Kingdom of Saudi Arabia

Strategic Priorities for Advanced Materials Technology Program

مدينة الملك عبدالعزيز
للعلوم والتقنية KACST
King Abdulaziz City for Science and Technology

Kingdom of Saudi Arabia
Ministry of Economy and Planning
http://www.mep.gov.sa

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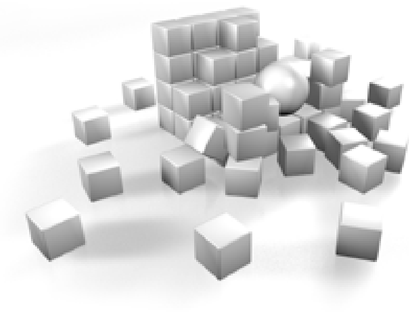

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Executive summary

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 document is the strategic priorities for one of these programs, the Advanced Materials Program.

Advanced materials are critical for the Kingdom of Saudi Arabia (KSA). There is a potential for the Kingdom to capture greater value-added from petroleum through the development of petrochemical-based materials, including polymers and composites. Further potential comes from natural mineral resources if coupled with advanced technologies to produce new advanced materials. There is a great need for improved materials for use in water desalination and in the petroleum and petrochemical industries. There are also needs for specialized medical materials, aerospace and defense materials, and new construction materials.

This plan is based on input from the users and stakeholders for advanced materials in the Kingdom, including government agencies, industry, universities, and medical centers that use advanced materials or conduct advanced materials R&D.

Executive summary

The planning process:

- Identified the main stakeholders in the Kingdom for advanced materials.
- Identified the key needs of the Kingdom in advanced materials.
- Assessed the strengths, weaknesses, opportunities, and threats for the program, including an analysis of KSA publications and patents in advanced materials and an assessment of international research institutes.
- Defined a mission and vision for the Kingdom's advanced materials program.
- Defined the key technologies and other program areas needed to address the Kingdom's needs in advanced materials.

Seven key technology fields emerged from this process:

- Membranes.
- Composite and Hybrid Materials.
- Polymers and polymer processing technologies.
- Metals and alloys.
- Ceramics.
- Smart Materials.
- Coating.

Examples of specific technologies to be pursued in these fields are shown in table ES1 below.

Table ES 1:

Key Advanced Materials Technologies for Saudi Arabia	
Field	**Technology**
Membranes	**Advanced function membranes:** biofouling resistant, chlorine tolerant, chemical and scale resistant, high reverse osmosis rejection and permeability membranes, gas separation and sterilization membranes. Development platforms: nano-, micro-, and ultra- filtration membranes, electrolytic membranes.
Composite and hybrid materials	**Advanced functions:** composites for desalination and construction processes; high pressure and temperature applications; fiber reinforced resins and polymers; ceramic and radiation shielding composites; lightweight and nanocomposites
Polymers and polymer processing	**Industrial applications:** pipeline and storage tanks, electronics, textiles, environment, agriculture and water, oil and gas drilling, dentistry, drug delivery. Development platforms: resin systems and high temperature ablative resins, nanostructure, water soluble and biodegradable polymers, flame retardants, UV light stabilizers and nanoparticles for polymer reinforcement.
Metals and alloys	**Advanced functions:** duplex and ferritic steels for thermal plants, materials for desalination plants, high temperature stress corrosion cracking, medical applications, defense and aerospace applications, equipment for oil/gas services. Specialized alloys: corrosion and erosion resistant, high temperature and strength.
Ceramics	**Advanced functions:** insulation, medical implants, building materials, industrial furnaces. Specialized ceramics: alum oxide, tungsten carbides, refractory oxide dispersion strengthened alloys.
Smart materials	**Advanced functions:** Photo-, thermo-, piezo-, tribo- and electro-chromic materials; smart glass, textiles and packaging; organic and inorganic LEDs and photovoltaic materials; self-cleaning and multifunctional materials and switchable systems
Coating	**Advanced functions:** corrosion resistant, UV light protection; self-cleaning and self-healing; light, heat and pressure switchable coatings; metallic, thermal barrier coating and electroplating.

Executive summary

The Advanced Materials Program will work to enhance the position of the Kingdom in these technologies and to apply the technologies to meet the needs of the Kingdom.

