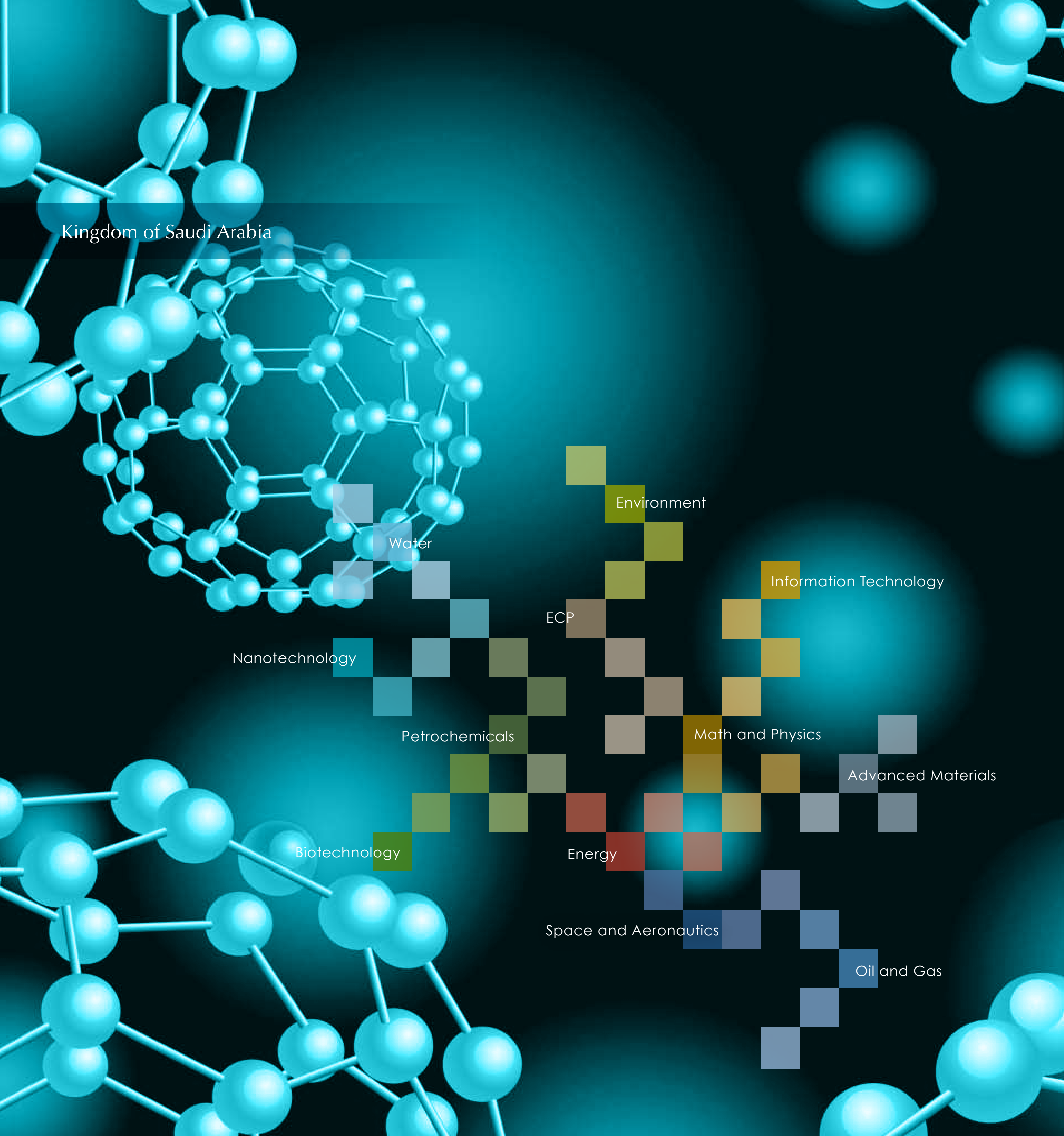
Kingdom of Saudi Arabia



Strategic Priorities for Nanotechnology Program

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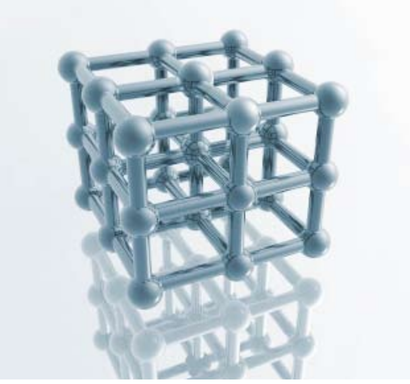

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Executive Summary

The National Policy for Science and Technology, approved by the Council of Ministers in 1423 H (2002 G), defined 11 programs for localization and development of strategic technologies that are essential for the Kingdom>s future development. This is the plan for one of these programs, the National Nanotechnology Program.Nanotechnology has recently become a prominent area of research. Outlines of fabrication methods have been laid out and a significant number of applications have been identified. Advanced nations have quickly reacted to the rise of nanotechnology, committing considerable resources to ensure that they benefit from this technology. Saudi Arabia intends to take part in this international effort.
To establish a position for itself among the benefactors of this technology, Saudi Arabia is coordinating its efforts at a national level. This strategic plan is intended to ensure that efforts are coordinated throughout the kingdom. It also is intended to provide a clear picture of how resources will be deployed and used to maximize return on investment.

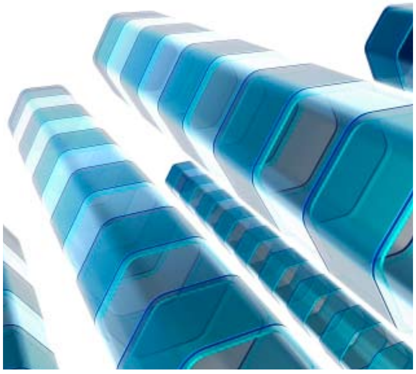
Mission and Vision

The Mission of the National Nanotechnology Program is to ensure that the Kingdom is a major player within the international community in the research and development of nanotechnologies. By taking a collaborative and interdisciplinary approach to nanotechnology, the plan will foster academic excellence and ensure that world-class research and development facilities are available to all parts of the economy, from academic institutions to industry, with a strong focus on supporting the future economic strategy of the Kingdom and transferring technologies from the research community to industry.
The Vision of the National Nanotechnology Program is to create a multidisciplinary program leveraging all branches of science in order to build competence and capability in nanotechnologies that will help to ensure the future competitiveness of the Kingdom.

Stakeholders

The stakeholders in the National Nanotechnology Program are:

- KACST.
- Universities (existing and future).
- Research Institutes (existing and future).
- Centers of Excellence (existing and future).
- Ministries and other government organizations.



- Local industry (and local operations of multinational companies).
- Members of public.

Strategy Components

Several key initiatives are required to foster the growth of nanotechnology in the Kingdom. These include:

- Strengthening academic research.
- Improving infrastructure.
- Linking research with economic and industrial strategy.
- Creating an international collaboration plan.
- Creating a management plan.
- Developing health, safety, and standards/processes plans.
- Strengthening education and workforce plans.
- Developing a commercialization plan.

Research Areas

There are three broad nanotechnology research areas in which the Kingdom will need to develop competence:

- Synthesis and characterization of nanomaterials.
- Quantum structure and nanodevices.
- Modeling and computations of nanostructure.

Areas that are strategically important to the Kingdom and are expected to benefit from the National Nanotechnology Program include:

- Improved desalination.
- Enhanced catalysis.
- Corrosion resistance.
- Monitoring nanodevices.
- Renewable energy such as solar cells.
- Enhanced oil recovery.
- Enhanced well productivity.
- Developments for deep drilling.
- Medical diagnosis & drug delivery.
- Electronic, and Photonic nanodevices, and MEMS/NEMS.

Background on Nanotechnology

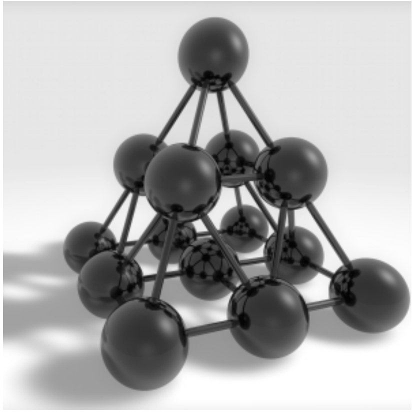
Nanotechnology Definition and History

Nanotechnology is a term that describes the field of science that studies and manipulates the properties of materials at a scale of less than 100 nanometers. At this size particles display unusual properties and products can be fabricated and tailored to achieve significantly better properties than can be achieved by manipulating materials on a larger scale.

Nanotechnology spans a significant number of scientific disciplines and some of the most exciting findings are at the junctions of different scientific disciplines, such as chemistry and biology. Hence multi-disciplinary approaches are often required to create innovative breakthroughs.

Nanotechnology is a relatively new discipline, with a popular following since the early 1990s. However, scientists have been working in this area for much longer, without actually labeling it as "nanotechnology". But due to the development of specialized tools in the 1980s such as atomic force microscopy (AFM) and scanning probe microscopy (SPM), scientists have a much better understanding of how to manipulate materials to achieve the desired effects.

This ability to manipulate materials on the nanoscale to create a host of different properties (heat resistance, greater strength, improved electrical conductivity) is being exploited in almost every industry. Although the discoveries in the field are still at the very preliminary stage, it is thought that nanotechnology has the power to revolutionize many aspects of current technology.



The Nanotechnology Market

After ten years of research and development, a highly developed supply chain and stable commercially available nanomaterials are finally enabling higher value-added applications. Recently the number of producers of nanomaterials has decreased as consolidation has increased and multi-national chemical companies now dominate the market. Today, most of the nanomaterials heralded just a few years back as new high-value materials are quickly taking on a bulk commodity stature.

While this commoditization and consolidation means that little money remains to be made by producing nanomaterials, the ability of these nanomaterials to enable higher-value products will lead to a US$1.5 trillion market by 2015. The highest growth rates will be in the healthcare and pharmaceutical sectors, but other many niche applications also have the potential to grow into very significant markets.

It is against this backdrop that the strategic plan for the introduction of nanotechnology research, development and commercialization in the Kingdom of Saudi Arabia is presented. As the field is still relatively new, there is still ample opportunity for nanotechnology to contribute to the future economy of the Kingdom. The key will be ensuring that resources are carefully deployed and effectively used to maximize the return on investment. The aim of this strategic plan is to provide the framework for this.

The Nanotechnology Market

Public Funding

Thirty five countries have announced the development of national nanotechnology initiatives and have appropriated funding. It is estimated that up to the year 2006, the combined amount of government granted funds for supporting nanotechnology research worldwide is US$24 billion. Table 1 below shows government funding for nanotechnology by country.

Background on Nanotechnology

Table 1: Global Government (Public) funding of nanotechnology 1997-2007

Global Government (Public) funding of nanotechnology 1997-2007											
($m)	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Government Spend											
W.Europe	126	151	179	200	225	400	1150	1495	1794	2099	2414
%chng yoy		20%	19%	12%	13%	78%	188%	30%	20%	17%	15%
Japan	120	135	157	245	465	720	800	960	1152	1325	1524
%chng yoy		13%	16%	56%	90%	55%	11%	20%	20%	15%	15%
USA	116	190	255	270	465	697	1074	1149	1264	1354	1449
%chng yoy		64%	34%	6%	72%	50%	54%	7%	10%	7%	7%
ROW	70	83	96	110	144	293	454	562	730	756	806
%chng yoy		19%	16%	15%	31%	104%	55%	24%	30%	4%	7%
Total	432	560	688	826	1300	2112	3481	4166	4941	5535	6192
%chng yoy		30%	23%	20%	57%	62%	65%	20%	19%	12%	12%

In 2001, there was a dramatic increase in nanotechnology funding in the United States (US) and Japan, which represented the launching of these countries' National Nanotechnology Initiatives. In 2003, the EU's funding increased dramatically with the launching of their nanotechnology initiative in the form of the Sixth Framework.

In absolute dollar terms, the 27 countries constituting the European Union (EU) have allocated the most to nanotechnology research and development (R&D). The EU is followed closely by the US and Japan. In 2006, the rest of the world (RoW) combined spent nearly half of what the US and Japan spent individually on nanotechnology.

Discussing government funding in absolute dollar terms only tells part of the story. One must look at the level of funding per capita to get a better picture of the level of commitment taken by governments in developing nanotechnology. Table 2 below shows nanotechnology funding per capita for a selection of countries and regions.

