Furthermore, in many developing countries, training becomes the means by which staff would leave the civil service. Care and balance, then, clearly must be exercised.

2.9.1.4 Assessing and Rewarding Human Resources

An important aspect of the human resources management function is the system and approach the organisation uses to collect information and provide feedback to individuals or teams. This means assessing the contribution of each staff member to distribute rewards (direct and indirect, monetary and non-monetary) within the legal regulations of the region and the organisation's ability to pay. The assessment and reward system should help the organisation retain good employees, motivate staff, administer pay within legal regulations, facilitate organisational strategic objectives, and support individual learning.

The evaluation and incentive system is a key component in an organisational analysis and is associated with overall organisational performance. Many issues must be addressed when looking at these components. With respect to assessing staff, an organisational approach is needed that links the needs of the organisation and the demands of the job. The incentive and reward structures within an organisation are complex to understand and address. There are both monetary and non-monetary rewards that interact as rewards (and punishments) in all organisations.

Individuals make choices based on their understanding of these incentives about whether to work or not, how hard to work, and so forth (Gerhart & Milkovich, 1990). Not everyone is motivated by the same rewards. Some people are motivated by money, others less so. Some want prestigious titles or positions, while others could care less. In some organisations, weak incentives lead to absences or corruption. In countries with more powerful labour unions, weak incentives can affect relations with unions and even cause strikes. With respect to this area of analysis, it is worth trying to understand both the visible and underlying patterns of the organisation.

2.9.1.5 Maintaining Effective Staff Relations

Keeping a supportive and content work force is becoming more important in this era of global competition. Today, it is increasingly difficult to find people with the right skills at the right price. When an organisation trains its staff, it is investing in future productivity. Creating the work and support structures to retain a loyal work force is difficult, but important, for an organisation. This aspect of the human resources function deals with all the programs and systems in place to ensure employees are protected and dealt with in accordance with appropriate legislation. It includes all the activities the organisation implements to address issues of health and safety, human rights, the quality of working conditions, and, in unionised settings, collective bargaining. In essence, it represents the concrete measures the organisation has taken to instil in employees feelings of ownership, self-control, responsibility and self-respect. Exactly what the organisation does to produce these outcomes will vary according to the nature of the organisation, its leadership style, and its cultural setting (Lusthaus, Adrien, Anderson, Carden, & Montalván, 2002) was revealed.

2.9.2 Organisational Infrastructure

While human resources and financial resources are quite typically reviewed in most organisational assessments, more attention needs to be paid in developing countries to the state of the infrastructure required to support organisational performance (Nourzad, 1997).

Infrastructure refers to the basic conditions (facilities and technology) that allow an organisation's work to proceed—for example, reasonable space in a building equipped with adequate lighting, clean water and a dependable supply of electricity, as well as viable transportation to and from work for employees. In developed countries that have the wealth and the governmental structures to support adequate infrastructure, these conditions are often taken for granted. In some developing countries, however, inadequate infrastructure presents an organisational problem that warrants assessment.

Each organisation has its own assets and liabilities with respect to infrastructure resources. If the organisation has its basic infrastructure in place, this area will represent a small component of the assessment. If the infrastructure is deteriorated, however, with electricity and water found to be problem areas, then infrastructure will become a major concern of the assessment.

2.9.2.1 Facilities Infrastructure

People (staff, clients, customers) spend a lot of time in their organisational surroundings. Some surroundings exude the spirit of performance and development. Others are just the opposite. As part of understanding the organisation’s capacity, it is necessary to consider the extent to which facilities support or interfere with the functioning or the potential functioning of the organisation. Although single deficiencies in one or more elements of infrastructure may not interfere with day-to-day work, at some point, work will be affected. Typically, the basis of many infrastructure problems is maintenance, which often suffers due to the lack of a recurrent budget for upkeep.

2.9.2.2 Technology Infrastructure

Globalisation and information and communication technologies are creating a new information society paradigm of economic growth, citizen action, and political liberty. The information revolution is happening everywhere, often in haphazard fashion. Information and communication technologies have fundamentally altered the nature of global markets, transforming social and economic interactions, and redefining work (Gagnon & Dragon, 1996).

Technological change is occurring faster than policies are able to respond. Information gaps continue to exist between the developed and developing world, with the potential to disenfranchise entire communities on the edge of the information revolution. What lie ahead is tremendous structural change, uncertainty and risk. The technological resources of an organisation encompass all of the equipment, machinery and systems (including the library, information systems hardware and software) that are essential for the organisation to function properly. Still, the instruments of technology are merely tools for enhancing services and products: ideas must still inspire the technology.

2.9.2.3 Technology Tools

Technology tools have been emphasised as an important antecedent for knowledge management practices by many researchers (Li, 2007). For example, Meso and Smith (2000) viewed knowledge management system as an advanced assembly of software, its associated hardware infrastructures for supporting knowledge work and/or organisational learning through the free access to and increased sharing of knowledge. In this study, technology tools are the set of IT tools for supporting collaborative SCM practices. At the simplest level this means a capable, networked PC for each knowledge user with standardised personal productivity tools so that people can exchange thoughts and documents easily. Various studies have attempted to identify the key technological components that are critical to the operations of organisational knowledge management systems. Hibbard (1997) and Chaffey

(1998) mentioned messaging, video-conferencing and visualisation, web browsers, document management, groupware, search and retrieval, data mining, push technology, and intelligent agent group decision support. Meso and Smith (2000) also identified ten similar key technologies: computer—mediated collaboration, electronic task management, messaging, video conferencing and visualisation, group decision support, web browsing, data mining, search and retrieval, intelligent agents, document management. Lin, Hung, Wu, and Lin (2002) summarised previous studies and argued that groupware and web-browser technologies are the most prominent. Following the works of Alavi and Tiwana (2003), and Smith (2001), this study approaches the technological infrastructure from the knowledge process perspective, which is based on Nonaka's (1994) knowledge creation and transfer model. Knowledge generation, storage, access, dissemination and application are the five essential processes that new knowledge is created, transferred and utilised in the business context. Five sub-constructs of technological infrastructure are identified which support the above knowledge processes.

2.9.2.4 Communication Support System

Communication support system includes the technological tools such as email, messaging systems, electronic whiteboard, discussion bulletins, and audio/videoconferencing systems. Explicit and factual knowledge can be shared with lean communication tools such as email or threaded discussion; while the more complex, ambiguous and tacit knowledge (e.g. believes, hunch, perspectives) can be transferred with videoconferencing and other rich media format as well. These functions expand system user's reach and scope in knowledge sharing, and significantly improve group collaborative interactions so that group members have greater exposure to each other's thoughts, opinions, and beliefs as well as getting feedback and clarifications from others, thus joint-creation of new knowledge becomes possible.

2.9.2.5 Knowledge Database Management System

Organisations generate a large volume of data in their operations, such as customer information, supplier delivery schedules, transaction log etc. Many of these data are functionally different thus needed to be locked in separated databases. A data warehouse is introduced as a centralised repository that integrates, summarises and creates a historical profile of such data, which would otherwise be fragmented (Inmon, 1996). While, data mining is the corresponding set of techniques to uncover the desired information from those in the data warehouse. The knowledge database management system provides a common repository platform to several distributed databases in different organisations. Summaries and aggregations of unstructured contents then become easier to provide inputs to other knowledge management tools which support managerial decision making. Data-warehousing and data mining stores and reuses knowledge in a common repository, thus reduces cost but increases efficiency in inter-organisational knowledge storage and retrieval. It facilitates across supply chain collaboration and knowledge sharing.

2.9.2.6 Enterprise Information Portal

An enterprise information portal is a central access point that enables the transfer of knowledge from knowledge repositories to and from individuals. It often has a web browser interface that looks like an online search engine. A key advantage of enterprise information portal is the ease of use and its ability to transfer knowledge to and from a diverse array of resources and places at any given time.

2.9.2.7 Collaborative System

A collaborative system is one where multiple users or agents engage in a shared activity, usually from remote locations. The users in the system are working together towards a common goal and have a critical need to interact closely' with each other: sharing information, exchanging requests with each other, and checking in with each other on their status (Baecker, 1993; Cil, Alpturk, & Yazgan, 2005). The purpose of setting up a collaborative system is to develop a web-based framework for a knowledge management and decision making on a special organisational problem. Cil et al. (2005) suggested the five elements of common collaborative systems: 1) asynchronisation and collaboration, which are provided by the Web to link all involved users together; 2) many multi-criteria decision making methods and social choice functions; 3) visualisations and the accessibility of data and information; 4) sharing the data among participants; and 5) screening, sifting, and filtering the data, information, and knowledge. All of these elements work together to enhance communication related activities among a team of users and facilitate peer interactions and joint problem solving. Hightower and Sayeed (1995) identified an important feature of a collaborative system is that it supports group discourse tasks by structuring the argumentation, and also provide a formal documentation of the process that is used to arrive at a decision.

2.9.2.8 Decision Support System

Decision support system is defined as computer based systems that support unstructured decision-making in organisations through direct interactions with data and analytical models (Sprague & NcNurlin, 2001). The advantage of the technology is its ability to combine existing knowledge with unstructured and context-specific information for problem solving. An expert system can facilitates routine application of knowledge through codification of expert's decision rules and embedding them into software-based systems (Lado &Zhang 1998). The utilisation of decision support system can frees knowledge workers from the monotonous reapplication of particular knowledge when such knowledge is relatively stable.

2.9.3 Organisational Capabilities

In addition to rules and ethos, every society has a certain combination of resources that influences the type and scale of activities undertaken by individuals and organisations, as well as how successful their efforts are likely to be. These include natural resources, human resources, financial resources, infrastructure (transport, roads, electricity, telecommunications), and technology. Together they form what we call "capabilities" (Lusthaus et al., 2002). They combine with rules and institutional ethos to create an enabling or inhibiting environment for organisations and development.

Of importance to all countries is the worldwide concern about the environment. Modern societies view protection of the environment as an essential objective. In developing countries, explicit environmental approval is frequently required before an organisation develops a new project. Failure by the organisation to comply with any of the regulations pertaining to the environment may result in political pressures from domestic or foreign environmental activists.

2.10 Other Dimensions in Literature

Perceptions about which of these capabilities or resources is more critical for development has shifted over time from natural resources to human resources, capital and technology. The emerging consensus is that an enabling environment is a combination of all the resources and the institutional framework (rules and ethos). There is no single ideal combination. Experience shows that in a highly interdependent world, it is possible to make up for the shortage of one resource (e.g., natural resources in Japan) by creating linkages and strengthening or developing other resources (e.g., human capital and technology). Thus, from a macro perspective for development assistance, the question is no longer whether more training or more transfer of equipment and technology is most crucial for development in developing countries. Rather, the question is what combination of training, technology, institutional reform and so forth is appropriate for creating an enabling macro-environment that maximises resource utilisation within a specific context?