Table 2: Nanotechnology Funding Per Capita

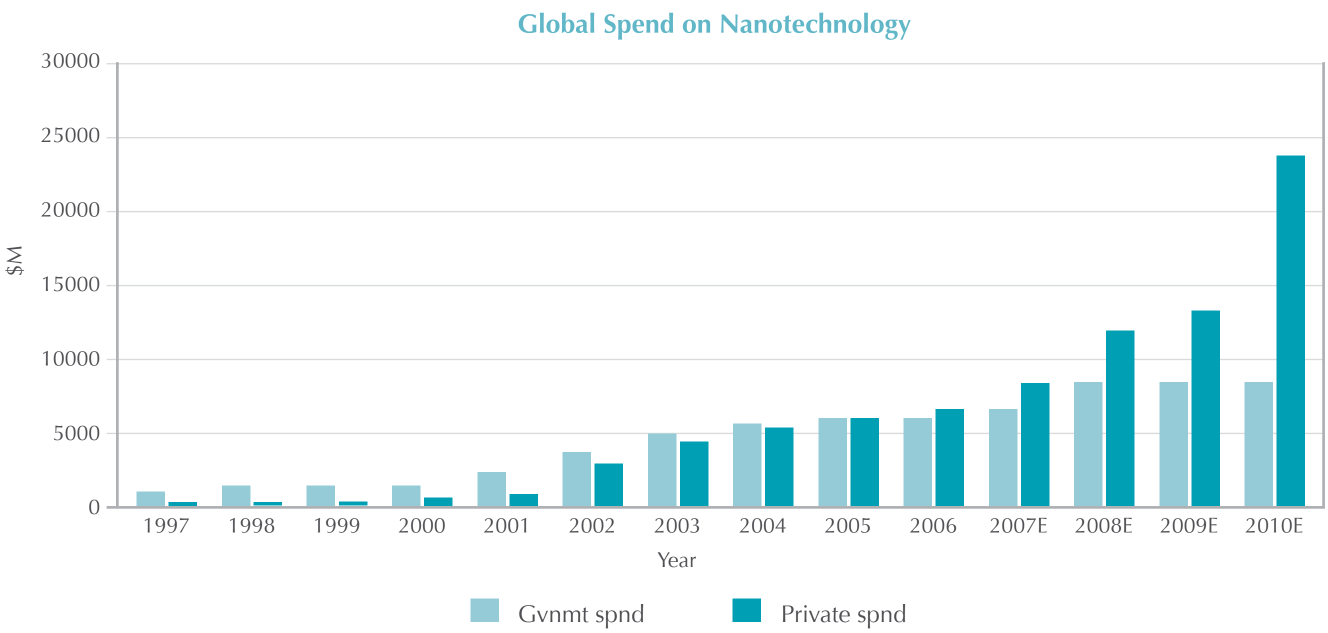
Nanotechnology Funding Per Capita						
		2003	2004	2005	2006	2007E
	Pop.04					
W.Europe	456 million	2.5	3.3	3.9	4.6	5.3
Japan	128 million	6.3	7.5	9	10.4	11.9
USA	293 million	3.7	3.9	4.3	4.6	4.9
ROW	5519 million	0.1	0.1	0.1	0.1	0.1
Global	6396 million	0.5	0.7	0.8	0.9	1

Private Funding

The development of nanotechnology in any country or region begins with a government supported nanotechnology initiative. This lays the foundation for businesses and industry to support and fund the research, which leads to commercial products. As figure 1 indicates, while private funding initially lagged behind public funding for nanotechnology, within a few years private funding is projected to far eclipse government expenditures.

The US leads in private funding of nanotechnology due in part to their highly developed venture capital market. However, both Europe and Japan are quickly catching up.

Figure 1: Total Global Spending on Nanotechnology including both Private and Public Funds



Nanotechnology R&D Indicators

Overview

Nanotechnology is a multidisciplinary field that relies on new theoretical and technical developments in a broad range of other disciplines, including: materials science, applied physics, physical chemistry, electrical engineering, optics, and instrumentation. The overall field, "nanotechnology", as well as sub-topics, were defined in close consultation with KACST researchers and other KSA stakeholders. Keyword terms derived from KACST strategic planning documents were used to query publication and patent databases.[2] The KSA nanotechnology program identifies three nanotechnology subtopics: quantum structure & nano devices, nano materials & synthesis, and computational modeling & theoretical analysis of nano systems. Nanotechnology is a fast moving field, so the scope of this study was restricted to only recent publication (2006-2007) and patent (2002-2006) activity in these three fields.

There is general agreement that publications and patents strongly correlate with scientific research capacity, although publication and patent counts alone do not fully represent the quality or scope of research. Nonetheless, publication and patent activity have long been used as indicators for knowledge creation and research output.[3] Several indicators are presented below. These include forward citations (the frequency at which publications and patents are cited by others), which is a measure of impact, and co-authoring relationships, which are an indicator of scientific collaboration.

Nanotechnology Publication Activity

Between 2006 and 2007, there were 32,661 articles published worldwide in nanotechnology fields related to KSA research priorities.[4] The United States was the world's largest producer of related articles, generating 8,657 articles over this time period. The People's Republic of China was second, producing 6,124 articles followed by Japan and Germany with 3,032 and 2,581 articles respectively. Saudi Arabia was tied for the 61st in a ranking of the largest producers of nanotechnology publications, producing 14 articles. Figure 2 shows the number of publications produced by select countries over this time period.[5]

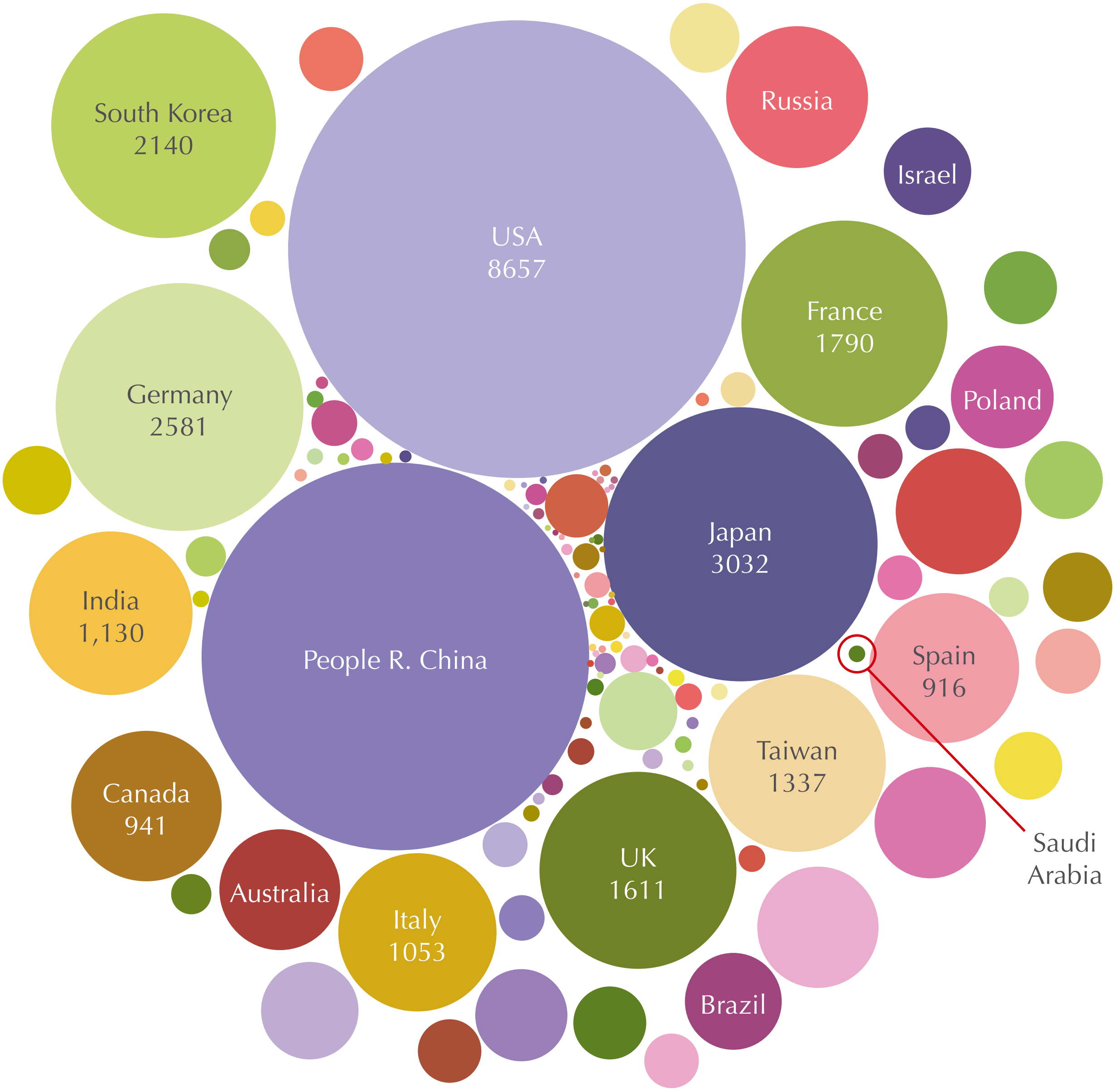
2 ISI Web of Science and Delphion were queried for scientific publication and U.S. patent application data, respectively. The ISI Web of Science is a database of peer-reviewed articles in major scientific journals from around the world. Delphion is a searchable database of global patent activity, including the U.S. Patent and Trademark Office (USPTO). The USPTO is one of the world's major granters of patents and it has been argued that the U.S. market is so large that most important inventions from around the world are patented there.

3 Seminal research in the use of publications as a measure of scientific productivity includes A.J. Lotka, "The frequency distribution of scientific productivity," Journal of the Washington Academy of Sciences, vol 16 (1926); D. Price, Little Science, Big Science, (New York: Columbia university Press, 1963); J.R. Cole and S Cole, Social Stratification in Science, (Chicago: The University of Chicago Press, 1973); J. Gaston, The reward system in British and American science, (New York: John Wiley (1978); and M.F. Fox, "Publication productivity among scientists: a critical review," Social Studies of Science, vol 13, 1983.

4 Throughout this report, "nanotechnology" refers only to the subset of nanotechnology identified in the KSA nanotechnology program.

5 A publication is assigned to a country if any of the publication's author's affiliations are located in that country. Because publications often have multiple authors, a single publication may be assigned to multiple countries. Aggregate figures, such as total global publication output, count each publication only once, but adding up sub-totals may yield a result larger than the reported total due to multiple counting.

Figure 2: Nanotechnology publications by selected countries



As shown in table 3, quantum structure and nano devices accounts for the largest share of nanotechnology related publications followed by nano materials and synthesis, and computational modeling and theoretical analysis of nano systems.

Table 3: Nanotechnology Sub-Topics (2006-2007)

Sub-Topic	Publications
Quantum Structure and Nano Devices	16127
Nano Materials and Synthesis	15815
Computational Modeling and Theoretical Analysis of Nano Systems	3849

Benchmark Countries

Average publication impact is calculated as the number of citations of articles from a particular country divided by the total number of articles published by authors from that country. For instance, a country that published 50 articles that were cited 100 times would have an average publication impact of two. Between 2006 and 2007, the United States had the highest average publication impact of all countries at 2.40 followed by the United Kingdom (2.09), Germany (2.00), and France (1.76). The average publication impact for Saudi Arabia was 0.57 with 8 citations of 14 articles. By this measure, the nanotechnology articles that are published by authors affiliated with KSA institutions appear to have a lower impact when compared with those from leading countries. Table 4 presents publication and citation counts for benchmark countries.[6]

6 Benchmark countries include global leaders in terms of total nanotechnology output in addition to a list of specific countries provided by KACST.

Table 4: Publication Impact (2006-2007)

Country	Publications	Total Citations	Average Publication Impact
USA	8657	20796	2.40
UK	1611	3363	2.09
Germany	2581	5174	2.00
France	1790	3156	1.76
Italy	1053	1654	1.57
Japan	3032	4504	1.49
South Africa	58	76	1.31
Peoples R China	6124	7954	1.30
South Korea	2140	2741	1.28
India	1130	1302	1.15
Taiwan	1337	1517	1.13
Iran	220	236	1.07
Egypt	82	52	0.63
Saudi Arabia	14	8	0.57
Kuwait	4	1	0.25
United Arab Emirates	8	1	0.13

Of the two most cited articles with authors affiliated with KSA institutions (3 citations each): "Effect of nitrogen reactive gas on ZnO nanostructure development prepared by thermal oxidation of sputtered metallic zinc,"[7] and "Structure and mechanism of the deposition of multilayers of polyelectrolytes and nanoparticles,"[8] the first is a collaboration with Algerian authors while the second is solely by KSA-affiliated authors.

7 Toumiat, A., Achour, S., Harabi, A., Tabet, N., Boumaour, M., Maallemi, M. 2006. Effect of nitrogen reactive gas on ZnO nanostructure development prepared by thermal oxidation of sputtered metallic zinc. Nanotechnology, 17 (3): 658-663.

8 Abu-Sharkh, B. 2006. Structure and mechanism of the deposition of multilayers of polyelectrolytes and nanoparticles. Langmuir, 22 (7): 3028-3024.

Nanotechnology Research Organizations

Several thousand research institutions in more than 110 countries participated in nanotechnology research from 2006 to 2007. As shown in table 5, the three institutions producing the largest number of publications related to nanotechnology R&D are the Chinese Academy of Sciences (1,300), Tsing Hua University (634), and the Russian Academy of Sciences (393). The Chinese Academy of Sciences is the leading producer of publications in all three sub-topic areas.

Table 5: Leading Nanotechnology R&D Organizations (2006-2007)

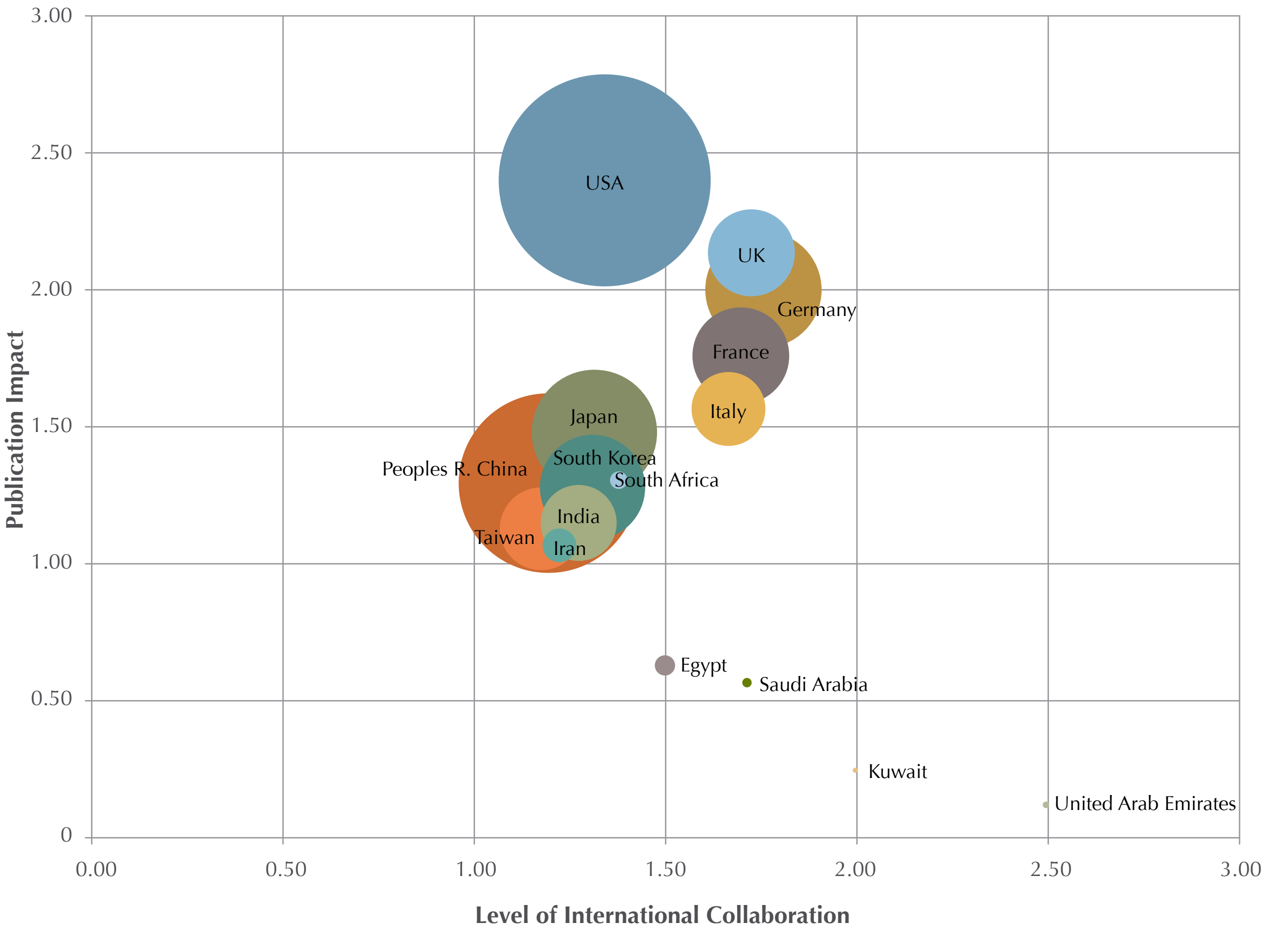
Institution	Total Publications	Average Impact	Quantum Structure and Nano Devices	Nano Materials and Synthesis	Computational Modeling and Theoretical Analysis of Nano Systems
Chinese Acad Sci	1300	1.66	620	695	102
Tsing Hua University	634	1.56	276	361	62
Russian Acad Sci	393	0.74	186	156	75
CNRS	378	2.22	198	173	35
Univ Sci & Technol China	366	1.40	163	193	36
Univ Texas	349	2.48	188	141	57
Natl Univ Singapore	347	1.96	207	134	49
Univ Tokyo	339	1.55	201	120	37
Univ Illinois	302	2.85	162	125	55
Tohoku Univ	289	1.49	164	127	20
MIT	288	3.84	159	105	53
Seoul Natl Univ	285	1.72	155	138	28
Indian Inst Technol	279	1.08	102	166	36
Univ Florida	273	1.42	150	106	52
Beijing Univ Technol	268	0.95	89	170	28

International Collaboration and Publication Impact

For countries with a similar level of publication activity, those countries with a high level of international collaboration also tend to produce publications with a high level of impact. International collaboration is calculated as the average number of countries represented per publication, based on authors' addresses.

Figure 3 below plots a country's level of international collaboration (horizontal axis) against the average impact of its publications (vertical axis). Countries such as the United Kingdom and Germany which show significant international collaborative activity also tend to produce papers with a higher average impact.

Figure 3: International Collaboration and Publication Impact (2006-2007)



KSA Collaboration Activity

As shown in table 6, authors affiliated with KSA institutions collaborated on more than one article with authors from: Algeria (4 publications), and the United States (2 publications). KSA authors also collaborated on single publications with authors from: Egypt, Kuwait, Switzerland, and the United Kingdom.

Table 6: KSA Publication Collaborators (2005-2007)

Country	Number of Publications
Algeria	4
USA	2
Egypt	1
Kuwait	1
Switzerland	1
UK	1

Nanotechnology Journals

Table 7 presents journals with a significant level of publication activity related to KSA nanotechnology sub-fields from 2005-2007.

Table 7: Nanotechnology Patents (2002-2006)

	Journal	Publications
Nano Materials and Synthesis	SURFACE & COATINGS TECHNOLOGY	477
	APPLIED PHYSICS LETTERS	463
	NANOTECHNOLOGY	380
	THIN SOLID FILMS	341
	JOURNAL OF APPLIED PHYSICS	311
	LANGMUIR	306
	JOURNAL OF PHYSICAL CHEMISTRY C	267
	APPLIED SURFACE SCIENCE	256
	MATERIALS LETTERS	247
	CHEMISTRY OF MATERIALS	244

	Journal	Publications
Quantum Structure and Nano Devices	APPLIED PHYSICS LETTERS	863
	PHYSICAL REVIEW B	519
	NANOTECHNOLOGY	499
	JOURNAL OF APPLIED PHYSICS	334
	NANO LETTERS	285
	JOURNAL OF MICROMECHANICS AND MICROENGINEERING	274
	JOURNAL OF PHYSICAL CHEMISTRY C	234
	SENSORS AND ACTUATORS A-PHYSICAL	232
	JOURNAL OF PHYSICAL CHEMISTRY B	222
	LANGMUIR	209
Computational Modeling	JOURNAL OF CHEMICAL PHYSICS	153
	PHYSICAL REVIEW B	147
	JOURNAL OF APPLIED PHYSICS	111
	JOURNAL OF PHYSICAL CHEMISTRY B	98
	APPLIED PHYSICS LETTERS	97
	NANOTECHNOLOGY	93
	JOURNAL OF PHYSICAL CHEMISTRY C	67
	LANGMUIR	62
	IEEE TRANSACTIONS ON ELECTRON DEVICES	54
	JOURNAL OF MICROMECHANICS AND MICROENGINEERING	46

Nanotechnology Patent Activity

Between 2002 and 2006, there were 781 nanotechnology related patent applications filed with the United States Patent Office (USPTO). As shown in table 8, the majority of these (440) listed at least one inventor from the United States.Other countries with a significant number of inventors include: South Korea (100 applications), Japan (96 applications), and Taiwan (55 applications). The most cited nanotechnology related patent application (44 citations): “Articles comprising nanoscale patterns with reduced edge roughness and methods of making same,”[9] listed only inventors from the United States. No nanotechnology related patent applications listed an inventor from Saudi Arabia.

While the majority of the nanotechnology related patent applications are defined as individually owned

Table 8: Nanotechnology Patents (2002-2006)

Country	Nano Materials and Synthesis	Quantum Structure and Nano Devices	Computational Modeling and Theoretical Analysis of Nano Systems	Total
United States	204	362	2	440
South Korea	35	93	0	100
Japan	38	72	0	96
Taiwan	22	45	0	55
Germany	6	13	0	18
China	9	11	0	17
France	3	10	0	12
United Kingdom	7	8	0	10
India	2	9	0	9
Italy	1	4	0	4
Saudi Arabia	0	0	0	0

patent applications (518 applications) by the United States Patent Office, institutions are designated as the patent assignee on a significant number of applications. These institutions, which have a record of invention in information technology fields related to KSA strategic priorities, could be future targets for collaborative efforts.

As shown in table 8, Nano-Proprietary Inc. is listed as the patent assignee on 21 nanotechnology patent applications followed by Nanotex (19 applications), Industrial Technology Research Institute (17 applications), and Samsung Electronics (15 applications).

Table 9: Leading Nanotechnology Patent Assignees (2002-2006)

USTPO Assignee	No. of Patents Apps.
Individually Owned Patents	518
Nano-Proprietary Inc.	21
Nanotex	19
Industrial Technology Research Institute	17
Samsung Electronics	15
Headway Technologies Inc.	10
University of California	8

9 Chou, Stephen Y., Yu, Zhaoning, Wu, Wei, U.S. Patent Application # 20040156108, 2004.

Key Applications of Nanotechnology

Nanomaterials and nanodevices have applications in the fields listed below. These applications represent areas that both demonstrate the breadth of nanotechnology's impact on various industries, and also represent application areas that are attractive to the international community.

Aerospace & Defence

- Lighter and stronger materials for aircraft.
- Improved coatings for radiation protection of electronics.
- New materials for improved weaponry, i.e. armor piecing shells.
- Miniature surveillance devices and systems.

Chemicals & Advanced Materials

- Vastly improved catalysts.
- Improved membranes and filtration.
- Improved paints and coatings for corrosion resistance, scratch resistance and electrical conductivity.
- Improved abrasives for polishing, especially for silicon wafer and magnetic disks.
- Improved lubricants.
- Improved composites.
- New material and nanostructure modelling.
- Thermal insulation.

Energy

- Improved materials for photovoltaics (solar cells) that make them more efficient.
- Improving the catalysts for fuel cells.
- More efficient transmission of power.
- Higher performing batteries.
- Controlling corrosion, friction and wear leading to less energy loss and consumption.
- Improving methods for fuel extraction.

Electronics & Photonics

- Miniaturization of computer processors.
- Improved data storage.
- Improved optical transmission and switching in telecommunications.
- Improved display technologies.
- Miniaturization of actuators.
- Miniaturization of RF by means of MEMS-based devices.
- Miniaturization of sensors.
- Improved detection of liquid and gas using Semiconductor laser.
- Improved quality of lights using new version of LEDs.
- Improved optical components & sensors.

Medical & Pharmaceutical

- Improved drug delivery to target diseases and ailments directly.
- Improved detection, analysis and discovery of diseases.
- Nanoengineered prosthetics with better biocompatibility.
- Improved real time Imaging.
- Improved real time monitoring using Bio MEMS devices.

Water Purification

- Improved membranes for purification and desalination.
- Use of nanocatalysts and magnetic nanoparticles to enable cheaper desalination processes.
- Improved nanosensors for detecting contaminants in water.

Nanotechnology Landscape in KSA

While the current nanotechnology capability within the Kingdom of Saudi Arabia is low compared to other countries that have launched nanotechnology initiatives, recently there has been an increase in nanotechnology R&D at both the academic and industrial level within the Kingdom.

The efforts that are underway are in the early stages and have mainly been the result of incidental work that began independently by individual research groups around the Kingdom as part of other programs. These efforts lack a unifying goal and lack the cohesion of purpose that would result from having a national strategic plan.

Although it is believed that these projects are not far enough along to have generated any tangible capability, they have laid the foundation on which nanotechnology capability within the Kingdom can be built.

Research Activities

Government

Currently, much of the expertise and many of the facilities for conducting nanotechnology research are located at the King Abdulaziz City for Science and Technology (KACST) and the following universities:

- King Fahd University of Petroleum and Minerals (KFUPM).
- King Abdul Aziz University (KAAU).
- King Saud University (KSU).
- King Abdullah University of Science and Technology (KAUST), which will officially open its doors in 2009.
- Other universities such as King Khalid University (KKU), King Faisal University (KFU) & Taiba University).

It is estimated that approximately 30 research projects in the field of nanotechnology have been launched in the Kingdom at the above universities and research institutes. KACST has funded a number of research projects related to Nanotechnology including projects focusing on silicon nanoparticles production, carbon nanotube production, catalyst nanocoating, and other projects on composite materials.

Much of this research has been in materials and synthesis. While the application of this research has often been aligned with the industrial and economic needs of the Kingdom, for instance, looking at improving fossil fuel extraction with nanomaterials, some research has looked at other nanotechnology applications such as:

- Structural materials and coatings.
- Biotechnology.
- Catalysis and membranes.
- Sensors and measurement.
- Electronics and magnetics.
- Energy and environment.

The state of nanotechnology academic research in the Kingdom is expected to change dramatically when King Abdullah University of Science and Technology (KAUST) in Rabigh opens its doors in 2009. KAUST plans to have a lab dedicated to nanotechnology research and this should lead to a significant rise in the number of nanotechnology-related projects undertaken in the Kingdom.

Industry

Industry in the Kingdom is well aligned to take advantage of nanotechnology research. Local companies such as Saudi ARAMCO and Saudi Basic Industries Corporation (SABIC) have devoted resources to conducting nanotechnology research.

It is estimated that these two companies alone have launched more than 20 research projects in the field of nanotechnology. To support this research it is estimated that they have more than 20 PhDs on staff with expertise applicable to nanotechnology research.

Industry research within the Kingdom has been aimed at applying nanotechnologies to improving fuel extraction. However, the research they have conducted has broad applications, including:

- Biotechnology.
- Catalysis and membranes.
- Sensors and measurement.
- Energy and the environment.

International Cooperation

KACST

KACST has already formed research and development partnerships and collaborative programs with some leading international institutions such as:

- The KACST/IBM Nanotechnology Center of Excellence to cover research in water desalination, catalysts for petrochemical applications, and solar energy.
- University of Auckland, focusing on the development of nano light emitting diodes (LEDs).
- MIT/KACST/Al-Faisal University Projects:
  - Nanopatterning of fuel cells electrodes.
  - Enhancement of transport phenomenon using nanofluid.
  - Photoacoustic detection system for the petrochemical industry.
  - Mid-infrared laser for sensing applications.
- University of Minnesota /KACST:
  - Formation of titanium oxide nanotube.
- University of Illinois, Urban-Champain /KACST
  - Development of electrochemical cell used for silicon nanoparticles formation.
- University of Michigan, Ann Urbor/KACST (under review)
  - Using nanoimprint to develop inexpensive solar cells.

- National Academy of Sciences of Belarus, Belarus
- Carbon nanotube production facilities.
- Development, production and installation of a scanning probe microscope.

Universities and Research Centers

KSA universities have been steadily increasing the number of their international partnerships with the hope of broadening their research and expertise. These collaborations include:

- In 2005, King Fahd University of Petroleum and Minerals (KFUPM) sent three faculty members to National University of Singapore to explore and initiate research collaborations.
- In 2007, KFUPM and Massachusetts Institute of Technology (MIT) announced preparations to inaugurate a Scientific Collaboration Agreement in the field of education and scientific research between the Mechanical Engineering Departments of both institutions.
- While still not officially launched, King Abdullah University of Science and Technology (KAUST) announced a partnership between itself and the Indian Institute of Technology, Bombay (IIT Bombay). This partnership will involve collaborative research in many areas related to nanotechnology.
- King Abdullah University of Science and Technology (KAUST) and American University in Cairo (AUC) signed a Memorandum of Understanding to establish collaborative research and academic programs. KAUST and AUC agreed to collaborate in many research areas including nanotechnology and advanced materials.