2.10.1 Resources

These issues are discussed in the growing literature on capacity building and development, and it is not our objective to review them here. It is important to understand, however, that the availability or shortage of these capabilities at the macro level can influence the performance of specific organisations at the micro level. Organisations need good human resources and other core resources (infrastructure, technology and finance) to improve their capacity to perform.

However, they must rely to a great extent on the macro environment to provide these resources. The amount and quality of available resources will depend on the institutional and policy environment.

2.10.2 Labour Force

The quantity and quality of the basic labour force available to both public and private sector organisations is influenced to some extent by the quality of the country's formal and technical education. This, in turn, is a function of the policies and rules the government puts in place over time to create the necessary incentives to develop an effective system of education. In other words, a sustained long-term solution to solving human resource capacity gaps in developing countries requires much more than providing scholarships to a handful of citizens to study in universities in developed countries. A more radical approach is needed, requiring institutional reforms to create the right incentives.

2.10.3 Access to Technology and Systems

The same argument applies to the development of indigenous technology and efficient financial systems. This point illustrates the overriding influence of rules and, as noted earlier, the interdependence of the various components of an enabling environment. Before launching ambitious programs to develop capabilities, it is important to conduct a thorough institutional analysis. This involves mapping the institutional environment in terms of politics, administrative capacity, culture, etc. in a manner that includes all stakeholders and measures their level of ownership and commitment to reform.

2.10.4 Process Management

Executives with many organisations today view their business as a series of functional silos concerned with their own requirements (Dent &Hughes, 1998). This perspective is particularly pervasive among managers accustomed to being rewarded for optimising the performance of their functions relative to the rest of the organisation. Although managers talk about “big picture” processes, their efforts are often focused inwardly on their own requirements and are measured accordingly. In such situations, there is an obvious need for common systems and operations that apply uniformly throughout the organisation and, like a thread, sew the various functional parts together into a common purpose. There is also a need for compatible strategies to optimise organisational performance. In other words, process management is required.

Taking a vision and making it a reality through smooth-flowing daily work in an organisation is largely dependent on ongoing “processes.” These are the internal value-adding management systems and operations that cut across functional and departmental boundaries. They are the mechanisms that guide interactions among all groups of people in an organisation to ensure that ongoing work is accomplished rather than hindered or blocked.

Thus, process management is the task of aligning and integrating the various practices and cultures of different segments of an organisation through the introduction of common systems and operations that apply uniformly to all segments of the organisation. These common operations or processes include problem-solving, planning, decision-making, communication, and monitoring and evaluation. People often interact to accomplish their work, and the way that organisational processes are set up dictates the tone of their interaction. If the processes are all working, the outcome is that the organisation is learning and accomplishing a great deal.

Process management takes place at every level of an organisation, from the board of directors to the line worker. The board and senior managers must know how to problem-solve, plan and make timely decisions. If they are deficient in these areas, organisational direction is often hampered. At the more operational level, program units, departments and other functional segments of the organisation must plan and set short- and medium-term goals, as well as solve problems, make decisions and generate strategies to carry out appropriate activities to achieve results.

2.10.5 Problem-solving

Problem-solving is probably the most universal or prevalent of all thinking activities. As individuals, we spend each day of our lives solving problems: deciding what to eat and what to wear, what needs to be done first and what can be put off until tomorrow. At this level, problem-solving skills become programmed or automated over time, and we rarely think about them.

At the organisational level, similar problems constantly confront every unit or department. How can we increase our revenues? Should a new product be introduced? Should more or fewer workers be employed? How can production costs be cut down without compromising quality? How can we best sell our products or services? Who should do what and when? Disparities in problem-solving approaches, which determine how well opportunities are capitalised on, partly explains why some organisations are so successful at improving their performance, while others struggle. All the other activities in process management—decision-making, planning, and monitoring and evaluation—are part of the problem-solving process.

The first step in a systematic approach to problem-solving is to identify or understand the problem and define it clearly. Sometimes, diagnosing a critical problem in time is the difference between survival and extinction. Often, what is perceived as "the problem" may only be a symptom of a much bigger and deep-seated problem. Therefore, successfully diagnosing the root problem and clearly defining it becomes the first prerequisite to removing bottlenecks and taking the organisation in the right direction. Once the exact problem is identified and defined, the next step is to devise alternative ways of solving it. This takes us into the realm of decision-making.

2.10.6 Decision-making

Decision-making is the process of selecting from among alternative courses of action generated during the problem-solving process. Decision-making is:

1. Programmed: a repetitive decision that can be handled by a routine approach;
2. Procedural: a series of interrelated steps used to respond to a structured problem;
3. Rule-based: depends on an explicit statement that tells managers what they ought or ought not to do;
4. Policy-based: provides a guide that establishes parameters for selecting among alternative courses of action.

Decision-making is often influenced or even constrained by limits to decision-makers' information processing capacity, as well as their background, position in the organisation, interests, and experiences. In this context, group decisions, although time consuming, may have significant advantages over individual decisions, since they can lead to more diverse and complete information, and can increase the legitimacy and acceptance of the proposed course of action.

2.10.7 Planning

Planning is the process of mapping where one is going and how one will get there. It permeates every activity of a successful organisation, from product or service initiation to production, selling and distribution. In a world that is ever more complex and uncertain, the adage that "failing to plan is planning to fail" is now truer than ever. Planning helps predict how organisational members will behave. The strategic plan sets an organisation's overall direction and, at operational levels, becomes the process by which strategy is translated into specific objectives and methodologies to accomplish goals. It involves optimally engaging resources, time and people by developing timelines and work schedules.

Policies and procedures are special types of plans that set out courses of action for members of the organisation. Generally, the degree to which plans, procedures and policies are explicit varies considerably across organisations, and even within a particular organisation. Organisation members need enough direction to know what to do to support the organisation's mission and goals. The planning of policies and procedures should provide this direction adequately at all levels of the organisation; that is, for projects, for departments, and for the organisation as a whole.

2.10.8 Communication

Communication is the process by which information is exchanged and shared understanding is achieved among members of an organisation. The top-down and bottom-up flow of information is a vital process that can facilitate or hinder the smooth functioning of an organisation. It includes both the formal and informal flow of information.

Internal communication can serve as the glue holding an organisation together. Alternatively, it can break it apart, for both information and misinformation constantly flow in organisations. Accurate information provided through a system of top-down flows and feedback is vital to keep employees aware about what needs to be done, and to keep managers informed about what was achieved. An effective internal communication system also helps to motivate employees, for apart from the specific information needed to carry out work, organisation members also need information that makes them feel they are part of an important effort and a wider purpose. The organisation must create mechanisms that help its members have access to both types of information. Coordinating committees, working groups, debriefing sessions, newsletters and meetings of all sorts are the vehicles through which effective communication is achieved within an organisation (Communication with external constituents is dealt with in the next section on inter-organisational linkages.)

2.10.9 Organisational Monitoring and Evaluation

Organisational monitoring and evaluation complement program monitoring and evaluation. Organisational monitoring can help clarify program objectives, link activities and inputs to those objectives, set performance targets, collect routine data, and feed results directly to those responsible. Monitoring is the ongoing, systematic processes of self-assessment.

Organisational evaluation looks at why and how results were or were not achieved at the organisational level. It links specific activities to overall results, includes broader outputs that are not readily quantifiable, explores unintended results, and provides overall lessons that can help adjust programs and policies to improve results.

2.10.10 Networks, Joint Ventures, Coalitions and Partnerships

While electronic linkages are opening organisations to new ideas and ways of communicating, a similar revolution is occurring with respect to new organisational patterns that support joint work and collaboration (Lorenzoni & Baden-Fuller, 1995). Many organisations find that they are unable to move toward their mission without the help and support of like-minded organisations. Many are forming new types of relationships (either formal or informal) with other organisations to support their desire to be more successful.

Networks are an informal type of linkage that involves loosely coupled groups that are linked together to serve common interests. At the more formal end are the new partnerships, coalitions and joint ventures. The most formal relationships are based on contractual agreements. All of these new linkages are breaking down the boundaries of organisations and are changing the way they operate.

2.10.11 Electronic Linkages

Electronic linkages are a worldwide assembly of systems, including communication networks, information equipment, information resources, and people of all skill levels and backgrounds. In other words, they represent a “network of networks.”Organisational capacity and performance increases through the appropriate use of new electronic technologies. These new technologies have the potential to improve communication and keep people informed about the latest ideas in the field. Organisational members can join discussion groups and other electronic mechanisms that link people of like minds and ideas. Electronic systems provide the opportunity to search the entire globe for new ideas and information, unlimited access to public services, cultural opportunities, commercial transactions, etc. (Lorenzoni & Baden-Fuller, 1995).

a. Application of Knowledge based system in business
    i. Background and history
    ii. Application in the industry
        1. Application in supply chain management research
        2. Application in nanotechnology industry
    iii. Published case studies

2.11 Chapter Summary

This chapter has covered the background of the nanotechnology industry from several perspectives, such as from the local and international scene. A review of the available literature had uncovered the timeline for the ‘discovery’ of this new technology, and the origins of which have been debatable, meaning to say that its starting point is not firmly established since the technology itself has only become visible due to the development in the detection processes. Nevertheless, this chapter has presented a promising outlook on the use of this technology and also the dimensions which may affect the supply chain management within this industry. The next chapter presents how the research was carried out.

CHAPTER THREE

METHODOLOGY

3.1 Research Design

The study was conducted with the intention to examine the collaborative supply chain management in the nanotechnology industry. This study is cross-sectional whereby data was gathered once to answer the study's research questions. A cross-sectional design is adopted for this research because it is less expensive and short time consuming compared to longitudinal design (Sekaran, 2003). This study used qualitative approach, both interviews and documents in order to enhance the finding to be more insightful.

3.2 Interview

The researcher interviewed the experts of selected laboratories, thus asked relevant questions which were compatible with the research objectives. Hence, the interviews has enhanced the result and provided clear insight about the issue and also gave this study valuable information.

Participants in the interviews were sufficient based on the nature of the study which is more on the management or managerial issues and knowledge (soft science); therefore the researcher had to exclude the answers from the "technology" aspects (hard science). The interviews were conducted with four informants from the research centres identified.