Industry

Saudi ARAMCO is funding and collaborating with the ARC Centre of Excellence for Functional Nanomaterials in Australia on a four-year research project. The project focuses on the development of catalytic materials suitable for the conversion and hydrogen separation of oil-based liquid petroleum fuels in a membrane reactor system. Saudi ARAMCO also has a contract with Integran Technologies Inc. (Toronto, Canada) for planning, implementing, and carrying out a product development program entitled «Application of Nanotechnology for In-Situ Structural Repair of Degraded Heat Exchangers,» to explore the feasibility of developing in-situ repair for conventional heat exchangers in the Oil & Gas Industry.

Available Infrastructure

KACST

KACST has successfully accomplished the following in regards to nanotechnology infrastructure:

- Completely established and equipped the nanoscopic laboratory.
- Prepared complete design, specifications and facility requirements for the cleanroom and the National Nanotechnology Center (NNC).
- Identified all required equipment for nanoscale processing in the cleanroom with complete specifications.

Universities and Research Centers

Currently, the facilities and equipment for conducting nanotechnology research are located at three Universities. Plans have been made for a fourth university to have an extensive laboratory that can be used for nanotechnology research. These universities are:

- King Fahd University of Petroleum and Minerals (KFUPM).
- King Abdul Aziz University (KAAU).
- King Saud University (KSU).
- King Abdullah University of Science and Technology (KAUST).

While some microscopy tools are currently located at these universities, the numbers are not currently adequate to have a significant impact on nanotechnology research. Most importantly, the absence of ISO-certified and well-equipped cleanrooms (outside the one currently under construction at KACST's NNC) is a key obstacle to conducting further research in nanotechnology.

While there does not currently exist a fully-equipped cleanroom outside of the NNC facility, the three other universities capable of conducting nanotechnology research have some or all of the following equipment:

- Microscopes: transmission electron microscope (TEM), scanning electron microsope (SEM), atomic force microscope (AFM), X-ray diffraction (XRD).
- Process Equipment: chemical vapor deposition (CVD).
- Process Characterization: Surface Profiler.
- Wet Process: Electroplating, Acid Benches.

Industry

Both SABIC and Saudi ARAMCO have some of the most advanced R&D facilities in the Middle East. SABIC's Research and Technology centers in Riyadh and Jubail are the largest in the Middle East. Saudi ARAMCO also has a state-of-the-art research facility that was completed in 2005. The equipment at these facilities is designed to support material science research, which is in line with nanotechnology research. Although the exact type and quantity of equipment at these facilities was not obtained for this plan, we know these facilities contain at least the following equipment:

- Microscopes: SEM, XRD.
- Process Characterization: Surface Profiler.
- Wet Process: Electro plating.

A cleanroom is not part of the facilities at these companies, or any others within the Kingdom.

Knowledge, Education and Training

KACST

KACST has undertaken initiatives to train their own employees, members of other academic institutions, and the general public about nanotechnology. Examples of KACST efforts in this area are listed below:

- KACST organized the first national nanotechnology workshop in January of 2006.
- KACST offered full graduate scholarships for a number of engineers and scientists to pursue their masters and Ph.D. in nanotechnology.
- The National Nanotechnology Center at KACST participated in the annual science and technology week.
- KACST published two special issues of Science and Technology Magazine on nanotechnology.
- KACST has funded several summer training programs in attempt to introduce members of higher educational institutions to nanotechnology research activities.

KACST has also made progress in commercialization, including:

- KACST is in the final planning stage of establishing a nanotechnology incubator.
- KACST is approaching a number of leading international corporations to discuss product development and technology transfer.
- KACST has already approached the major nanotechnology stakeholders in the Kingdom to identify their needs.

Universities and Research Centers

It was the view of the stakeholders of KFUPM, KAAU and KSU that there was so little targeted training and education at their respective universities that it would best be considered zero. As a result, the knowledge base for embarking on a nanotechnology initiative in the Kingdom is currently limited. This is a critical part of the landscape for nanotechnology in the Kingdom that must be strengthened.

Program Strategy

This chapter outlines the elements of the National Nanotechnology Program. The following chapter describes how these elements should be implemented.

Mission Statement

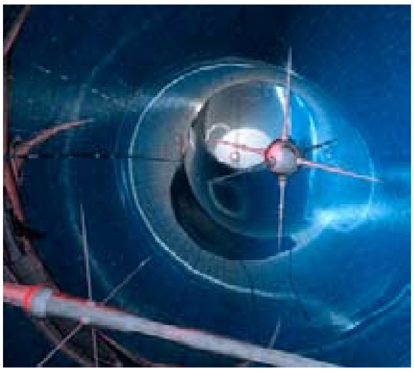
The Mission of the National Nanotechnology Program is to ensure that the Kingdom is a major player within the international community in the research and development of nanotechnologies. By taking a collaborative and interdisciplinary approach to nanotechnology, the plan will foster academic excellence, and ensure that world-class research and development facilities are available to all parts of the economy, from academic institutions to industry, with a strong focus on supporting the future economic strategy of the Kingdom and transferring technologies from the research community to Industry.

Vision

The Vision of the National Nanotechnology Program is to create a multidisciplinary program leveraging all branches of science in order to build competence and capability in nanotechnologies which will help to ensure the future competitiveness of the Kingdom.

Justification

Nanotechnology has the potential to revolutionize the world. Although the field has a short history, it is growing exponentially. Nanotechnology brings promise of an unprecedented sophistication in the development of new tools and techniques that can benefit all other existing technologies. Fabrication methods have been outlined and applications are being developed. Advanced



nations have reacted quickly to the rise of nanotechnology, committing considerable resources to ensure that they benefit from this technology. Saudi Arabia needs to take part in this international effort.

To establish a position for itself among the benefactors of this technology, Saudi Arabia will coordinate its efforts at a national level. Establishing a clear strategic plan will ensure that efforts are coordinated throughout the Kingdom. It is important that this strategy provides a clear picture of how resources will be carefully deployed and effectively used to maximize return on investment.

The National Nanotechnology Program must take a multi-institutional and multi-disciplinary approach. It will support and guide research and development in the field of nanotechnology, will lead the development of supporting infrastructure, promote and guide applicable education, encourage knowledge diffusion, and help lay the groundwork for creating new commercial ventures that will diversify the economy.

Stakeholders

The major stakeholders in the National Nanotechnology Program are:

- KACST
- Universities (existing and future)
- Research Institutes (existing and future)
- Centers of Excellence (existing and future)
- Ministries and other government organizations
- Local industry (and local operations of multinational companies)
- Members of the public

Strategy Components

Strengthen Academic Research

The nanotechnology research being conducted in the Kingdom needs to be both expanded and focused in order for the Kingdom to maximize the benefits from nanotechnology.

Nanotechnology is a very large field and touches on most areas of science. It is essential that the National Nanotechnology Program focuses and coordinates all individual and team efforts in order to make progress.
To support this focus and coordination, a detailed technical strategy should be developed to strengthen academic research. This will include details of how nanotechnology programs and projects will be initiated.

Obviously, freedom must be given to researchers to follow research interests and interesting leads, but the selection of research projects for funding should be based on a set of criteria that are associated with successful, high-impact research.

An internationally accepted set of criteria for evaluating research projects, adopted by the European Union, takes into account the following three aspects:

- Science and technology quality.
- Implementation.
- Impact.

The Program should also ensure that the Kingdom maintains an adequate balance of research. It is important to clearly define the different types of research such as: fundamental, platform,[10] and applied. Ensuring the correct balance between these kinds of research enables a vibrant, innovative, and productive research environment.

Improve Infrastructure

In order for nanotechnology research to thrive, a substantial investment must be made to expand the Kingdom's infrastructure. The National Nanotechnology Program will move toward the establishment of both a centralized and a regionally distributed nanotechnology R&D infrastructure within the Kingdom.
One of the primary aims of the National Nanotechnology Program is to create a cutting-edge national infrastructure for nanotechnology. The proposed facilities will include a characterization and testing service which will be highly subsidized by the government. This will enable the technology to be accessible to both business and academia despite the high capital and maintenance costs associated with such high technology facilities.

The National Nanotechnology Center (NNC) will be coordinated by KACST, located in Riyadh, and is intended to be the core nanotechnology facility. However, the centralized labs at the NNC are just the beginning. The National Nanotechnology Strategic Plan envisions that the nanotechnology infrastructure within the Kingdom will be distributed so as to provide specialized facilities located around the country. This will allow easy access for all parties. Tools should be distributed in large groups according to need.
As a general principal, large-scale equipment to be used by the entire nanotechnology community should be centrally located. This allows the creation of a pool of skilled operators and technicians who are available to support

10 "Platform research" refers to research that provides the basis for a broad area of research and many potential applications, such as research in nanoparticles synthesis that supports research to develop high efficiency solar cells or low cost fuel cells. Platform research is applied in the sense that the work is motivated by applications, but the potential applicationS are very broad and there are additional steps required before developing these applications.

the entire community. Examples of this kind of equipment include: State-of-the-art TEM, X-ray photoelectron spectroscopy (XPS), E-Beam lithography, Molecular Beam Epitaxy (MBE), and CVD.

Equipment required on a daily or routine basis for specific projects should be located at distributed facilities. Examples of this kind of equipment include: Broad-based TEM, Research grade SEM, XRD, and AFM.

Linking Research with Economic and Industrial Strategy

One of the key goals of the National Nanotechnology Program is to ensure that nanotechnology research is focused on improving the local economy. In order to accomplish this it must be linked to the Kingdom's overall industrial and economic strategies. The principal industrial sectors that stand to be beneficiaries of a mature nanotechnology research enterprise are the following:

- Oil & Gas
- Defence & Security Systems
- Petrochemical
- Telecom Infrastructure
- Construction
- Mining and Materials
- Water
- Health
- Transportation

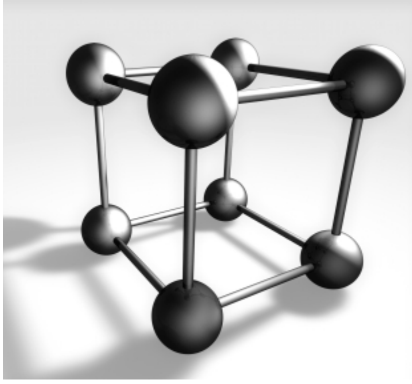
Specific technical sub-fields within each of the major industrial sectors are the following:

- Improved desalination ***(Water)***
- Enhanced catalysis ***(Petrochemicals)***
- Corrosion resistance ***(Oil & Gas, Petrochemicals, Defense, Water, Construction & Infrastructure, Mining & Materials).***
- Monitoring nanodevices ***(Defense, Water, Medical).***
- Renewable energy such as solar cells ***(Industry, Water).***
- Enhanced oil recovery ***(Oil & Gas).***
- Enhanced well productivity ***(Oil & Gas).***
- Developments for deep drilling ***(Oil & Gas).***
- Medical diagnosis & drug delivery ***(Health).***
- Electronic, and photonic nanodevices, and MEMS/NEMS ***(Defense, Water, Oil, Industry, Medical, and Transportation).***

The establishment of the National Nanotechnology Program will also help attract and retain the newly identified industrial clusters to the Kingdom. The new industries targeted for introduction to the Kingdom are: industrial automation, construction materials, metals, home appliances, and flexible packaging. Table 10 shows the nanotechnology applications in each of these industries.

Table 10: Nanotechnnology applications in industry

	New Industrial Clusters for KSA				
	Industrial Automation	Construction Materials	Metals	Home Appliances	Flexible Packaging
Applications	Nanosensors and nanoelectromechanical systems (NEMS) for assembly measurement and control	Nanotechnology in cement-based materials: sustainable and ultra-high strength cements, nanostructure characterization, new functionalities	Improved characterization of metals	Antibacterial nanocoatings for home appliances	Nanocomposites for improved Barrier Packaging
	Nanoscale assembly and manufacturing techniques	Multi-functional nanocoatings for: fire protection, biocide activity, self-cleaning, self-repairing	Development of alloys for increased strength or corrosion resistance	Nano-enabled "smart materials" for intelligent home appliances	Nanocoatings for improved transparency, antifog, antimist
		Embedded sensor materials for security and comfort applications: corrosion, fire, wind, noise, impact energy		Nanomaterials for removing odours from home appliances	Protective nanocoatings for antimicrobial capabilities and UV filters
		Nanocomposites for construction polymers: fiber reinforced polymeric elements (FRP), agglomerated marble, adhesives, polymer mortars		Nanocoatings for easy-to-clean surfaces	Thin film electronics for sensory packaging
		Nanotech for energy efficient buildings: solar cells, isolation materials, insulation		Nanomaterials for improved heat resistance	Nanobarcodes for track and trace



International Collaboration Plan

As discussed earlier in this report, there are 35 countries that have launched nanotechnology initiatives. With this level of international activity in nanotechnology research, there are many opportunities for the Kingdom to collaborate with other countries. Not only is the environment ripe for cooperation, in a globalized R&D environment, international cooperation is necessary for academia and industry. International collaboration can lead to more focused nanotechnology research and increase the rate at which the Kingdom closes the knowledge gap with other more advanced countries.

The Kingdom must engage in international R&D collaboration. Facilitating this collaboration can be accomplished through: student exchange programs, support for international benchmarking activities, sponsorship of Saudi researchers attending international nanotechnology conferences, and a reduction of visa restrictions. International collaboration is a hallmark of the U.S. National Nanotechnology Initiative and the EU FP6 and FP7 Programmes, and has been cited by these organizations as a critical component of their success.

An emphasis on collaboration can be undertaken in Saudi Arabia by focusing on three key areas:

- Expanding the mobility of researchers.
- Participating in internationally recognized nanotechnology initiatives, such as the EU FP6 and FP7 Programmes, and standards bodies such as the ISO Technical Committee on Nanotechnologies TC229.
- One-to-one collaboration between research institutes.

Management Plan

The National Nanotechnology Program will be directed by a Program Manager, who will be a KACST-NNC employee, and who will be responsible for the overall execution of the plan, which will involve coordinating activities of universities, industry, KACST institutes, the advisory committee, and international consultants. The Nanotechnology Advisory Committee will oversee the implementation of the plan and ensure that investments and outputs are in line with the plans. It will provide advice to the Program Manager, and will also report to the National S&T Plan Supervisory Committee, which will oversee all of the Strategic Technology Programs.