3.3 Procedure

The qualitative approach was conducted in this study to get insight on the subject matter. The interview protocol was used as a guideline for the researcher, which used to all participants. In this first part, we conducted the interview in order to gain general information about the research centres and to identify the key issues pertaining to the supply chain management in nanotechnology.

The participants were first provided with information about the purpose of the study in general and how the information would be used. The ice breaking questions were asked them to describe their work in general. After that, the questions were specifically focused on the key objectives to be obtained by the study. Each interview lasted approximately about half hour and notes were made during the interviews. After each interview the notes were transcribed.

Table 3.1. Interview: Main questions.

1.	What is the current state of nanotechnology in Malaysia?
2.	What are the challenges for the supply chain management in nanotechnology?

3.4 Qualitative Data Analysis

The qualitative data were gathered from the semi-structured interviews on the issues related to the supply chain management in nanotechnology. The interviews were then transcribed and analyzed using a content analysis procedure whereby major issues were identified and categorised. The data were compared to identify changes in key issues of qualitative result and used multiple sources of evidences, therefore to provide a degree of triangulation for the research study Esterberg (2002).

3.5 Data Collection and Analysis

The used of triangulation approaches interviews and document analysis facilitated the research to meet the objectives. The researcher had successfully fixed appointment amidst the busy schedule of the participants, prior to the one-on-one interviews. The data then was transcribed and analysis using a thematic approach.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The study attempts to understand the nanotechnology roadmap in Malaysia. Besides that, the study interested to link nanotechnology industry with the supply chain issues particularly on the collaborative supply chain. In accomplishing these objectives, the study has gained insight information mainly via qualitative approaches on the current state of art practices of supply chain management in Malaysian nanotechnology industry, the challenges for the supply chain management and the application of collaborative supply chain within the context on nanotechnology industries.

4.2 Development of R&D in Nanotechnology in Malaysia

Nanotechnology, although well accepted by the global community, is still yet to be firmly established in this country. The report by Hashim et al. (2009) had highlighted this, even though the NNI was initiated several years earlier. This is due to the fact that setting up such an industry requires intensive capital costing in setting up the initial infrastructure to support this industry.

Firstly, after establishing the theoretical part of this study through the literature review, this research attempted to identify and source out the nanotechnology community players that are active in maintaining the growth of this industry. It was discovered that the main players of this industry is characteristically different from the other industries. This is because of the nature and stage of development of this industry. Other established industries such as in electronics and automotive manufacturing, all have established supply chains, and these industries have been researched fairly extensively. Other industries, such as the construction industry, have also started taking up the SCM concept and integrating it into their operations, but like nanotechnology, researchers have revealed the characteristics that makes that industry unique. Therefore, in order to identify the players in Malaysia, several agencies were approached for a directory listing of the players in Malaysia. It was identified that the players can be categorised into three broad categories, which are the suppliers, the research centres, and the private companies that commercialises the nanotechnology products.

However, initial attempts had proven difficult. Enquiries made to several agencies had yielded in little useful information, even though nanotechnology would be under their jurisdiction. With regard to nanotechnology suppliers, there is no listing or directory that is being maintained by any agency. These suppliers need to be obtained from the research centres and private companies themselves.

With regard the research centres, a previous study in surveying the nanotechnology industry (Elliazir, 2009) had used nine agencies involved directly in nanotechnology, which are shown below in Table 4.1.

Table 4.1. Identified research centres from previous research.

Research Centres	Specialisation
1) Nanochem and Nanophys Lab (IIS-UTM)	• Nanocatalyst, nanoelectronics devices, carbon nano-tubes, nanostructured materials
2) Universiti Putra Malaysia (UPM): • Advanced Material	• Nano-composites, carbon nanotube
3) Universiti Sains Malaysia (USM) • Nano-materials Research • Medical Biotechnology	• Supramolecules, carbon nanotube, nano-composites, OLED • Drug delivery systems, sensors
4) Universiti Kebangsaan Malaysia (UKM) • IMEN	• Nanoelectronics
5) SIRIM (AMREC)	• Nano-materials, processes
6) Universiti Malaya (UM): • Combicat • Centre for Nanotechnology, Precision and Advanced Materials	• Advanced materials and catalysis, glycolipids and photonics.
7) Universiti Teknologi Petronas (UTP)	• Devices and Sensors

However, after some consultation with these centres, it was quickly discovered that this list is outdated. Therefore, this research has to identify manually the actual agencies involved. Through some extensive Internet search, many individuals numbering in the hundred and attached to different research centres and agencies were identified. After through some cross-checking and grouping, it was discovered there were many centres that were newly identified, and that some which were identified in previous research were not listed at active. Therefore, for this research, the identified organisations are as follows (Table 4.2):

Table 4.2. The organisations and number of interest groups identified for the research

No.	Name of Organisation	Number of Centres/Interest Groups
1.	Universiti Teknologi Malaysia (UTM)	19
2.	SIRIM	6
3.	Universiti Teknologi Mara (UiTM)	5
4.	Universiti Teknologi Petronas	4
5.	Universiti Malaya	3
6.	Universiti Kebangsaan Malaysia	2
7.	Universiti Putra Malaysia	2
8.	Universiti Sains Malaysia	2
9.	Universiti Malaysia Sarawak	2
10.	Universiti Pertahanan Nasional Malaysia	1
11.	Universiti Malaysia Perlis	1

Further inspection of these organisations had revealed much information. Some organisations had established research centres, which they display on their on their website. Other organisations had listing of individuals involved in nanotechnology-related research, while others had listed interested groups related to nanotechnology. From all the information that was gathered, the research team members identified the contact persons for each of the identified research centres/institutes/interest groups related to nanotechnology. This is shown in Table 4.3 below.

Table 4.3. Identified research centres/institutes/interest groups related to nanotechnology for the research

No.	Org.	Research Centre / Institute / Interest Group Name
1	UTM	Ibnu Sina Institute*
2		Advanced Photonic Science Institute*
3		Zeolite and Nanostructured Materials Laboratory*
4		Material Innovations and Nanoelectronics Research Group (MINE)
5		Nano & Mesoporous Materials for Biological Applications (NAMBAR)
6		Novel Materials and Process Materials (NoMPTec)
7		Separation Science and Technology (SepSTec)
8		Catalytic Science and Technology (CST)
9		Nanophotonics
10		Industrial And Scientific Computation (ISC)
11		Scientific Computational and Industrial (SCNI)
12		Applied Algebra and Analysis Group (A3G)
13		Laser
14		Phosphor RG
15		Fiber Optics
16		Quantum Nanostructures Research (QuaSR)
17		Theoretical and Computational Modeling for Complex Systems (TCM)
18		Terahertz & Optical Imaging
19		Mathematics Statistic Industrial Group (MSIG)
20	UPM	Advanced Materials and Nanotechnology Laboratory (AMNL)*
21		Institute of Advanced Technology
22	USM	School of Materials and Mineral Resources Engineering*
23		Nano-materials Initiative Group
24	UKM	Institute of Microengineering and Nanoelectronics*
25		Institut Sel Fuel (Biohydrogen Research Group)*
26	SIRIM	Advanced Materials Research Centre (Amrec) - Advanced Polymer & Composites Programme*
27		Advanced Materials Research Centre (Amrec) - Biomaterials Programme*
28		Advanced Materials Research Centre (Amrec) - Electrochemical Materials Programme*
29		Advanced Materials Research Centre (Amrec) - Industrial Nanotechnology Research Centre*
30		Advanced Materials Research Centre (Amrec) - Photonics & Electronic Materials*
31		Advanced Materials Research Centre (Amrec) - Structural Materials Programme
32	UM	Centre for Fundamental and Frontier Sciences in Nanostructure*
33		Centre for Research in Nanotechnology and Catalysis (NANOCEN)*
34		Centre For Nanotechnology, Precision And Advanced Materials (CNPAM)*
35	UTP	FAS
36		ME
37		EE
38		CHE

39	UiTM	Centre of Nanoscience & Nanotechnology*
40		Centre of Advanced Material*
41		Centre of Nano-material*
42		Centre of Research & Innovation In Sustainable Energy
43		Centre of Synthesis & Chemical Biology
44	UniMAS	Faculty of Engineering - Dept of Chemical Eng & Energy Sustainability*
45		Faculty of Resource Science and Technology - Department of Chemistry*
46	UPNM	Fakulti Kejuruteraan - Unit Penyelidikan Perlindungan dan Sustainabiliti*
47	UniMAP	Institute of Nano Electronic Engineering (INEE)*

*Centres involved in on-going research projects

From this field of 47 identified centres and after more confirmation, 22 companies were identified as currently involved in on-going research projects.

From the private sector side however, obtaining a list of companies that are actually involved in nanotechnology is somewhat difficult. In certain directory listings that are maintained by overseas companied only yield in one or two companies involved in nanotechnology. Meanwhile, other directory listings had returned more than 290 companies that had the term “nano” in their company name or product. In order to confirm whether each of these identified companies actually deal with nanotechnology, and not just use the term nano in order to market their product and increase sales, each company would have to be contacted. However, due to the varied numbers being returned, as well as the large number of companied that needed to be contacted, the research team members had decided that this was beyond capabilities scope of this research endeavour. Besides, the list is maintained by companies not associated with the government or government agencies, which means that these listings may not be certified and verifiable. Therefore, more reliable sources were required for this research.

As for the government agencies that are monitoring the progress of the nanotechnology industry in Malaysia, only one agency maintains a list, even though there was admission that the list is somewhat outdated. After personal contact was made, a representative of the Malaysian Industry-Government Group for High Technology (MIGHT) had released a listing of actual nanotechnology companies, meaning that these companies were either involved in the research, development, production, and/or commercialisation of nanotechnology related products. The list, along with a brief description of each company is exhibited in Table 4.4 below.

Table 4.4. Listing of private companies dealing in nanotechnology products as provided by MIGHT.

No.	Name of Organisation	Description
1.	Gelanggang Kencana Sdn Bhd	In 2007, MaerogelTM was patented in Malaysia and marked a new chapter in the history of Aerogels. The product was produced by Prof. Dr. Halimaton Hamdan, of the Department of Chemistry at Universiti Teknologi Malaysia. She had patented an innovative method to produce aerogel from rice husks at a fraction of the normal cost. The features of the Maerogel that make it unique are: lightest solid – only 3 times the density of air, consists of 96% air, space-age nano-materials, porous amorphous solid with pore diameter of 1 - 30 nm, large surface area - 600 to 900 m2 per g and have the properties of dielectric material with thermal, electrical and acoustic insulating behaviours. This invention relates to silica aerogels and to a method for their preparation from rice husk. Rice husk is very rich in silica, and its ash can contain up to 92-97% of amorphous silica. The rice husk ash is prepared by burning the rice husk on a heating plate with excess air until the white ash is obtained. Silica from rice husk ash is in a very active form and has been found to be a very potential starting material for silica aerogels. Here, a low cost process utilising low cost raw material was developed. The overall production cost was reduced by 50-75%).