The Nanotechnology Advisory Committee will also sponsor and oversee studies of emerging areas of nanotechnology to serve as the basis for developing new program areas. This plan is intended to be a dynamic document that will be updated at least annually and more frequently if required. In addition to the advisory committee input, it is expected that workshops with the research community, users, and other stakeholders will also contribute to both a continual evolution of the plan as well as a stronger nanotechnology R&D network in the Kingdom.

Health, Safety and Regulations

International regulations are playing an increasing role in the international business environment. Many regulations related to nanotechnology are just starting to be developed. It is timely for the Kingdom to join the international community in developing regulations so that the Kingdom can both influence outcomes and form new relationships. The Kingdom will participate in the development of international nanotechnology regulations and will also ensure that the regulatory climate within the Kingdom is optimal for investment by foreign industry and investors.

A national body overseeing nanotechnology would be ideally situated to discuss and monitor the regulation of nanotechnology. In addition, this central body could focus on matters of environmental improvement, such as recycling technologies.

Strengthen Education and Workforce Plan

The National Nanotechnology Program will provide new ways to attract and retain technically skilled workers, enhance training for industry, and increase the number of PhD holders in the Kingdom. It is hoped that this initiative will also generate new educational programs like materials science departments in universities. There are already plans to create a graduate nanotechnology program and a post-doctorate research position as found elsewhere in the developed scientific nations.

This initiative will also enhance public awareness and knowledge of technical subjects being debated and researched in other countries. Being a part of exciting nanotechnology breakthroughs around the world will likely engage people in the Kingdom and engender an interest and love of science within the culture. The initiative will also educate the local community within the Kingdom, engendering a science and technology culture and helping members of the public to appreciate the research, development and commercialization of nanotechnology. This is important as it will help build a new generation of Saudi Arabian scientists and foster support from the populace.

Traditional indicators of the success of the scientific educational system, such as the number of science and engineering graduates from local universities, do not go far enough to capture the outcomes of this initiative. Other measures should be generated and linked to a broader outreach strategy. However, a detailed strategy needs to be developed before such metrics and measures are defined. For example, such a strategy could include: public education events in science, industry awareness events, school awareness events, and initiatives such as a publication explaining nanotechnology to the general population. New measures would be linked to the success of these outreach activities.

Commercialization Plan

The ultimate aim of investing in nanotechnology research and development is to increase the level of income and volume of business within the Kingdom. The immediate commercial aim is to generate spin-off companies and thus create new high technology industries to diversify the current oil-gas economy and predominately trade and commerce industry.

To ensure the maximum benefits from the National Nanotechnology Program, an effective and active technology transfer policy and commercialization policy must be established. Once the National Nanotechnology Program has been established, it is hoped that it will attract both industry and Venture Capital investment. A key factor in achieving this will be the optimization of the Kingdom's patent process.

Expected Outcome

The launching of the National Nanotechnology Program in the Kingdom is expected to lead to substantial increases in scientific knowledge, publications, patents and new jobs in the many areas of science and nanotechnology.

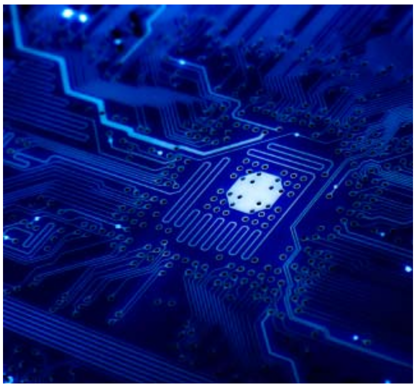
In five years the science and technology infrastructure to support the development of nanotechnology will also be transformed. It is expected that approximately 1,800 more scientists, engineers and technicians will be needed to work on projects related to nanotechnology in the Kingdom. By 2012, it is expected there will be 200 nanotechnology-related research projects in varying states of completion and 75 more launched that same year.

By 2012, many of the research projects begun in 2007-2008 will be at or approaching the stage of commercial development that can begin to be used to support local industries, such as the oil and gas, energy, healthcare, defense, and infrastructure industries. In addition, these technologies will help attract and launch new industries for the Kingdom.

This transformation will support not only local industry and diversify the economy but will also help to transform the social conditions of the Kingdom, moving towards a more knowledge-driven economy, and inspiring entrepreneurial aspirations. It will make possible leadership and resource development, research and technology transfer, workforce development, business growth, stronger national security, and improved quality of life.

Implementation Plan

This chapter describes how the strategy discussed in the previous chapter should be implemented. It begins by proposing nanotechnology research topics and priorities and then discusses key implementation issues.



Research Projects & Prioritization

Given the low amount of nanotechnology expertise currently existing in the Kingdom, it is important that the Kingdom focuses on building expertise in producing nanomaterials & structures, and modeling and fabricating nanodevices. A fundamental understanding of basic materials and synthesis science is an essential base for any serious nanotechnology research activity.

The nanotechnology research topics proposed in this chapter fall into three broad categories:

1- Quantum structure and nanodevices.

2- Synthesis and characterization of nanomaterials.

3- Modeling and computations of nanostructure.

Within each category, specific research projects are recommended that will allow the Kingdom to develop the core competence required to perform goal oriented research.

The proposed list of research topics reflects both the need to establish baseline capabilities and the understanding that the future of nanotechnology will not be in establishing nanodevices or nanomaterial companies but in creating technologies that can support industry both locally and internationally.

Implementation Plan

R&D Priorities

Nanotechnology is all about properties of materials at the nanoscale and then transferring those properties to the macro-scale. As such, all nanotechnologies, whether biological, inorganic or semiconductors, begin at the level of materials. Below is a list of proposed nanotechnology research topics.

1- Quantum Structure & Nanodevices

- MEMS:
  - Sensors.
  - Actuators.
  - RF MEMS.
- Nano-Bio:
  - Drug delivery.
  - Imaging.
  - Bio MEMS devices.
- Nano Photonics:
  - Laser & detection.
  - LEDs.
  - Integrated optics.
  - Optical components.
  - Optical sensors.
  - Photovoltaic and solar cells.
  - Photonic crystals.
- Nano Electronics:
  - Spintronics.
  - ASIC.
  - Nano fabrication and processing.
  - Displays.
  - Nano sensors.
  - Functionalization of nanotubes, nanowires and nanoparticles.
- Quantum Structure:
  - Semiconductor laser and detectors.
  - Quantum devices.

2- Material & Synthesis

- Nanocatalyst.
- Fuel additives.
- Fuel extraction.
- Thin films and Coatings:
  - Anti-corrosion.
  - Self cleaning.
  - Radiation protection.
- Nanofiltration.
- Composite material.
- Thermal insulation.
- Nanotubes (NTs) and nanowires (NWs).
- Material enhancement using nanoparticles, NWs or NTs.
- Nanoparticles and quantum dots.
- Textile: fire/water resistant.
- Adhesives.
- Energy harvesting.
- Energy storage:
  - Fuel cells.
  - High performance batteries.
- Lubrication.
- Water purification, desalination, and decontamination.
- Water quality monitoring.

3- Modeling

- New material and nanostructure modelling.
- Nano devices modelling.

Figures 4-6 below are block representations of the nanotechnology research area priorities and time frames by category.

Figure 4: Quantum Structure and Nanodevices Research Topic Priorities and Time Frame

Program	Research Topics	Priority	2008	2009	2010	2011	2012
Nana Devices & Qauntum Structure	**MEMS**						
	MEMS Based Sensors	High		■	■	■	■
	MEMS Based Actuators	High		■	■	■	■
	RF MEMS	High		■	■	■	■
	Nano-Bio						
	Drug Delivery	Meduim		■	■	■	■
	Imaging	High	■	■	■	■	■
	Bio MEMS Devices	High		■	■	■	■
	Nano-Photoincs						
	Laser & Detection	High	■	■	■	■	■
	LEDs	Meduim		■	■	■	■
	Integrated Optics	Meduim			■	■	■
	Optical Components	Low		■	■	■	■
	Optical Sensors	High		■	■	■	■
	Photovoltaic & Solar Cells	High	■	■	■	■	■
	Photonic Crystal	Low			■	■	■
	Nano-Electronics						
	Spintronics	Low			■	■	■
	Application-Specific ICs	Medium				■	■
	Nano-Fabrication & Processing	High		■	■	■	■
	Displays	Low				■	■
	Nano-Sensors	High		■	■	■	■
	Funtionalization of NTs & NWs	High	■	■	■	■	■
	Quantum Structure						
	Qauntum Devices	Low				■	■
	Semiconductor Laser	High			■	■	■

Figure 5: Material and Synthesis Research Topics Priorities and Time Frame

Program	Research Topics	Priority
Material & Synthesis	Nanocatalyst	High
	Fuel Additives	High
	Fuel Extraction	Meduim
	Thin files & Coating	
	Anti-corrosion	High
	Self Cleaning	Low
	Radiation Protection	Meduim
	Nanofiltration	High
	Composite Material	Meduim
	Thermal Insulation	Meduim
	Nanotubes (NT) & Nanowires (NW)	Meduim
	Nanoparticles (NP) & Quantum Dots	Meduim
	Material Enchancement NP, NW or NT	High
	Textile: Fire/Water Resist	Low
	Adhesive	Meduim
	Energy Harvesting	Meduim
	Energy Storage	
	Fuel Cells	Meduim
	High performance Batteries	Meduim
	Lubrication	High
	Water Purif, Desalen & Decont	High
	Water Quality monitoring	High

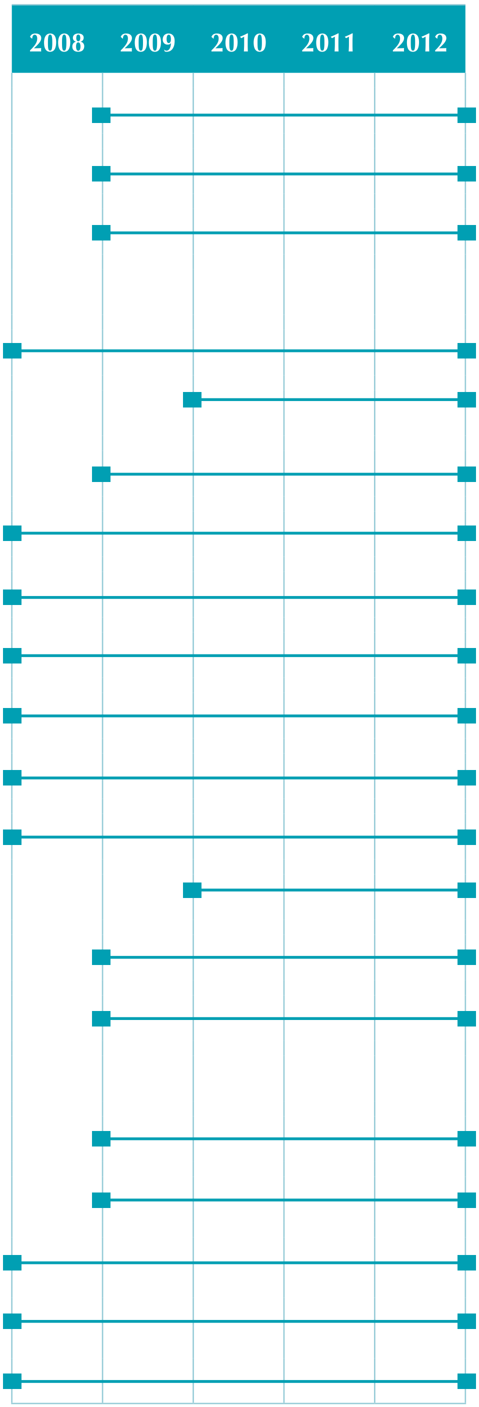


Figure 6: Computations and Modeling Research Topics Priorities and Time Frame

Program	Research Topics	Priority	2008	2009	2010	2011	2012
Computation & Modeling	Nano-Devices Modeling	High					
	New Material & Nano-Structure Modeling	High					

Project Milestones & Timelines

Each of the proposed research topics encapsulates a vast amount of research and development. Each topic will need to be thoroughly reviewed before a technical strategy is decided upon. It is suggested that in each technology area a project split of 30:40:30 for "basic : platform : applied" research is aimed for.

The specific timescales and milestones of the projects will be developed as part of the detailed project plans. At this time, the correct balance of fundamental/applied research will be assessed for each program. Some projects will be primarily in the fundamental area—such as those relating to the basic understanding of electrical properties. Other projects will be positioned more in the application area. The correct balance of fundamental vs. platform vs. applied research must be maintained overall though not within each individual project.
There will be some areas of research where specific high-end tools are required on a regular basis, such as NMR in polymer synthesis. Planning to ensure that these projects are undertaken in places near to an NMR facility will factor into the project plans. Such tools will need to be identified during the detailed project-planning phase.

It will also be essential to start each new project with some experts in the technology area. Subsequent project members can be recruited with a basic understanding of nanotechnology and be trained in the field on the job.

Conferences and workshops to make industry aware of the work and potential of nanotechnology research can be started as soon as the nanotechnology experts are recruited to kick-start the initial projects. Such experts will be well positioned to give regular briefings to appropriate stakeholders and encourage interest and involvement.

Each of the research topics described above will be run by a Technology Program Manager. Under each program will be a number of individual projects each led by a Principal Investigator (PI). This person should be experienced in the technology area, and have a PhD together with many years of experience leading research projects. Each Technology Program Manager will work with the PIs to develop the Program plan and the individual project plans.

Infrastructure Projects

The National Nanotechnology Program will establish a high technology research and development infrastructure within the Kingdom.

In addition to the need to commit a significant amount of time and investment to this initiative, it is essential that the projects do not become over burdened with bureaucracy. In addition to an initial lump sum injection for the setting up of facilities and infrastructure, funders must realize that such facilities require significant specialist maintenance and this will require a significant annual funding commitment.

Facilities and Equipment

The National Nanotechnology Program will need to implement the following in regards to facilities and equipment:

- A project-based procurement plan in which equipment is distributed around the Kingdom at appropriate universities and research centers based on project requirements.
- Major equipment in one, centralized center where appropriate.