2.	Unitechnologies Sdn Bhd	This company focuses actively in nanostructured catalysts, nanomembranes and nanoherbs. This company works with UniMAP in producing nanosized herbs extracts which are functionalised and used as drug delivery systems to treat brain cancer, brain healing, HIV, influenza H1N1, immunization improvement and bone healing.
3.	UPM Holdings Sdn Bhd	This company focuses on research and commercialisation activities involving nano-composites and nanobiofertilizers.
4.	Nanopac (M) Sdn Bhd	Malaysia's pioneer in providing nanotechnology solutions, Nanopac (M) Sdn Bhd, has invested about RM 8 mil to set up the countries first nanotechnology Research and Development (R&D) facilities and plant. Nanopac, established in November 2003, is a joint venture between a Malaysian party and South Korea-based Nanopac (Korea). Nanopac was granted pioneer status by the Malaysian Industrial Development Authority and had successfully commercialised its nano solutions, currently adopted by several multinational companies manufacturing air-conditioners in Malaysia, Thailand, Japan and South Korea. Under the joint-venture agreement, Nanopac (Korea) will transfer their unique and advanced nanotechnologies to Nanopac Malaysia. Nanopac is establishing strong overseas network covering China, Australia, Poland, Germany, the United States and Japan.
5.	USains Holdings	The company focuses on research and products related to carbon nano-tubes, nano-particles. Their product on biosensor kits was developed jointly with UniMAP and able to carry out halal product detection, early cancer detection (stage 1) and conduct medical diagnostics.
6.	Malaysian Biotech Corporation	The Malaysian Biotech Corporation is set to commercialise its maiden and home-grown nanotechnology-based product. The nanotechnology product is healthcare-related and is ready for commercialisation for any Malaysian biotechnology company. It is mainly for the export market. BiotechCorp bought the exclusive worldwide license of a nanotechnology platform from French biotechnology company Nanobiotix and the two rollouts are part of a minimum eight nanotechnology projects that it plans to get into the market by 2011.
7.	Nanobiotix	This company owns 14 nanotechnology applications in healthcare, environmental and agricultural applications (five) and food and cosmetic applications (four), which are obtainable from Nanobiotix's current products, meaning no further research and development is required.

8.	MIMOS Berhad	MIMOS is also taking steps in developing nanotechnology-based products, primarily towards nanoelectronics and currently exploring nanotechnology based sensor and photovoltaic cell devices. Their main focus in the nanotechnology research is the growth of nanostructures, which includes characterisation, testing and integrating these nanostructures into Nano/Micro Electronic Mechanical Systems (NEMS/MEMS).
9.	JC Nanotech Sdn Bhd	JC Nanotech, a subsidiary of JC International, devotes in nanotechnology development geared towards environment protection. The company provides solutions in car care, automotive and construction industries.

Of these companies, Nanopac (M) Sdn Bhd has often been cited in other directories available on the Internet.

An interview protocol was created using the literature in order to obtain information regarding the current scenario of the nanotechnology industry as well as to get an idea of the supply chain in the nanotechnology industry. A leading research based in the northern region was selected as a convenient sample. Initially, the interview was expected to last for an hour or so, but due to the respondent's willingness to share vast amounts of information, the interview lasted a little over three hours. A recording was made of the interview which was then taken back and transcribed. This transcription formed the supporting evidence for understanding the study in more in-depth and classifying the specific nanotechnology in particular industry.

4.3 Challenges for the Supply Chain Management in Nanotechnology

4.3.1 Human Resource

Previous reports (Hashim et al., 2001; ATIP, 2006) had indicated that the Malaysian public is not ready in terms of expertise and training. This is further emphasised upon during the interview, where the “manpower” is sorely lacking in Malaysia.

The interviewee gave examples of large projects that wanted to come into the country, which did not eventuate because of the problem of lack of expertise in the human capital at that time. Even thought the approval was given by the Minister of International Trade and Industry at that time for bringing in all the required expertise from overseas to Malaysia, the company had opted to open up its expansion in Singapore, our neighbouring country instead.

The interview also highlighted that the fabrication facilities (also known as “fabs”) are large businesses which can churn out profit in a short time, even though the start-up costs is phenomenal when compared to industries of a similar size.

Another example that been highlighted during the interview was the scenario in China, where they have 400,000 trained nanotechnology workers, which is why the USA find it viable to invest in and open up their business in that country. Furthermore, the key to capable human capital in servicing the nanotechnology industry is that it needs to be based on a stable and solid education. Other examples given were Russia, Iran, and several other settings.

It is aware that the nanotechnology industry requires first class students. This is because due to the nature of the industry, the human capital for the nanotechnology industry needs to have good problem-solving skills. The interviewee described a typical production in Malaysia, where it starts with the operators having SPM level qualification, and then we have the line supervisors, which are followed by the engineers (maintenance and process). Line supervisor plays a critical role in ensuring what should be done is normal and emergency conditions, which means that when there is a problem with the line, he or she will know to contact either the maintenance engineer or the process engineer. This is because one second of down time can cost millions, which is why problem solving skills is very important. These days, operators in high technology industries need to be Diploma holders.

In addition, the interview highlights the concern by the government regarding human capital to service the nanotechnology industry. There are two institutes being set up for this reason, one in Kulim and one in Kuala Lumpur (Beranang), one under MARA and the other under Ministry of Human Resource. However, these two institutes have not been finalised yet, and is still at the discussion stage. The respondent speculated that the agencies are not brave enough to proceed, perhaps due to lack of qualified manpower to train these potential nanotechnology workforce.

After the line supervisors stand the engineers, as mentioned above. These engineers need to be first class, due to the same reasons for first class line supervisors. Thus, again the respondent stressed that man power is very important. At the government level, for high technology industries, the Key

Performance Indicator (KPI) is manpower. There is still a need for engineers, even though hundreds of thousands are being produced. This is because these engineers are more of general engineers that are perhaps not suitable for the nanotechnology industry. The respondent strongly emphasised that “retooling” (retraining) is extremely expensive, therefore basic or starting education is pertinent. The respondent gave an example of a US-based company in Malaysia that sent its first batch of workers to Santa Clara in the USA for training. He mentioned that the training courses lasted for a duration of 3, 6, and 12 months, depending of the job. He also revealed that the total cost for the retooling was RM200 million. He also added that the MIDA had allocated RM30 million for training to foreign companies that are interested in coming to Malaysia. The respondent concluded that there needs to be a stepping stone for outside companies to come into the Malaysian nanotechnology industry, and human resource is a potential stone.

Since human capital is a crucial issue, the research team members started an initial probing into the education system, which had revealed an interesting phenomenon. The call for improving and enhancing the workforce from the nanotechnology standpoint has been received by the various education institutions, and a movement toward improving the future of nanotechnology workers can be observed.

An initially search had pointed the research team to a Wikipedia page containing links and listing on the various institutions of learning that provide nanotechnology education throughout the world. From listing, the following Table 4.5 shows the number of institutions and programmes that are being offered related to nanotechnology according to the country that has been documented on Wikipedia. Even though this list is maintained by the public, is clearly illustrates the development and acceptance of this field of science by the global community.

Table 4.5. Nanotechnology related courses offered around the world.

No.	Country	Number of Courses	Level of Education
1.	India	24	Undergraduate & Postgraduate
2.	United States	23	Undergraduate & Postgraduate
3.	United Kingdom	18	Undergraduate & Postgraduate
4.	Mexico	16	Undergraduate & Postgraduate
5.	Australia	13	High School, Undergraduate, & Postgraduate
6.	Germany	11	Undergraduate & Postgraduate
7.	Canada	9	Undergraduate & Postgraduate
8.	France	7	Postgraduate
9.	Turkey	6	Postgraduate
10.	Brazil	5	Undergraduate & Postgraduate
11.	Denmark	5	Undergraduate & Postgraduate
12.	Netherlands	5	Postgraduate
13.	Sweden	4	Undergraduate & Master
14.	Norway	3	Undergraduate & Master
15.	Spain	3	Undergraduate & Master
16.	Thailand	3	Undergraduate & Postgraduate
17.	Belgium	2	Master
18.	Czech Republic	2	Undergraduate
19.	Switzerland	2	Undergraduate & Postgraduate
20.	New Zealand	2	Undergraduate
21.	Malaysia	2	Undergraduate
22.	Egypt	2	Master
23.	Greece	1	Master
24.	Italy	1	Master
25.	Poland	1	Undergraduate & Postgraduate
26.	Israel	1	Postgraduate
27.	Hong Kong	1	Postgraduate
28.	Singapore	1	Undergraduate
29.	Japan	1	Postgraduate

It is interesting to note that the Wikipedia listing shows that most of the focus of nanotechnology education is more on the postgraduate level, which makes sense because most of these programmes will involve nanotechnology research, which is what drives the innovative application of materials at the nano-scale. However, certain countries recognise that without the support from education of the undergraduate levels, the postgraduate education would not be so successful and fruitful. Some countries, like Australia, go even earlier in educating its potential future workforce by teaching nanotechnology related matters at the high school level.

Going deeper into the listing and taking one of the leading countries as an example, another search into the courses offered in the United States of America had yielded in a list provided by the National Nanotechnology Initiative website (http://www.nano.gov/education-training/centre/university-college). The website highlighted the fact that nanotechnology is gaining more and more acceptance by the general public, and they are aware of the importance of education regarding the development of this field. The website also advised potential students who are interested in nanotechnology at an early stage, not to be disappointed if their school or college does not offer a specific nanotechnology course. These potential nanotech scientists should choose to go into chemistry, physics, engineering, biology, IT, or other technology fields. They can, with the help of a college advisor or a trusted professor or mentor, navigate college-level science courses to learn a great deal about nanotechnology, while keeping in mind that the further they get in their education, the greater the options and choices that become available to them.

The following table provides the list of courses available in the USA from the undergraduate degree level to the doctorate degree level. The following Table 4.6 shows this comprehensive list.

Table 4.6. List of available nanotechnology related courses in the USA.

Bachelor Degree Programmes

1. Clarion University – Minor in nanotechnology
2. Drexel University – BSc Materials Engineering with Specialisation Nanotechnology
3. Louisiana Tech University – B.S. in Nano-systems Engineering
4. Michigan Technological University – Minor program in nanotechnology
5. Northwestern University – B.S. in Physics with Nano-scale Physics Concentration
6. University at Albany College of Nano-scale Science and Engineering (CNSE) – BS in Nano-scale Science and Nano-scale Engineering
7. University of California, Riverside – B.S. in Chemical Engineering with Nanotechnology Concentration
8. University of California, San Diego – B.S. Nanoengineering
9. University of Central Florida – B.S. in Nanoscience and Nanotechnology track in Liberal Studies
10. University of Maryland, Maryland Nanocentre – Interdisciplinary minor in nanotechnology
11. Pennsylvania State University, Centre for Nanotechnology Education and Utilisation, Nanofabrication Manufacturing Technology (NMT) Capstone Semester – Minor in nanotechology

Masters Degree Programmes

1. Arizona State University – Professional Science Master (PSM) in Nanoscience and M.A. in Applied Ethics (Ethics and Emerging Technologies)
2. Johns Hopkins University – M.S. in Materials Science and Engineering with Nanotechnology Option
3. Joint School of Nanoscience and Nanoengineering (collaborative project of North Carolina A&T State Univ. and Univ. of North Carolina Greensboro) – M.S. in Nanoscience and M.S. in Nanoengineering
4. Louisiana Tech University – M.S. in Molecular Sciences and Nanotechnology
5. Rice University, Centre for Nano-scale Science and Technology – Professional Science Master (PSM) in Nano-scale Physics
6. Stevens Institute of Technology – M.Eng. with Nanotechnology Concentration and M.S. with Nanotechnology Concentration
7. University at Albany College of Nano-scale Science and Engineering (CNSE) – Nanoscience/Nanoengineering + MBA program; M.S. degrees with Nano-scale Science and Nano-scale Engineering tracks
8. University of California, San Diego – M.S. Nanoengineering
9. University of Pennsylvania – M.S. in Nanotechnology
10. University of Texas at Austin – MSc Engineering Nano-materials Thrust

Ph.D. Degree Programmes

1. Brown University – Nano/Micromechanics Laboratory
2. City University of New York, Chemistry Department
3. California Institute of Technology (CalTech) – Materials and Process Simulation Centre
4. Clemson University – The Laboratory for Nanotechnology

5. Cornell University – The Nanobiotechnology Centre and Cornell Nanofabrication Facility Home Page
6. Florida Institute of Technology - Division of Engineering Sciences
7. Georgia Institute of Technology - Nanocrystal Research Laboratory and Nanostructure Optoelectronics
8. Iowa State University - Ames Laboratory Condensed Matter Physics Group (Department of Energy)
9. Johns Hopkins University – Institute for NanoBioTechnology
10. Kansas State University - Visual Quantum Mechanics
11. Kaunas University of Technology - Research Centre for Microsystems and Nanotechnology
12. Massachusetts Institute of Technology - NanoStructures Laboratory
13. Michigan State University - The Nanotube Site
14. New Jersey Institute of Technology - Nonlinear Nanostructures Laboratory (NNL)
15. New York University - Nadrian C. Seeman's Laboratory
16. North Carolina State University – “NANO@NCState” program
17. Northeastern University, NSF’s Integrative Graduate Education and Research Traineeship (IGERT) - Ph.D. in Nanomedicine
18. Princeton University - Nanostructure Laboratory
19. Purdue University - Graduate Level Courses in Nano-scale Science and Engineering
20. Rensselaer Polytechnic Institute - Nanostructured Materials
21. Rice University - Centre for Nano-scale Science and Technology
22. Seoul National University - Centre for Science in Nanometer Scale, ISRC
23. South Dakota School of Mines and Technology – Nanoscience and Engineering program
24. Stanford University - Stanford Nanofabrication Facility and NanoNet
25. Stevens Institute of Technology
26. University at Albany College of Nano-scale Science and Engineering (CNSE)
27. University of Arizona - Nanomechanics and Mesoscopic Physics and Prof. Srin Manne's AFM Lab
28. University of Chicago - University of Chicago Materials Centre
29. University of Cincinnati - Nanoelectronics Laboratory
30. University of Connecticut - Advanced Technology Centre for Precision Manufacturing
31. University of Delaware - Department of Chemical Engineering, Centre for Molecular Engineering Thermodynamics Department of Electrical and Computer Engineering, Centre for Nanomachined Surfaces
32. University of Illinois at Urbana-Champaign - Beckman Institute Home Page and Scanning Tunneling Microscopy Group
33. University of Michigan - Centre for Biologic Nanotechnology
34. University of Nebraska - Department of Electrical Engineering, Quantum Device Laboratory
35. University of New Mexico - Nanoscience and Microsystems
36. University of North Carolina at Chapel Hill - North Carolina Centre for Nano-scale Materials and The Nanomanipulator Project
37. University of North Carolina Greensboro/ North Carolina A&T University Joint School of Nanoscience and Nanoengineering

38. University of North Carolina at Charlotte - Ph.D. Program in Nano-scale Science
39. University of Notre Dame - Centre for Nano Science and Technology and Engineering Molecules for a New Technology
40. University of Southern California - Laboratory for Molecular Robotics
41. University of South Florida - Centre for Molecular Design & Recognition
42. University of Texas at Austin
43. University of Utah – Certificate in Nanotechnology while earning science field Ph.D.
44. University of Washington - Centre for Nanotechnology
45. University of Wisconsin Madison - Department of Physics: Nanowires Materials Research Science and Engineering Centre Seed Project, Magnetic Nanostructures
46. Virginia Commonwealth University
47. Washington State University - Nanotechnology Think Tank
48. Yale University - Department of Engineering, Microelectronics and Optoelectronic Materials and Structures

Therefore, from this comprehensive list, there are more and more courses being offered by the USA institutions of higher learning, (11+10+48 = 69 courses) as compared to the Wikipedia list of 23 courses.

However, after further inspection, this USA government website had suggested two other directories for further information regarding nanotechnology education, Trynano.org (http://www.trynano.org/university_listings.html) and Nanowerk.com (http://www.nanowerk.com/nanotechnology/nanotechnology_degrees.php).

The Trynano.org provided similar entries to the Wikipedia listing (with an additional entry for Korea, Taiwan, Ireland, and Russia, and omission of Egypt, Malaysia, and Poland), and this is summarised in Table 4.7 below.

Table 4.7. Listing provided by Trynano according to countries.

Country	Number of Courses	Level of Education
United States	32	Undergraduate & Postgraduate
United Kingdom	19	Undergraduate & Postgraduate
India	17	Undergraduate & Postgraduate
Australia	13	Undergraduate & Master
Germany	12	Undergraduate & Master
Canada	6	Undergraduate & Postgraduate
Netherlands	5	Postgraduate
Brazil	4	Postgraduate
Denmark	4	Undergraduate & Postgraduate
France	4	Postgraduate
Korea	4	Undergraduate & Postgraduate
Sweden	4	Master
Belgium	3	Master
Spain	3	Master
Czech Republic	2	Undergraduate & Master
Italy	2	Master
Mexico	2	Undergraduate & Postgraduate
Norway	2	Undergraduate & Master
Switzerland	2	Undergraduate & Postgraduate
Taiwan	2	Master
Thailand	2	Undergraduate & Master
Turkey	2	Master
Greece	1	Master
Hong Kong	1	Postgraduate
Ireland	1	Master
Israel	1	Postgraduate
Japan	1	Postgraduate
New Zealand	1	Undergraduate & Master
Russia	1	Undergraduate & Master
Singapore	1	Undergraduate

Nanowerk had provided a matrix or cross-tabulation between country and level of education, which is presented in Table 4.8 below. It can be concluded here that even though the directories that are being maintained by different organisations are not consistent, the global community can be observed to be moving toward establishing nanotechnology as a proper field of study. The main players or drivers of educating the workforce are being spearheaded by the developed nations, like USA, UK, Australia, and Germany to name but a few, with some developing countries following suit, like India.

Table 4.8. Listing provided by Nanowerk according to countries and course levels.

Country	Level of Education				TOTALS
	Bachelor	**Master**	**Other**	**Ph.D.**	
Australia	13	4	2	-	**19**
Austria	-	1	-	-	**1**
Belgium	-	3	-	-	**3**
Brazil	-	2	-	-	**2**
Canada	11	2	1	1	**15**
Czech Republic	1	-	-	-	**1**
Denmark	3	3	-	3	**9**
Egypt	-	1	-	-	**1**
Finland	-	1	-	-	**1**
France	-	9	-	1	**10**
Germany	11	16	1	2	**30**
India	2	13	3	4	**22**
Ireland	2	1	-	-	**3**
Israel	-	1	-	1	**2**
Italy	-	4	2	1	**7**
Netherlands	1	5	-	1	**7**
New Zealand	2	1	-	-	**3**
Norway	1	3	-	1	**5**
Poland	1	1	-	-	**2**
PR China	-	1	-	1	**2**
Singapore	-	-	1	2	**3**
South Korea	-	1	-	-	**1**
Spain	1	5	-	-	**6**
Sweden	-	6	-	-	**6**
Switzerland	1	4	-	-	**5**
Turkey	-	2	1	1	**4**
UK	6	32	1	1	**40**
USA	7	18	24	18	**67**
TOTALS	**63**	**140**	**36**	**38**	**277**

4.3.2 Nanotechnology Education in Malaysia

When compared to Malaysia, Wikipedia identified two courses being offered, which are shown in Table 4.9 below. It is interesting to note that both these courses are offered at the undergraduate level, and they are being offered by private institutions of higher learning. With regard the approaches taken by these institutions, MMU has approached the subject of nanotechnology from the engineering perspective, while MUST has taken the science and management route.

Table 4.9. Courses offered in Malaysia as listed by Wikipedia.

Name of Institution	Level of Education	Name of Degree
Malaysia Multimedia University (MMU)	Bachelor Degree	Electronic Engineering majoring in Nanotechnology (Nano-Engineering)
Malaysia University of Science & Technology (MUST)	Bachelor Degree	Science in Nanoscience & Nanoengineering with Business Management

An online search directory related to education (http://www.uniguru.com), it was discovered that there are six courses that are being offered at various levels here in Malaysia. The description of these courses is shown in Table 4.10 below.

Table 4.10 Nanotechnology courses offered in Malaysia.