By 2012, it is predicted there will be almost 2,000 highly technical staff working on nanotechnology related projects throughout the country. The infrastructure to support this will need to be significant. For example there should be roughly one Scanning Electron Microscope (SEM) for every 50-100 people in a facility. Thus, 2,000 people will require about 30 SEMs.

It is also recommended that there be one AFM for every 200 hundred people and one TEM, XRD and XPS for every 500 people. These are extremely expensive pieces of equipment, but as other countries have discovered, a good way to attract experienced people is to provide excellent, cutting edge facilities and equipment. In addition, there should be thermogravimetric analysis (TGA), dynamic mechanical analysis (DMA) and Fourier transform infrared spectroscopy (FTIR) instruments for every 200 people and one liquid and one solid nuclear magnetic resonance (NMR) for every 500 people.

It must be noted that several pieces of equipment are highly vibration and/or electromagnetic interference sensitive and proper provisions for a vibration proof or electromagnetic interference shielded building must be provided. Specialist advice must be sought (usually available from equipment suppliers) about where to place such equipment.

A detailed Technical Strategy should be developed that sets out the focused areas of nanotechnology and breaks them down into capability groups. Staff can then be sourced by expertise in these areas. Recruitment plans can be established to ensure "an heir and a spare" policy (two extra people) to back up each project leader in areas requiring critical capabilities.

A detailed facility and equipment plan should be developed. This would be in parallel to development of technical project plans and involve equipment purchase, housing, operations, management and booking, and training. The plan would need to be extensive and involve individuals with expertise in nanotechnology equipment operation and facility management.

Maintenance and Facility Management

The laboratory technologists who run nanotechnology facilities must be highly trained and proficient in the use of the equipment. Experienced consultants would be used to carry out regular equipment maintenance. If there is a lack of such experienced personnel in the Kingdom, it will likely make the maintenance even more expensive. This should be budgeted for on an annual basis as part of the cost of running a nanotechnology facility.

A nanotechnology facility also requires a significant investment in consumables, such as gold for microscopy and evaporation targets and specialist wafers for nanofabrication. The high running cost of such a facility, which is considerably more than the initial upfront payment must be appreciated at the outset.

In order to manage the facility it is suggested that an on-line equipment booking and management system be developed. This would allow staff to see the availability of equipment and book it on line if they were an authorized user of that equipment. It would also allow for timely reminders about maintenance and calibration of the equipment and would allow the capture of utilization data.

International Cooperation Projects

Cooperation on an international level is essential to the success of the National Nanotechnology Program. This cooperation is required on a number of levels from the exchange of researchers to international standards. A few ways to accomplish this are described below:

- Exchange of Ph.D. students and post docs between the various institutes within the Kingdom and leading centers in the rest of the world.
- Set up a research cooperation program and a number of positions designed to encourage researchers from other regional universities (GCC[11] countries, Jordan, Egypt, etc.) to cooperate with and eventually join the Kingdom's National Nanotechnology Program.
- Participation in external research programs funded by the European Commission, such as Framework 7, which allows and encourages the participation of non-EU states.

Nanosafety & Regulation

It is the aim of the National Nanotechnology Program to include safety standards that are in compliance with international standards. There are significant international concerns regarding the potential health and safety hazards associated with the production and use of engineered nanomaterials. However, the state of international standards related to nanotechnologies is currently in a state of flux.

In the midst of these still developing standards, both national and international regulatory agencies and standards organizations such as the US EPA, NIOSH, ANSI, BSI, APPIE, DIN, EEC, and ISO[12] are collaborating to develop a unified approach to standardization. In addition, there are a variety of existing international standards that address the measurement of nanoscale materials and the quantification of exposure to some types of airborne nano or ultrafine materials.

The current international standards organizations involved in development of nanotechnology standards include:

- American Society for Testing and Materials International (ASTM International).
- International Organization for Standardization (ISO).

While these organizations have not established definitive standards, they are actively pursuing this goal. Both of these organizations are seeking international partners both in the form of companies and countries.

The National Nanotechnology Program should participate with one or both of these organizations with the intention of adopting their final recommendations and standards. It is important to participate in these

11 Gulf Cooperation Council

12 U.S. Environmental Protection Agency (EPA), National Institute for Occupational Safety and Health (NIOSH), American National Standards Institute (ANSI), British Standards Institution (BSI), Association of Powder Process Industry and Engineering (APPIE), Deutsches Institut für Normung (DIN), European Economic Community (EED, and International Organization for Standardization (ISO)

organizations to further international collaboration and to position Saudi Arabia as a country that is approaching nanotechnology in an environmentally responsible way. Also, by following all available standards from highly respected organizations such as the ASTM and ISO, any products that are produced through nanotechnology will be considered safe for international export.

In addition to participating in these international standards, the National Nanotechnology Program should develop a detailed Health, Safety and Environment Plan and associated training based on the latest information.

Nanotechnology Education

A primary focus of the National Nanotechnology Program is to provide enhanced education through the teaching of nanotechnology. A significant number of Saudis will be trained in this growing area and will be available to work on projects in nanotechnology. To advance this training, the National Nanotechnology Strategic Plan includes the following objectives:

- Creating nanotechnology courses and certificate program awards at major universities.
- Encouraging and providing full support for graduate students.
- Providing scholarships for students pursuing studies in nanotechnology abroad.
- Partnering with existing educational programs to create mutual benefits.
- Making programs for introducing nanotechnology to students of all ages.
- Developing public outreach programs.

The following steps will be taken to improve the quality of the workforce:

- Providing financial incentives for nanotechnology practitioners for at least the next ten years. This is required because such expertise is essential to bring KSA technology in line with the global cutting-edge technology, but the commercial financial incentives will not be viable until about ten years from now.
- Providing jobs outside academic environments. This is essential for the understanding that nanotechnology is not just an academic pursuit and to get industry to take an interest and influence the project aims.
- Promoting partnerships between industry, education and training providers, and the government funded workforce system. Industry will initially be reluctant to take on a highly paid nanotechnology expert or engage in training and will therefore need to be given incentives to do so. However, once this has started and industry recognizes a real benefit, the incentive schemes will no longer be needed.
- Providing hands-on-training for higher education at universities and other government institutions. There will be a gap between the nanotechnology experience in universities and the nanotechnology practical projects required by industry. Such an initiative will enable the graduates to be significantly more efficient and productive once starting work.
- Supporting the development of technician training programs. The availability of highly trained and relatively highly educated technicians is essential to the success of nanotechnology across the Kingdom. The maintenance and operation of the equipment and cleanroom facilities is extremely complex and requires a ready pool of technicians.

As nanotechnology is an emerging technology, sustained government support is required for long-term development of these skills within the Kingdom. Education and training will be supported by an educational support infrastructure. This infrastructure will provide centers of excellence geographically distributed around the country with a centralized facility at the KACST.

By using the nanotechnology knowledge being developed within the Kingdom at its universities, research center and industries, a "Nanotechnology Newsletter" should be published and distributed on a monthly or quarterly basis. Plans for such a newsletter or journal have already been discussed.

In addition to the initiatives above, there should be a wider initiative led by the various stakeholders in the National Nanotechnology Program to engage school children through a series of short educational presentations at the schools. While KACST has already started planning initiatives like this, it should be the responsibility of all the stakeholders to become involved in educational programs such as these. Eventually it is hoped that nanotechnology will be introduced as a topic into the national school curriculum.

Plans for training courses specifically designed for Industry are also being developed so that they may be offered by mid-2008. It should be the responsibility of all the stakeholders to broaden and institute these training courses.

Training and Workforce Recruitment/Retention Projects

Manpower recruitment and retention was one of the primary issues to emerge from the nanotechnology workshops and meetings. As the number of highly trained and capable staff within the Kingdom is limited, much of the recruitment will have to be from overseas and this issue is critical to the success of the National Nanotechnology Program.

There is a concern that the students from the local universities are currently not well-prepared to work with such cutting edge technology. It was noted that using the technology and equipment proposed in the National Nanotechnology Strategic Plan will need capable trained staff.

The elements that can make the Kingdom attractive to foreign scientists is top-level facilities and high investment into science and engineering so that top-level foreign scientists can afford to hire large teams, buy new equipment and have no problem buying consumables. This could be a key way for the Kingdom to attract foreign talent – but it requires significant investment in terms of salaries, facilities, and infrastructure.

Staffing Requirements

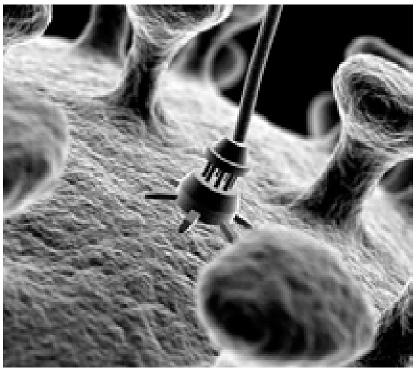
The specialist technical staff to be recruited as part of the National Nanotechnology Program can be split into several groups:

- **Technical Director:** One or two very experienced scientists to direct the technical focus of the National Nanotechnology Program. They would, in collaboration with the other stakeholders, set the direction and review proposed projects.

- **Technology Program Managers:** These staff members would be equivalent to senior professors at KACST or in a University. They must be extremely experienced in both the technology they are focused on and management and communication skills. It is expected that most of these will initially be expatriates.

- **Principal Investigators (PI):** These people would need to have a PhD and several years of post doctoral experience. They would manage research projects and teams.

- **Research Scientists and Engineers (RSEs):** These



people would have a relevant PhD and a few years postdoctoral experience.

- **Research Officers (ROs):** Most of these staff would be new PhD holders or experienced MSc staff.

- **Technical Officers (TOs):** These staff would have a degree in engineering or science and assist in the laboratory with practical work.

Recruitment Plan

Each project under the National Nanotechnology Program would require a Principal Investigator to lead it. Depending on the size of the project it is expected that between 3 and 15 staff will work on it. Thus, we can assume each project has an average of 1 PI, 3 RSEs, 3 ROs and 2 TO.

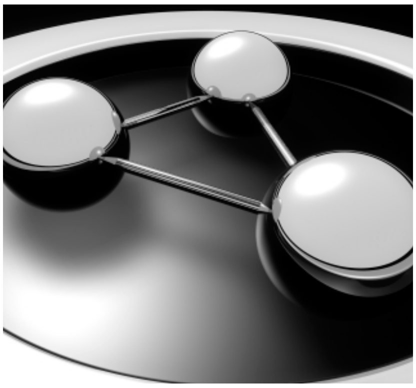
It is particularly important that capacity is built up beyond an individual, to give stability. This will involve building research teams focused on specific areas, rather than hiring foreign talent and working in whatever area they happen to be a specialist in.

During the nanotechnology workshop, an initial manpower recruitment plan was discussed. The number of local and ex-pat personnel was computed using the ratio of PI:RSE:RO:TO discussed above (1:3:3:2). It is expected that by 2012, 1800 personnel will need to be recruited.

It will be significant challenge to recruit so many quality people. Government support is sought up front to be exempt from the laws concerning the percentage of Saudi citizens employed in the first few years. A sliding scale of conformance can be agreed to in return for a training program for Saudi citizens.

Rewards, Incentives and Accountability

A series of rewards and incentives, in addition to a competitive salary, is necessary to attract and retain the staff required. Rewards can be financial, such as an end of year bonus linked to performance of the project. Rewards can also be non-financial such as recognition as the “most innovative person” of the year – or a meal at a restaurant with the advisory committee of the National Science and Technology Strategic Plan for a team who achieved a certain number of published papers.



We hope to establish an effective reward system by 2008. By mid-2008, there are plans to conduct individual "initiative reviews" with linked rewards. It is important that thought be given to both individual rewards and team rewards as such initiatives will drive behaviour. By 2009 there is a plan to create "Work Cells" with associated team incentives.

In terms of accountability, it is recommended that a detailed quality plan be created along with the management roles and responsibilities plan. In order to minimize problems involved in large projects, it is important to have clear roles, responsibilities, and processes.

Commercialization Projects

KACST has already taken initial steps addressing commercialization by identifying the main stakeholders from industry that are expected to have a significant role. KACST has undertaken initial negotiations with some of the main stakeholders and hopes to build strong relationships with them so that they can start to see the benefits of a nanotechnology initiative.

All the stakeholders in the Kingdom need to be encouraged to see the National Nanotechnology Program as a beneficial long-term investment. To facilitate this, the Program proposes the following:

- Sponsoring a number of gifted individuals to develop their skills to become business leaders of the future.
- Identifying the nanotechnology related needs of agencies.
- Establishing groups for exchanging nanotechnology information among commercial sectors.
- Encouraging cooperation between academia, government and industry.
- Mandating partnership between each R&D institution and an industry entity.
- Using incubators to start up new business ventures.
- Participating in the development of standards.

Understanding the reluctance of industry to become involved with high-cost initiatives that make dubious promises about the future, the Program proposes initiatives to encourage enthusiasm:

- Encouraging industry entities to use the National Nanotechnology Strategic Plan.

- Expanding industry liaison activities to cover sectors not involved.
- Funding multidisciplinary teams with researchers from industry and academia.
- Exchanging researchers between academic institutes and industry.
- Recommending government motivation for industries to establish nanotechnology related manufacturing facilities.
- Cooperating with world leading nanotechnology industries.

Once the role of industry in nanotechnology has advanced significantly, further steps will be undertaken to ensure a smooth transition to full industrial output. Manufacturing research is the key to achieving this and the following steps work to improve it:

- Industrial sectors will be urged to build their own research labs.
- Direct research efforts will be focused towards issues of nanotechnology manufacturing.

Additional nanotechnology commercialization activities that have been proposed include the following:

- Setting up workshops and electronic means to strengthen ties between regional and local initiatives.
- Licensing of intellectual property from research funded by National Nanotechnology Program.
- Supporting national patent and trademark registration.
- Gauging the advancements made in nanotechnology by taking part in international collaborations, workshops, and conferences.
- Offer annual excellence awards for supportive investors.
- Including nanotechnology development in the national five year plans.

Technology Transfer Policy

To enable the commercialization and implementation of nanotechnology, it is important that prototypes and testbed trials are set up to test and prove the new technologies. These should ideally be carried out with potential industrial partners to allow technology buy in and adoption and also to ensure an easy transfer of technology.

The research topics that have been proposed are chosen to enable optimum technology transfer. The research topics: have clear areas of application, are topics which industry is excited about, and are in areas where there is a strong need for advancement.

NNC intends to start compiling the Center's information database that will be used to record all knowledge in the area of nanotechnology. This will be performed in collaboration with international universities, partnering research centers, and the equipment suppliers of each of the centers. This database may be used to introduce end products and for industrial entities' research use or end product development.

Technology Incubators

Since the primary aim of commercialization is to spin out companies, the technology incubator will be an important aspect of the commercialization strategy. Although spinning off companies is a major aim of the National Nanotechnology Program, it is currently complex to set up (spin–out) a company. There is much bureaucracy and the process is not clear. In addition, the process of patenting and decision-making must be made more efficient if companies are to be able to spin out.

Regional competition for VC funding does not seem to be a current issue, as the surrounding countries have much less technical infrastructure. However, countries such as UAE (Dubai, specifically) are seen as less bureaucratic.

While the VC market is getting established, it is possible that the Kingdom may need to play a role in the short term. It may be possible to create a separate entity that would act as a VC and use business metrics and measures to judge the merit of investing in each potential spin-out company. The investment would be in return for equity as with any normal VC deal, and if the company were to become a success this would create additional income to carry out the National Nanotechnology Program. A typical example of an agency which plays this role is the UKs National Endowment for Science and the Arts (NESTA). NESTA uses public money to provide early stage seed funding for technology start-ups in return for an equity stake. NESTA and similar organizations address concerns often faced by start ups that the investment is either too risky or the investment required is too small for traditional venture capital firms.

The creation of spin-out companies relies heavily on individuals with an entrepreneurial spirit taking a risk and starting up a company. Scientists and engineers are more likely to try and spin out a company if: they see successful examples of other spin-out companies, they know they will not be blamed if the company fails, they will receive enough salary while they are starting up the company. In addition, it is important that the scientists that spin out companies have some prior exposure to commercial issues and have somewhere to turn for advice in business aspects.

The National Nanotechnology Program should create a small organization staffed by experienced business people. They will work with the company incubator to advise the incubating companies. This advice should cover all aspects of business commonly not understood by scientific entrepreneurs, such as accounting and marketing, and assist the companies in sourcing KSA and regional government funding.

As nanotechnology becomes increasingly important to many international products, intellectual property issues will grow in importance. It is vital that the Saudi Patent system is internationalized and intellectual capital developed in Saudi is maximized for economic return. Moreover, as other countries explore nanotechnology and generate patents, there is a danger that inactive countries will be unable to take advantage of opportunities. Therefore, a detailed plan for IP management should be developed including incubation and spin-off of companies.

Lastly, a small committee or organization should be set up to oversee the assessment, funding, and incubation of spin out companies that are provided seed funding initially by the government. It is recommended that industry pays to be involved in this and that international business experts be consulted. It will be crucial to build a spin-off savvy ecosystem of experienced technology-focused entrepreneurs.

IT Projects

It is very important that the information and knowledge generated by the nanotechnology research projects within the National Nanotechnology Program be stored in an appropriate way from the outset. This will enable effective knowledge mining and optimization of the application of the knowledge at later stages.

Within the next year, a full system of interconnected software systems should be under development. These will aid the day-to-day operation of the Program by collecting and storing data at every step along the way.

Often the extra work of collecting data means that the data is not collected in its entirety and the knowledge storage system becomes ineffective. By incorporating the data collection as part of the IT operations system this minimize the additional time spent on data collection.

The IT system proposed will be used to do all the following operations:

- Project management.
- Financial management.
- Human resource management.
- Contact and relationship management.
- Purchase order applications and approvals.
- Training applications.
- Equipment booking.
- Facility management.
- Calibration and maintenance management.

Measurement and Benchmarking

Standards & Processes

As with other government-linked research and development organizations in the world, the measurement of success in initiatives such as this is not simple. Unlike a commercial company where the success can be measured in financial terms, or a University where success can be measured in terms of academic papers published or students trained, a government-linked research organization has a complex range of objectives. Often some of the most important success factors are interlinked with other factors and are difficult to measure.

The solution to the measurement problem used by most research organizations is to have a selection of "Key Performance Indicators (KPIs)". These KPIs are chosen to reflect the measurable aspects of performance and to reflect the range of requirements a government research initiative is usually tasked with.

When choosing the KPIs for the National Nanotechnology Program, it is essential to focus on the following issues:

- They must be easy to measure.
- They must be quantifiable.
- They must be objective.
- They must cover all the areas the National Nanotechnology Program is expected to perform.

In order to allow benchmarking with international organizations to be more easily achievable, it is suggested that KPIs in similar government organizations around the world be assessed and, as far as possible, take similar measures for the National Nanotechnology Program. This will allow easier comparisons.

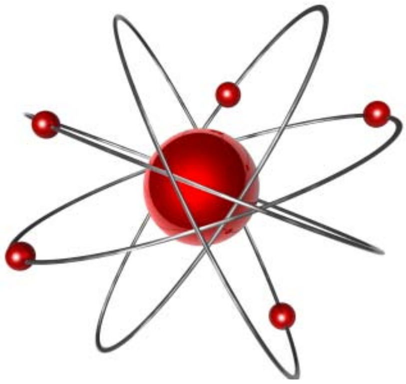
Suggested KPIs

- **Training**

- Number of PhD students trained.
- Number of Masters students trained.
- Number of school visits.
- Number of school students attached.
- Number of conferences or seminars held.

- **Intellectual Property and Academia**

- Number of papers published in high impact journals.
- Number of invited talks.
- Number of invention disclosures submitted.
- Number of patents filed.
- Number of patents granted.
- Number and value of licenses.
- Number of research collaborations signed nationally.
- Number of research collaborations signed internationally.



- **Industry**
  - Number of research collaborations signed with industry.
  - Value of income from industry.
  - Number of NDAs signed with industry.
  - Number of researchers spun out to work in industry.
  - Number of companies spun out of institutes involved in the program.

It is important to note that these KPI do not yet cover the all the key aspects of the program, such as infrastructure development, and so other KPI may need to be developed. It is also important use these KPIs carefully, because quality is usually more important than quantity and there is a risk that a reliance on KPIs can lead to an overemphasis on achieving numerical targets without the necessary quality. The KPIs should be reviewed as one element of an annual review by the program advisory committee, which should also consider qualitative factors.

Benchmarking

It is important to find organizations which have similar interests when choosing who to benchmark against. In the case of KACST National Nanotechnology Center, similar government institutes are: A*STAR in Singapore, the Nanofabrication Center at Cornell, and the relevant departments in UCLA, etc. It is hoped that an external benchmarking system will be in place by 2009.

Division of Roles among Nanotechnology Stakeholders

Nanotechnology Stakeholders Duties and Responsibilities

The major stakeholders involved in the National Nanotechnology Program are as follows:

- KACST research institutes.
- Local universities.
- Local industry.
- Government organizations.

KACST/NNC Responsibilities

The National Nanotechnology Center at KACST will serve as a centralized laboratory for the Kingdom. Its research will be focused on the research priorities discussed earlier in this chapter. It will promote and encourage collaboration with universities and industry in the field of nanotechnology. In addition, KACST/NNC will:

- Serve as a monitoring and coordinating body for other research institutes to ensure that the other stakeholders have the resources they need to conduct their research and serve as a checkpoint so that the research remains focused on national nanotechnology research goals.
- House the central national database on nanotechnology research and activities. However, it will be the responsibility of all stakeholders to ensure that the IT infrastructure required for this database is maintained.
- Support universities to enhance the current university curriculum with nanotechnology topics and work to build a new graduate nanotechnology program.
- Conduct technology transfer to strengthen the base of Nanotechnology in the Kingdom.
- Supervise stakeholder initiated projects to ensure compatibility with national nanotechnology objectives.

Since KACST is considered the primary link between fundamental research that is mainly conducted in universities and the commercialization and implementation of nanotechnology, KACST should also play a big role in establishing technology transfer and product development policies.

Universities Responsibilities

The universities' responsibilities include ensuring that appropriate infrastructure, tools, and facilities are built and installed in line with the goals of the National Nanotechnology Program. They also will need to ensure that current and future research projects in the field of nanotechnology are in line with goals of the National Nanotechnology Program. In addition, universities need to:

- Promote and encourage collaboration with other universities, national research institutes and industry both domestically and internationally.
- Ensure that all required information for the nanotechnology database that is run by KACST is delivered in complete and updated format.
- Establish new nanotechnology graduate programs to be added to the current engineering and science curriculum.

Industry Responsibilities

Local industry needs to promote and encourage the collaboration with local academia and other research institutions to develop products based on nanotechnologies. This will involve seeking out local research partners in solving technological issues that can be addressed by nanotechnology, as well as sharing, where appropriate, their expertise and facilities. Local industries are also encouraged to deliver all required information for the nanotechnology database that is run by KACST.

Government Responsibilities

The government, represented by the higher committee of science and technology strategic plans, will serve as the primary funding body. It will review current status and milestones of the National Nanotechnology Strategic Plan based on the input of all parties under the coordination of the NNC at KACST.

Appendix A: Swot Analysis

The Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis, initiated during the nanotechnology workshop and then built upon by an international panel of nanotechnology experts, can be seen below. This shows in a tabular form the result of the group's assessment of the Strengths, Weaknesses, Opportunities and Threats for the National Nanotechnology Strategic Plan within the Kingdom. The findings are then discussed below. Where the Weaknesses and Threats are discussed, suggested solutions are recommended.

Table A: Strength, Weaknesses, Opportunity, Threat (SWOT) Analysis Chart

Strengths	Weaknesses
■ Good government and political Support ■ Good economic situation (oil prices are high) ■ Funding is already available ■ Highly educated population ■ Good general infrastructure (water, power, roads) ■ Good basic education resources from which to build ■ Existing National Technical Initiative ■ Long-term R&D strategy ■ Some national centers of excellence already established ■ Leveraging existing big industries (oil and water) ■ Right timing without history of setbacks ■ Motivation within government and academia	■ Lack of nanotechnology infrastructure ■ No advanced technology economy ■ High level of bureaucracy ■ Lack of knowledge and know-how in nanotechnology ■ Lack of awareness of applications and benefits of nanotechnology ■ Lack of industrial culture within the Kingdom ■ Lack of incentives or motivation in human resource management ■ Qualified manpower shortage ■ Lack of R&D performance indicators ■ Not much commitment or funding from private sector ■ Lack of focused education (training) in nanotechnology ■ Little collaboration within the Kingdom ■ Lack of professional planning ■ No clear vision and organization ■ Not much new technology within the Kingdom

Appendix A: Swot Analysis

Opportunities	**Threats**
■ Strong potential applications in Kingdom ■ International collaboration ■ Existing research centers ■ Desalination of water ■ To diversify economy ■ Small improvements in desalination or diversification of economy will have a large, positive effect ■ International nanotechnology trends and globalization of information ■ Industrial needs meet applications ■ Alliances with other centers ■ Government support ■ High demand ■ Good timing ■ Build alliances and encourage sharing ■ Potential for regional dominance ■ We can choose which industry to get into ■ Available natural resources ■ Investment attraction	■ Single source of economy/drop of oil price ■ Lack of support from the private sector ■ Outside competition from advanced technology countries ■ Saudization: Having more Saudis in the workforce. ■ Technology is developing quickly: can we keep up? ■ Competitive states around us ■ Losing our momentum through the years ■ Technology monopoly: fear that some countries will monopolize nanotechnology ■ Funding shortage ■ Over-hyped? Tendency to focus on well established technologies ■ Health & safety issues ■ Unknown Funding stability

Strengths

One of the strongest points of the National Nanotechnology Program is the strong governmental support, recognized by all stakeholders involved. The current economic situation of extremely high oil prices, with likely increases, suggests a positive economic situation in the Kingdom for the foreseeable future. This, in turn indicates that a high level of funding for investment in nanotechnology and the necessary attraction of experts will be possible. In addition, the security of economy allows long term research & development strategies to be developed and followed through.

The big industries of oil and water currently present in the Kingdom can both benefit from a thriving nanotechnology capability. The presence of these two industries will enhance the initiative.

Although the Kingdom's population is not knowledgeable in nanotechnology, there is a large population and generally a high level of education that makes it easier to increase the technology capability still further. The good and improving educational resources will enable this, as will the high importance attributed to education in the Kingdom. The good IT being developed in the Kingdom will also benefit the initiative.

The Saudi Arabian culture values and ideas has generated an expressive, thoughtful and inventive population which will be good for developing unique nanotechnology capability in future years. The stakeholders are also enthusiastic and motivated. Some national centers of excellence have already started to be established.

Weaknesses

The **current lack of nanotechnology infrastructure** is seen as a weakness and it will take time and significant planned investment to overcome this. In addition, most of the economy relies on relatively low technology industries. It is considered a big task to engage such industries in the nanotechnology program at the outset.

Recommendation: *Develop a detailed facility and infrastructure plan. This would be in parallel to development of technical project plans and involve equipment purchase, housing, operations, management & booking and training.*

The **high level of bureaucracy** surrounding some past government initiatives is seen as a significant weakness in making progress on the National Nanotechnology Strategic Plan.

Recommendation: *In order to minimize bureaucracy and, at the same time, ensure government investment can be properly accounted for, it is suggested that detailed processes be developed in association with clear and detailed organizational and management plans. In this way the necessary bureaucracy can be seen and reviewed before the rules are implemented.*

Recommendation: *Implement an on-line approval system. Once these processes are developed they can assist in the drawing up of clear and effective management and responsibility diagrams.*

Lack of knowledge and know-how in nanotechnology is seen as a daunting issue for many of the stakeholders. This is exacerbated by a general lack of awareness of applications and benefits nanotechnology throughout the Kingdom.