No.	Name of Institution	Level of Education	Name of Degree
1.	Malaysia Multimedia University (MMU)	Bachelor Degree	Engineering (Hons) Electronics majoring in Nanotechnology
2.	Universiti Teknologi	Master of Science	Advance Material and Nano Technology (By Research)
3.	Mara (UiTM)	Doctor of Philosophy	Advanced Material and Nanotechnology (PhD)
4.	Universiti Putra Malaysia	Master of Science	Physics - Nanosciences
5.	(UPM)	Master of Science	Advanced Materials Engineering Nano-Materials and Nano Technology (with thesis)
6.		Master of Science	Nanobiotechnology
7.		Doctor of Philosophy	Physics - Nanosciences (PhD)
8.		Doctor of Philosophy	Nanobiotechnology (PhD)
9.		Doctor of Philosophy	Advanced Materials Engineering Nano-Materials and Nano Technology - PhD (with thesis)

10.	Universiti Malaysia	Master Degree	Surfaces and Nanostructures by Research
11.	Sarawak (UNIMAS)	Doctor of Philosophy	Surfaces and Nanostructures (PhD)
12.	Malaysia University of Science & Technology (MUST)	Bachelor of Science (Hons)	Nanoscience and Nanoengineering with Business Management
13.	Akedemi Tentera Malaysia	Master of Science	(Electric and Electronics Engineering) - Nanotechnology (By Research)
14.	(ATMA)	Doctor of Philosophy	(Electric and Electronics Engineering) - Nanotechnology (By Research)

4.4 Specific Evidences

4.4.1 Infrastructure

Nanotechnology is high tech industry, which the setup capital very high. For example, the packaging industry is worth RM40-50 million, while Silterra is USD2.5 million, even though they are same size industry. Furthermore, Infineon is RM600 million and expands significantly. Another German company is coming in, and also the TSMC from Taiwan, which is the biggest microchip producer. Singapore moving to biotech, electronics sold to Middle East countries. Therefore, with the right strategy, for example establishing the infrastructure, the companies can make profit.

4.4.2 Organisational Capabilities

The nanotechnology industry is definitely equipment dependent. Without the proper equipment, research work in nanotechnology cannot even take-off. These equipment and scientific machines need a certain level of quality in the reagents.

During the economic downturn, Silterra was supposed to collapse, (like in Germany Ziemen). High tech industry collapses when too matured. Like computer, it keeps moving, and the latest technology needs to be followed. Multicore is 65nm in chips. Highest is 16 cores.

Microchip issue is reliability at high temperatures. Based on the rule of thumb, the shelf life is 100 hundreds for electronic component. However, facing the heat problem, this life span is reduced. This is becoming a consensus or acceptable rule, though Taiwan and China do not consider this, whereas Intel and AMD perform this reliability check. Nevertheless, the United State and Japan both are very particular, which their yield is higher than 88%, and 100 years shelf life.

4.4.3 Process Alignment

The process alignment should involve more key players such as MIGHT to seriously initiate study for new industry to come into Malaysia, in order to determine whether the industry is viable. For example, the Nanoherb is a business opportunity. However, the role should enhance on the technology focused since the current herb is still traditional, Therefore, if we move to nano, it becomes modern medicine. The application of the herbs, for brain cancer, H1N1, and HIV should significant results if we changed to nano, we would not need large tablets, which are mostly fillers; which we consume less. The brain cancer can be cured after 10 days. Another is silicon carbide tube, embedded with bone implants to make lighter bone implants. Process alignment through the collaboration is very critical in order to ensure nano can benefit medical fields.

4.4.4 Collaborative Supply

Since nanotechnology is equipment dependent, one can tell whether a lab is nanotechnology capable by looking at equipment. Nanotechnology needs high quality water and electricity. Exemplars that are Infineon and Silterra cannot move to the nano-scale, they are still at micro level. Nanotechnology requires separate set of equipment. 0.13 (130 nanometres) need to move to 0.09 at Silterra. The lithography equipment can handle, but other equipment has not been upgraded. We need to plan beforehand during facility set up. 1 micron to 0.5, each range has different cost. For example pattern transfer equipment from 1micron to 0.5 one system costs RM20 million, 0.5 to 0.13 RM50 million. It should be noted that nanotechnology is RM100 million over. Microelectronic business need to decide the right technology at the right time.

In terms of the standard and quality, SIRIM leads the way for standards. In Taiwan, a nano-product needs to be certified before it is classed as a nano product according to established standards. They also have kits for educating the public. In China, they teach nanotechnology at primary school level.

In addition, in terms of the collaborative partners, Russia was consulted and technology evaluated by the respondent, which was placed directly under the Prime Minister of that time (Tun Mahathir). The military satellite technology had cost the government USD200 million to take over, but the evaluation resulted in a non-agreement because of the lack of honesty and sincerity on the part of the Russian counterparts.

The supply chain in nanotechnology in Malaysia, a number of 11-12 companies that are nano-material based. For example, shoes are wrapped in silver particle power, which will be shiny for a long time. Particle based material. The country that survives is Iran, which can produce almost everything, including scientific equipment. Iran's nanotechnology is great, in which the education system plays a pivotal role. Therefore, the right education system will make the country prosper. Similar to Germany, in which the children at primary schools education have been specialised to nanotechnology.

4.4.5 The Collaborative SCM in semiconductor industry

The manufacturing companies have been the pioneer in developing SCM in many years. Due to dynamic consumer demand and global competition, SCM has played a big role particularly managing the companies' value chains collaboratively. In this study, an attempt is made to understand the collaboration of SCM in the nanotechnology industry. The semiconductor industry has been selected to its nature to technology intensive and most of the valuable operations work in collaborative manner.

4.4.6 Description of Wafer Fabrication Supply Chain

The respondent had talked about the wafer fabrication supply chain, which is unique when compared to other manufacturing supply chains. Firstly, the respondent had given several graphical illustrations in order to assist with the explanation of the wafer fabrication supply chain. Then a short description was given for each picture, which is shown below. Figure 4.1 shows examples of wafers containing the microelectronic circuits.

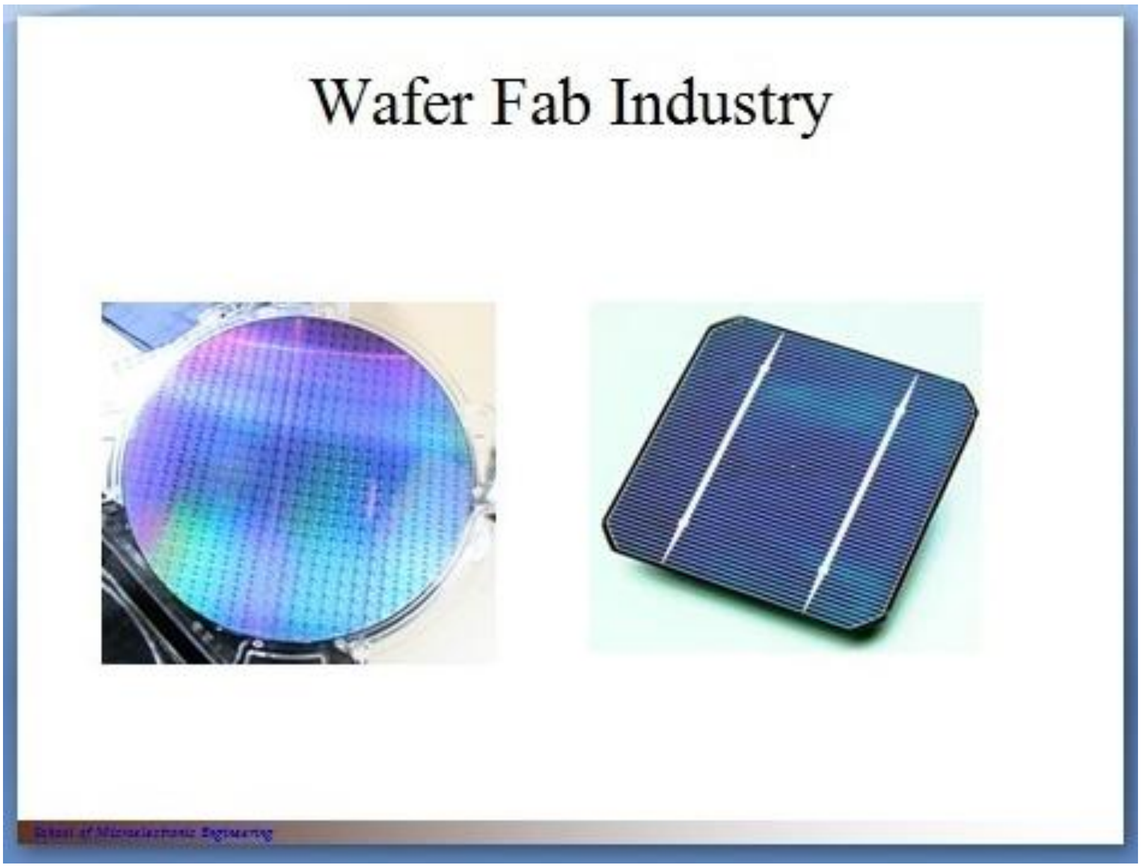

Figure 4.1. Example of wafers given by the respondent.

The respondent described the supply chain as being highly specialised, meaning that each actor within the supply chain is not numerous. Figure 4.2 below shows the initial material that is required for the wafer fabrication industry. The illustration shows that the starting material can consists of, such as:

1. Silicon
2. Germanium
3. Silicon-Germanium compound
4. Gallium-Arsenic compound
5. Indium-Gallium-Arsenic compound
6. Indium-Arsenic compound

These compounds form the starting material for wafer fabrication and the respondent had stressed that the quality and purity of the starting material is of paramount importance. Normal wafer fabrication would require a fairly high level of purity, more so when dealing with fabrication at the nano-scale level. Because of this, the respondent had stated that for nano-scale wafer fabrication, there are only a handful of high quality starting material suppliers in the whole world.

The respondent mentioned that there are three or four suppliers capable of producing the required standard of starting material, but did not identify the names. The respondent, however, mentioned that these suppliers are located overseas, which is due to the geographical availability of the sand material that only exists in certain parts of the world.

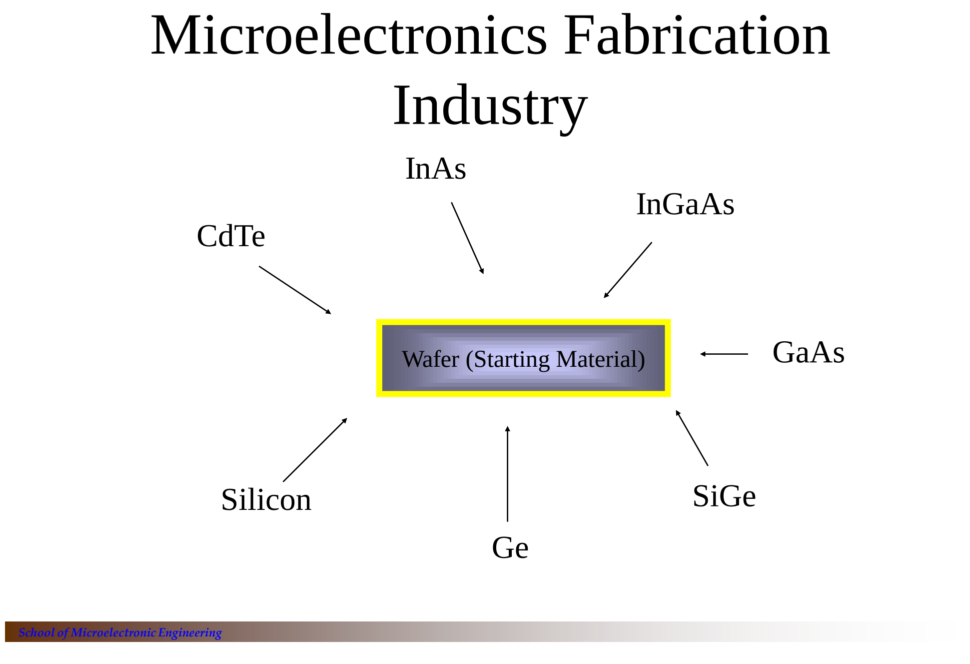

Figure 4.2. The starting raw material for the microeletronics wafer fabrication industry.

From the list of starting material, it can be observed that two of the seven are pure periodic table elements, namely Silicone and Germanium, while the rest are compounds made up of elements within the similar group with Silicone.

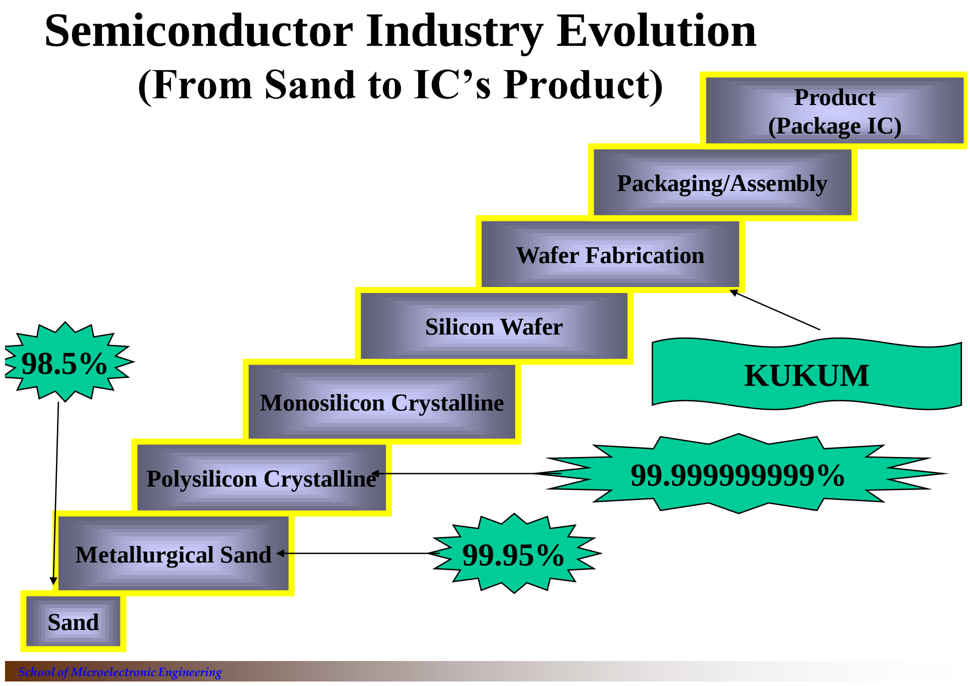

Figure 4.3. The overall supply chain of the microelectronics wafer fabrication industry.

The respondent described the supply chain (Figure 4.3) starting with the raw sand suppliers which mine and quarry the sand from locations from all over the world. These locations are restricted geographically because of the availability of the starting sand. This sand is not the everyday kind of sand, since it has to be of a certain grade and quality, as well as purity.

The sand is then transformed in several steps. Firstly, the 98.5% pure sand is processed to become metallurgical sand, which needs to be of 99.95% purity. This metallurgical sand is further processed to become the poly-silicon crystalline reagent, which has to be at least 99.99% pure. This multiple silicone compound is then processed to become mono-silicon crystals, which is then transformed into the silicon wafer.

The next step is the wafer fabrication. This is the stage where the research centre enters the supply chain, as shown in Figure 4.4 below. Continuing on the same supply chain, the next step of wafer fabrication is the packaging/assembly stage. Finally, this is then followed by the Integrated Circuit packaging of the product. All this stages will be briefly described later on in this section.

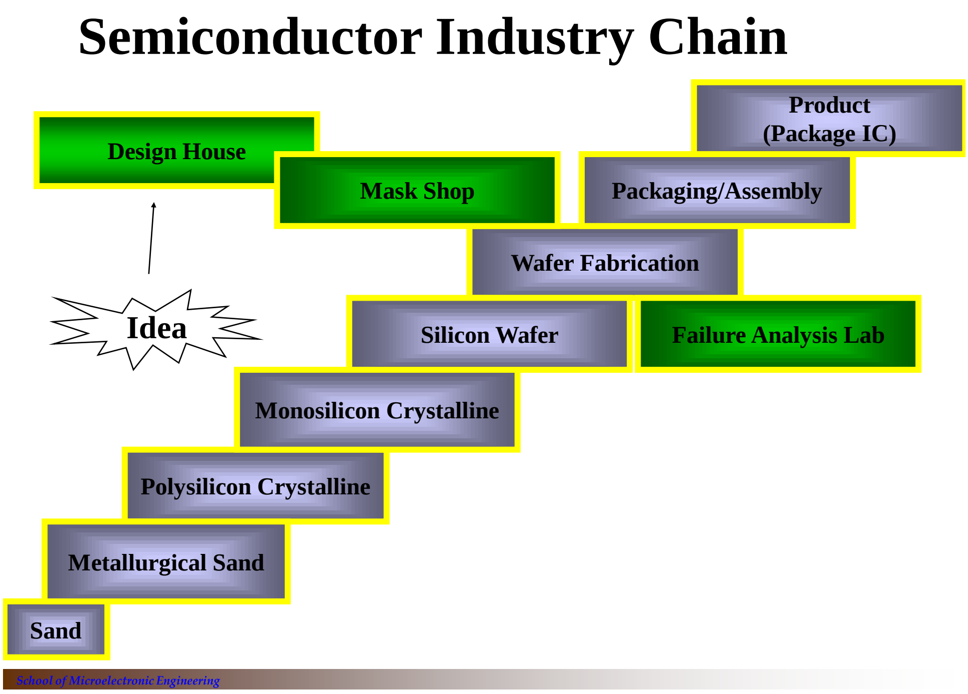

Figure 4.4. The role of the research centre in the microelectronic wafer fabrication industry.

Figure 4.5 below shows the initial stage of the research centres' role in the industry supply chain. Initially, a potential idea or solution is proposed and tested in the design house. Here, various matters need to be considered before solidifying the idea for use in the other stages. These considerations include:

1. Analogue
2. Digital
3. Mix-signal
4. RF
5. MEMS/NEMS
6. Power devices

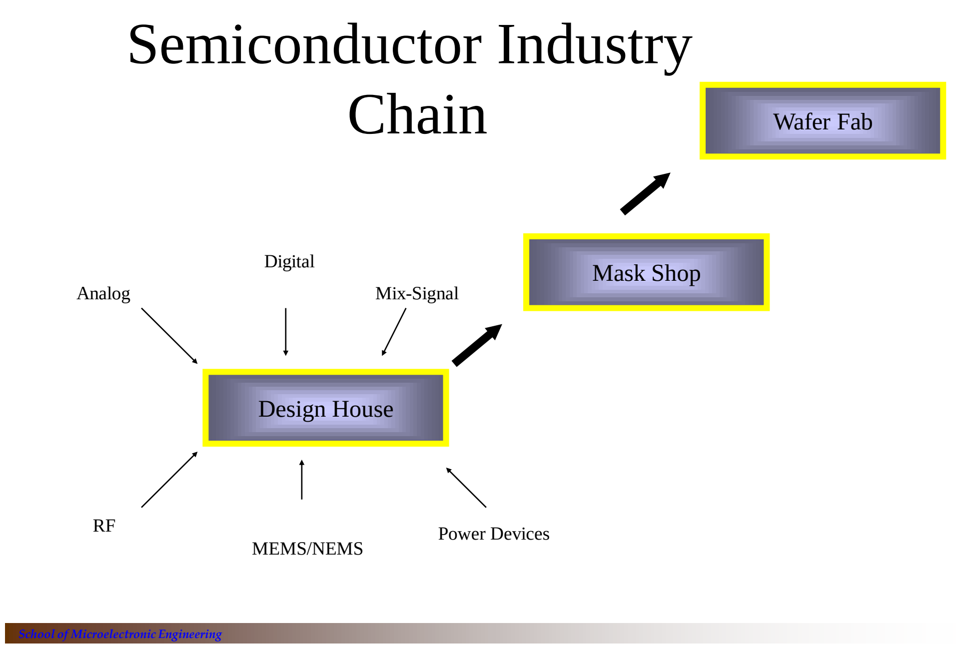

Figure 4.5. The initial stage of the research centres' role in the microelectronic wafer fabrication industry.