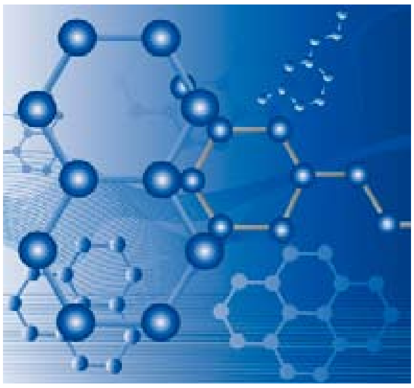
Recommendation: *Develop a detailed training plan for all different categories of staff and stakeholders, including the on-going budget to sustain and grow this effort.*

Recommendation: *Organize a series of forums on nanotechnology subjects for industry, and publish informative articles in local newspapers.*

There is currently a **lack of technical business culture and expertise**. Doing business in high technology is different than in the lower technology areas. Understanding of quality and expertise plays a large part in business decisions and this is new to many business leaders in the Kingdom.

Recommendation: *Organize a series of forums on business matters in high technology industries and publish informative articles in local newspapers.*

There is currently a major difficulty in **recruiting and retaining good staff**. There are not enough trained people locally to fulfill the requirements of the National Nanotechnology Program and so a significant number of expatriates must be attracted to work in the Kingdom to fulfill the Program's mission. In addition there is a concern that the students from the local universities are currently not prepared to work with such cutting-edge technology. It was noted that using the technology and equipment proposed in the National Nanotechnology Program will need capable trained staff - otherwise



technical aversion may occur. The shortage of suitable manpower combined with a lack of incentives or motivation in human resource management means that staffing the nanotechnology initiative in the numbers proposed will be extremely challenging.

Recommendation: *Develop a detailed manpower recruitment, management, recognition, and retention plan. In addition to hiring the correct number and level of staff, the plan would embody the management and reward aspects to encourage retention of staff and maintain a high motivation and enthusiasm.*

Recommendation: *A staff handbook should be written which clarifies all aspects of the National Nanotechnology Program that a staff member should be aware of. This will extend from information about holiday allowance and working hours to the management structure and health and safety policy.*

A lack of R&D performance indicators means that the funding agencies cannot see the specific progress they hope for and the initiatives in the Kingdom cannot be benchmarked against other countries. In addition, the staff working on the initiatives cannot, themselves, see the progress and therefore can be potentially demoralized. There is a definite requirement to measure performance against a set of Key Performance Indicators (KPIs) and benchmark the National Nanotechnology Program against similar international organizations. This will be very important to show performance to stakeholders, staff, and external organizations. However, it is equally important that these measures are not used to control the National Nanotechnology Program and stifle its growth and innovation.

Recommendation: *Develop a set of relevant and appropriate measures to monitor on a regular basis. These can also be used to benchmark against other organizations.*

There is a perception that **government funding schemes tend to be short term** in nature. This translates to a lack of enthusiasm among staff to start new initiatives, such as the National Nanotechnology Program, when earlier ones have failed or stalled due to bureaucracy or change of policy. The earlier projects and outcomes need to be addressed to enable some stakeholders to move on (e.g. solar village). In addition to a need to commit to such an initiative for a significant amount of time and investment, it is essential that the projects do not become over burdened with bureaucracy. In addition to initial lump sum injection of resources for the setting up of facilities and infrastructure, it must be realized that such facilities require significant specialized maintenance and this will require significant annual funding.

Recommendation: *Develop a detailed facility and equipment investment plan.*

Although the generally high level of **education** within the population was seen as a strength, the quality of aspects of the education and training is also viewed as a weakness.

Recommendation: *Engage the education and training institutes within the Kingdom with the experts brought in to lead nanotechnology projects. These experts are often highly experienced in the academic world and will be able to advise how to improve the education and training.*

The lack of collaboration within the Kingdom, combined with the lack of professional planning, and unclear organizational structures, responsibilities and visions is currently a weakness.

Recommendation: *Implement professional project management for all projects within the National Nanotechnology Strategic Plan. All Principal Investigators will be trained in project management at the start of their contract. All projects will have a detailed project plan before approval, incorporating budget, staff requirements, commercial relevance, and collaborations. Certain collaborative relationships can be encouraged through this and also through setting such collaborations as a KPI. All projects will be monitored and progress assessed throughout the lifetime of the project, including successful meeting of milestones and working within the budget. Also detailed management and responsibility plans will be developed.*

Concern was expressed about the **ability to convey the complexity of nanotechnology** to the government and senior fund holders. The ability to attract investors into nanotechnology in the Kingdom was also a concern.

Recommendation: *A group of international nanotechnology experts can give a regular a high level briefing session to key senior members of the government to explain the issues and successes involved in the National Nanotechnology Program.*

It was felt that the research must be of high quality and be meaningful. This again emphasizes the **importance of the initial projects** and the importance of making measurements and benchmarking of progress and value visible to everyone. As far as possible, a plan to gain economic return from the more applied projects should be worked out from the start of the project and industrial partners sought to facilitate this. The large number of research centers and also the autonomy of the universities was also seen as a weakness.

Recommendation: *Some specific technical areas have been recommended as potential focus areas for National Nanotechnology Program, taking into account all the information to date. If there is still some concern about the areas chosen however, it is recommended that an international group of about 10 renowned experts be brought together for a day's workshop to debate the different areas of nanotechnology and to select those that are most beneficial, in their opinion, for KSA.*

The background in this report will help establish the framework for their discussion.

Recommendation: *It is also recommended that some form of monitoring and coordination of nanotechnology facilities be established across the Kingdom. When the Universities are given funding under the program it should ideally be attached to specific milestones and deliverables that are nanotechnology related. The equipment purchased should be accessible to the rest of the stakeholders of the National Nanotechnology Program and the research direction and results coordinated as part of the National Program.*

Recommendation: *An on-line equipment booking system is recommended. The benefits of such a system are that it collects data on utilization of equipment and the identity of the primary users. It can also record the percentage downtime of equipment and also their calibration and a maintenance status. It is particularly useful for monitoring and controlling equipment which is not co-located.*

Procurement is currently an issue with "poor agents, poor buyer representation, slow shipments and heat degradation". Agency regulation for supplies/ chemicals is onerous and not practical.

Recommendation: *Develop a detailed procurement plan.*

Opportunities

The initiation of international collaborations in association with the existing research centers is seen as a major opportunity for the Kingdom. Indeed, there is also an opportunity to build partnerships and alliances between different organizations within the Kingdom.

Some of the potential applications of nanotechnology in KSA are strong and considered excellent opportunities, particularly in the area of water desalination. These have a high economic potential as even just small improvements in desalination or the diversification of the economy will have a large, positive effect on the Kingdom.

The high international demand of nanotechnology solutions, globalization of information and the growing realization by industry that nanotechnology can advance their product or service mean that the timing for embarking on such an initiative is good. It is also an opportunity to bring external investment into the Kingdom.

The Kingdom has a selection of natural resources, such as sand, which are not being exploited fully. The development of a nanotechnology capability may make it possible to exploit such resources to the benefit of the economy.

Threats

Labour Laws involving "Saudization" which involve requirements to hire a high percentage of local staff could prove to be a threat in the short term. Initially the expert staff in nanotechnology will primarily be from overseas until the local population can be trained up to the necessary technical standards.

Recommendation: *Government support is sought up front to be exempt from these laws in the first few years. A sliding scale of conformance can be agreed in return for an agreed training program to allow a high employment rate of Saudi citizens in the later years.*

Reducing **corruption** & code of practice for **quality**

Recommendation: *A detailed quality plan is recommended, in associated with the management organization roles & responsibilities plan. In order to minimize the corruption involved in such large projects it is important to have clear roles, responsibilities, and processes.*

The potential that the **private sector does not buy into** the nanotechnology initiative, even after the capability has been established, is a threat to the long-term viability of the initiative.

Recommendation: *Engage industry through forums and press articles.*

Due to the **lack of experienced project leaders** in nanotechnology and also the issues associated with manpower retention, there is a threat that a capability may rely on one individual and be lost when that individual leaves the initiative. Building capacity beyond an individual, to give stability is considered essential. This will involve building research teams in specific areas, rather than hiring foreign talent and working in whatever area they happen to be a specialist in.

Recommendation: *Develop a detailed Technical Strategy which sets out the focused areas of nanotechnology and breaks them down into capability groups. Staff are then sourced with expertise in these areas and recruitment aims to ensure "an heir and a spare" policy (two extra people) to back up each project leader in the critical capability.*

Spinning off companies is a major aim of the National Nanotechnology Program, as there is not much relevant industry in the Kingdom to license the nanotechnology IP to at the moment. Thus the best form of commercialization of this technology within the Kingdom is by spin out. However, the VC market is immature (most cash goes to commerce) and it seems to be non-trivial to set up (spin–out) a company. There is much bureaucracy and the process is not clear. In addition, the process of patenting and decision-making must be optimized and sped up if companies are to be able to spin out.

Recommendation: *Develop a detailed plan for all IP management including incubation and spin-off of companies.*

Recommendation: *Set up a small committee or organization to oversee the assessment, funding, and incubation of spin out companies seed funded initially by government money. It is recommended that industry pay to be involved in this and that international business experts be consulted. It will be crucial to build a spin-off savvy ecosystem of experienced (and that includes failed-first-time-round) technology focused entrepreneurs.*

There are extremely **competitive states** located around the Kingdom. However, regional competition does not seem to be a current issue, as the surrounding states have much less technical infrastructure. Specific countries, such as Dubai, are seen as less bureaucratic (hence attractive for making quick progress) and showing potential in technical niches (Qatar, for example). Collaboration is unlikely in the short term.

Potential competition is also inevitable from advanced technology countries as the Kingdom will initially be playing catch-up in the technology. There is also a fear that some countries will monopolize nanotechnology. However, assuming the Kingdom remains focused, motivated and investing in specific strategic areas of nanotechnology, it can expect to gain expert status relatively fast. The wide range of technologies and their potential application will ensure a major supply of both major market and niche opportunities. This assumes no issues from other aspects, such as recruitment and retention.

Identifying the correct research areas/projects is seen as a big issue before the initiative can progress. It is important not to miss a line of research at the start which may be important to the future of the Kingdom. In addition, some researchers consider nanotechnology to be over-hyped and feel the investment would be better employed on well-established technologies.

Recommendation: *If necessary consult a group of international experts.*

A concern about the **long term funding** and stability of funding is evident. This emanates both from an unlikely event that oil prices will significantly decrease and therefore bring about a drop in the economy, but also the concern that the government funding agencies may switch the investment to a different project.

In the area of nanotechnology there are **Health, Safety and Environmental unknowns**. Due to the new aspects of nanotechnology, the effect on certain aspects of the technology, such as engineered nanoparticles, on the human body and the environment is still largely unknown. There is therefore a potential risk to researchers and associated environments exposed to such nanoparticles and nanofibres.

Recommendation: *Develop a detailed Health, Safety and Environment Plan and associated training invoking the latest understanding in the area. This plan would be associated with the management roles and responsibilities plan and could be developed by consultants.*

Appendix B: National Nanotechnology Center Equipment

The equipment that the National Nanotechnology Center (NNC) will eventually host is listed below. This equipment will be purchased on a staged basis according to capability requirement and budget.

- Cleanroom:
- Lithography section (class 100):
  - Mask aligner.
  - E-beam lithography.
  - Coaters.
  - Coater bench.
  - Bake oven / Soft bake oven.
  - Developer wet bench.
  - Inspection microscope.
- Wet processing section (class 1,000):
  - Electro plating bench.
  - Electroless plating bench.
  - Developer bench.
  - Solvent benches.
  - Acid benches.
  - Various chemical wet benches.
- Dry processing section (class 1000):
  - E-Beam evaporator (mirrors).
  - E-Beam evaporator (metals).
  - Sputter.
  - PECVD.
  - RIE.
  - LPCVD.

- MBE.
- RTP.

□ Characterization section (class 1000):

- XRD (X-ray Diffractometer).
- Ellipsometer.
- PL-Mapper.
- Optical surface profiler.
- Stylus surface profiler.

■ Equipment in the microscopy room (separate laboratory):

- TEM (Transmisson electonic microscope).
- SEM/FIB (Scanning electronic microscope with focused Ion beam).
- AFM (Atomic force microscope).

■ Epitaxial growth room.

■ MOCVD (Metal organic chemical vapor deposition).

■ Back end processing room.

■ Lapping & polishing.

■ Scribing & breaking.

■ Die attach.

■ Wire bonder.

Appendix C: Plan Development Process

The process of developing this plan included a three-day stakeholder workshop. Following the workshop, KACST prepared a draft plan with the assistance of Scientifica. As part of the planning process, an advisory committee was formed, and the committee met to review and comment on the draft plan. The advisory committee members are listed below. Workshop participants and advisory committee members represented themselves as individuals, and did not necessarily represent their organizations.

Table A-1: Advisory Committee Members

Name	Organization
Tim Harper	Cientifica Co., UK
Adrian Burden	Singular ID, Singapore
Dexter Johnson	Cientifica Co., UK
Abdulrahman A. Al-Muhanna	King Abdulaziz City for Science and Technology

Table A-2: Workshop Participants

Name	Affiliation
Qassim Fallata	Aramco
Mohammed Albagami	AEC
Abdulmajeed Almazroo	STC
Riyad Alrawase	STC
Muteb Alonezi	Yamama Cement Co.
Fawwaz Almutari	Qassem Cement Co.
Saleh Alfawzan	SWCC
Abdulrahman Alarifi	SWCC
Ahmad Aleid	Military Hospital

Name	Affiliation
Ibraheem Babilli	Government
Khalid Albaiz	Government
Homod Almodaini	Government
Abdulrazzag Alsofyani	Government
Fahad Alghobayni	Government
Abdullah Alsaif	Government
Faisal Alsaif	Government
Abdulmuhsen Algorayni	Government
Hani Alghamdi	Government
Abdullah Alsabti	KACST
Khondakar Idrees	KACST
Mohammad Abdulhadi	KACST
Abdullah Alahdal	KACST
Zain Yamani	KFUPM
Mahmood Sulyman	KSU
Maher Alodan	KSU
Sami Habeeb	KAU
Abdullah Alja'afri	KFU

The management team for the planning project from KACST are:

Table A-3: Planning Project Core Team

Name
Abdulrahman A. Almuhanna
Khalid A. Aldakkan
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