Next, the wafer fabrication stage is described in Figure 4.6 below. This figure details out the modules required for wafer fabrication. It must be noted here that the wafer fabrication process must go through a quality control and assurance cycle, which involves the packaging and failure analysis processes. The wafer fabrication process has been identified to occur in the manufacturers of wafers. The modules in the wafer fabrication process which are:

1. High temperature process
2. Metalisation
3. Metrology
4. Lithography
5. Integration
6. Dry etching
7. Wet processing
8. Thin film
9. Implantation
10. Electrical test/Reliability

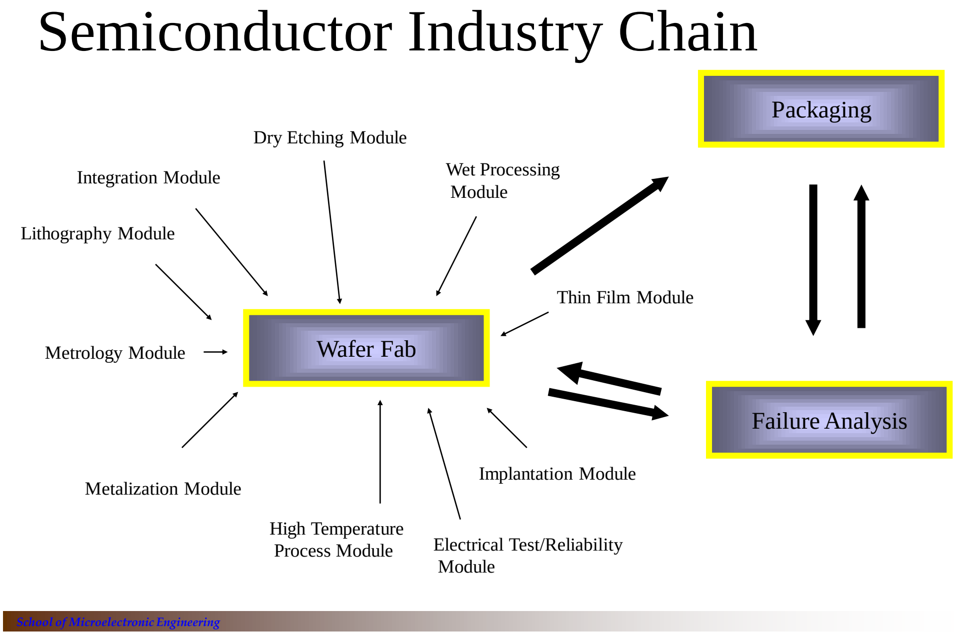

Figure 4.6. The modules within the wafer fabrication process.

The next figure supplied by the respondent is regarding the packaging of the wafer (Figure 4.7 below). This stage involves the following modules:

1. Wafer mounting
2. Wafer dicing
3. Pick and place
4. Moulding
5. Trimming
6. Shear/Pull test
7. Wire bonding
8. Electrical test
9. Environmental test
10. Marking

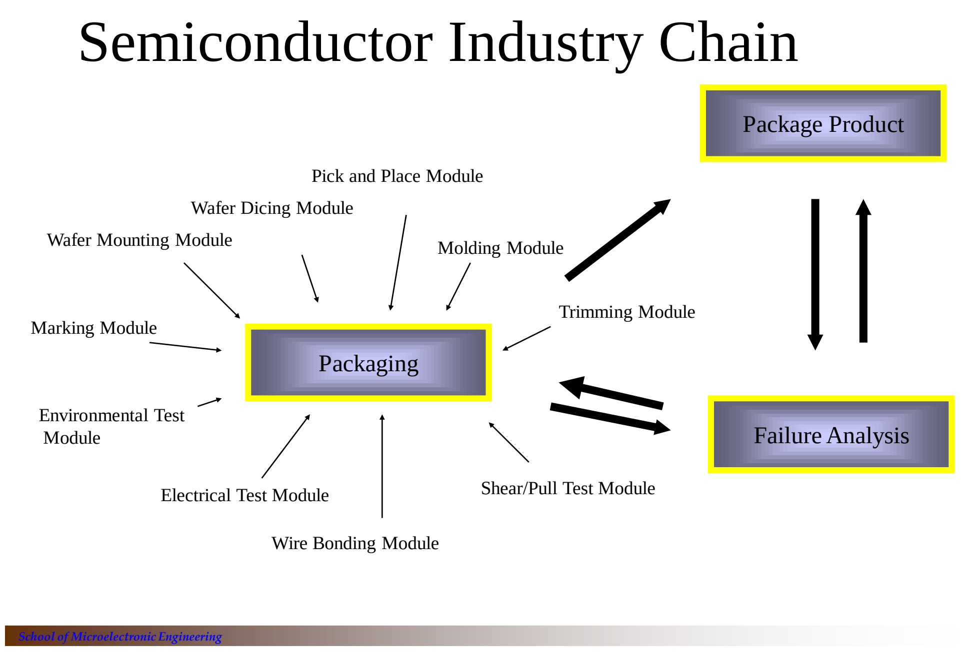

Figure 4.7. The modules contained in the packaging stage of the microelectronic wafer fabrication industry.

The failure analysis stage contains several modules, which are listed below (and shown in Figure 4.8 below):

1. Physical observation
2. Optical observation
3. Polishing/Cross sectioning
4. Dry etching
5. Wet etching
6. Electrical functional test
7. Open/Short test
8. Advance test

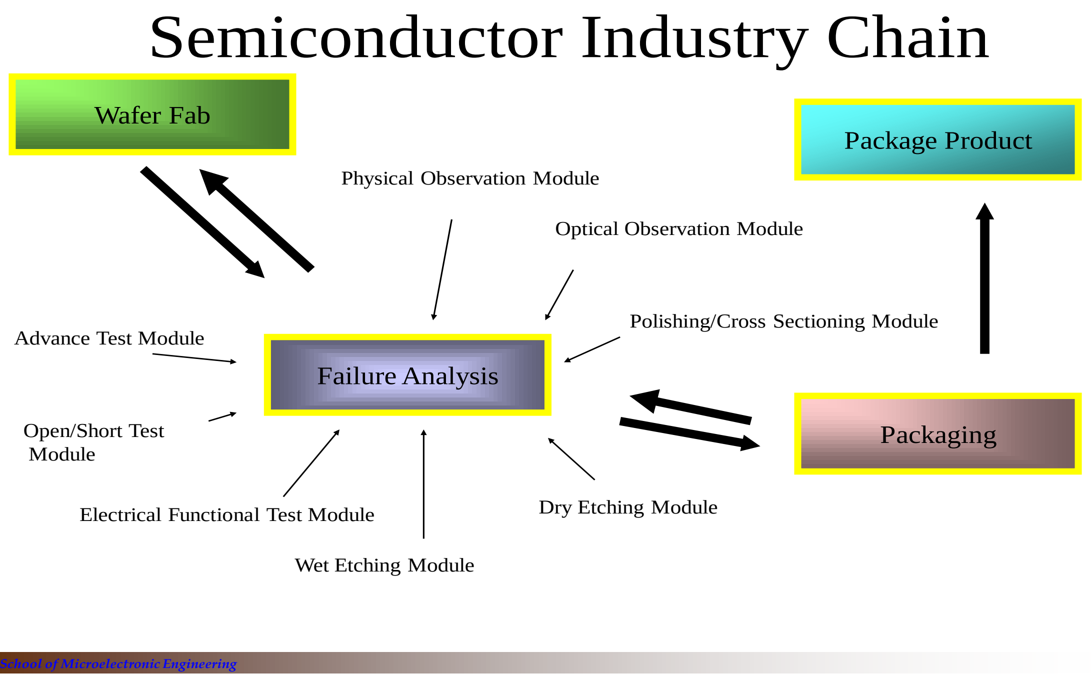

Figure 4.8. The failure analysis stage contains several modules.

Finally, the finished product is then packaged for distribution to electronics assemblers, and eventually sold to retailers for sales purposes. Therefore, from the description provided by the respondent, the microelectronic wafer supply chain players can be identified as:

1. Raw material suppliers
2. Sand processors
3. Wafer fabricators
4. Electronics assemblers
5. Distributors/Retailers

4.5 Chapter Summary

This chapter presented the findings of the survey performed on secondary sources as well as the interview findings for this research. It was revealed that some headway has been done in trying to promote nanotechnology as a mainstay technology in Malaysia, even though reports had given that nanotechnology is a relatively unknown technology in Malaysia. Initiatives by the government coupled with the drive by the private sector, it can be observed that nanotechnology can be a promising technology for Malaysia to excel in. The next chapter provides the conclusion and recommendations of the study.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion on Specific Project

As stated in the previous Chapter, the interview had yielded many interesting facts and information. Overall, the research had revealed that nanotechnology in Malaysia is still at an early stage whereby the emphasis has been placed solely on the research and development of the technology and there is a lack of focus on the management of the supply chain in this industry, what more of collaboration within this supply chain. The outcome of this research had revealed also that the nanotechnology industry spans across many fields of knowledge as the starting base for nanotechnology, and as a consequence, the applications of nanotechnology spans across various industries, including electronics, agriculture, pharmaceuticals, and many more. It is because of this that there are several weaknesses within the nanotechnology industry that needs further exploration. There is also the need for the introduction of collaboration within the nanotechnology industry in order to facilitate its growth and development since it is the next major technology that has a great impact on the nation's well-being and would affect our everyday lives.

5.2 Recommendations

The nanotechnology costs billions, and can be commercialised to overcome these costs many times over. It is because of this simple fact that it needs to be supported by the sufficient knowledge in the area, and needs a solid system of education for supporting and producing capable human capital, which is paramount. Furthermore, the government support and political influence are important to ensure the sustainability of the industry. The collaborations of SCM are in terms of the techniques and methodology, and application, ultimately to achieve the national interest, organisation interest, and personal interest.

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APPENDIX – RESEARCH OUTPUT

Papers presented at:

1. **The 2nd International Conference on Logistics and Transport (ICLT) 2010, 16 - 18 December 2010, Rydges Lakeland Resort Hotel, Queenstown, New Zealand**. This is the second international conference organised by Thai Researchers' Consortium of Value Chain Management and Logistics (Thai-VCML) Chartered Institute of Logistics and Transport (New Zealand), and Lincoln University (Canterbury, New Zealand). The conference focuses on research in the fields of operations, logistics, value/supply chain, transportation management, and operations research. The conference seeks to be a great opportunity for operations, logistics, supply chain, and transportation researchers and practitioners to share ideas, research findings and future directions of researching and teaching. The ICLT will be held annually and rotated to other universities or organizations located in the Asia-Pacific Region.

2. **Third International Nanoscience and Nanotechnology Conference 2011 (NANO-SciTech 2011), 2 - 3 March 2011, Intekma Resort and Convention Centre, Shah Alam, Selangor, Malaysia**. In order to promote this gathering of scientists and academicians, Institute of Science, Universiti Teknologi MARA (UiTM) will organise its Third International Nanoscience and Nanotechnology Conference 2011 (NANO-SciTech 2011). The NANO-SciTech 2006 has been organised for the first time in 2006 and about 180 participants from national and international level have been participated. Almost 230 participants from national and international level have been participated in the NANO-SciTech 2008. NANO-SciTech 2011 is a meeting point to encourage scientists and academicians around the world to meet and discuss their advances and inventions in this new century. This is also due to the overwhelming response received from local and international participants from the previous international conference.