The Advanced Materials Program will be directed by a Program Manager, who will be responsible for the overall execution of the plan. The main selection criteria for the projects in the program are:

- Potential impact of the project on the Kingdom's needs for advanced materials.
- Potential contribution of the project to new knowledge.
- Technical and managerial capabilities of the performer.
- Portfolio balance among program goals, technology tracks, stakeholder needs, and research performers.

The key performance indicators are:

- Number and impact of successful applications of advanced materials to stakeholder needs.
- Expansion of number of research-active material scientists in Kingdom.
- Number of papers published in journals listed in ISI and their impact.
- Number of generated patents.
- Number of products successfully entering the market.
- Number of successfully incubated new companies.
- Number of researchers trained and applications developed in Technology Innovation Centers.

The Advanced Materials Advisory Committee, with stakeholder membership, will oversee the implementation of the plan. It will review performance metrics and provide advice on the portfolio of projects. The Committee 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 National S&T Programs.

Introduction

Background

The National Policy for Science and Technology, approved by the Council of Ministers in 1423 H (2002 G), defined 11 programs for the localization and development of strategic technologies that are essential for the Kingdom's future development. The King Abdulaziz City for Science and Technology (KACST) was given responsibility for developing 5-year strategic and implementation plans for each of these 11 technology programs. This document is the plan for one of these programs, the Advanced Materials Program.

Advanced materials are widely recognized by many nations to be a critical technology. For example, the U.S. National Science and Technology Council recognized that advanced materials were the foundation of manufactured products, and Japan includes "nanotechnology/materials" as one of its four priority areas for investment.

Advanced materials are critical for the Kingdom of Saudi Arabia (KSA). There is a potential for the Kingdom to capture greater value-added from petroleum through the development of petrochemical-based materials, including polymers and composites. There is a great need for improved membranes and separations technologies for use in water desalination and in the petroleum and petrochemical industries. Advanced materials are also needed to withstand the various environmental conditions present in the Kingdom. Corrosion resistant materials are needed for the petroleum and water sectors, and temperature and abrasion resistant materials are needed for many applications. There are also needs for specialized medical materials, aerospace and defense materials, and construction materials.

This plan defines a vision for advanced materials research and technology development for the Kingdom; identifies key needs; assesses strengths, weakness, opportunities, and threats; and defines a set of programs to meet these needs. It presents a plan for advanced materials based on input from the users and stakeholders for advanced materials in the Kingdom. These include companies, government agencies, and medical centers that use advanced materials, as well as the universities and other research organizations that conduct advanced materials R&D. The plan received input from stakeholders at a one-day stakeholder workshop on June 17, 2007, and received extensive input, review, and comment from a stakeholder advisory committee that met repeatedly in the following months.

Introduction

Program Scope

The scope of this plan is advanced materials science and technology programs for Saudi Arabia. The scope of the program includes the Kingdom's government, university, and industry research and technology development efforts in advanced materials. This plan targets the first 5-year phase of the 20-year National Policy for Science and Technology.

The term "advanced" materials is used to emphasize that the focus is on higher value-added materials, rather than commodity materials. There is no clear division between advanced materials and ordinary materials based on the type of material. While some kinds of materials, such as photonic materials, are generally considered advanced materials, many other kinds of materials, such as metals and ceramics may or may not be advanced materials, depending on their level of technology. For the purpose of this program, materials that are the subject of significant research and technology development efforts are considered advanced materials.

Alignment with National Science & Technology Policy

The National Policy for Science and Technology defined four main goals for S&T programs:

1. Preserving national security.
2. Serving sustained, balanced, and comprehensive development.
3. Promoting the citizens' standard of living and quality of life.
4. Contributing to human civilization.

It also defined General Objectives that can be summarized as follows:

1. Adopting a comprehensive view of the national science, technology, and innovation system that supports system development as well as coordination and integration of its components and beneficiaries.
2. Developing qualified human resources in science and technology fields.
3. Fostering and supporting scientific research to serve national security and sustainable development.
4. Supporting and developing the technical capabilities of various national sectors to enable technology localization and development, and production of high added value, internationally competitive products.
5. Continuously developing and coordinating the official regulations related to science and technology.
6. Promoting effective international cooperation in science and technology.
7. Enhancing science and technology support activities, such as information and standardization services, patents, consulting and engineering firms, and scientific societies.
8. Developing and investing in a knowledge-based economy and community and their required information technologies.
9. Exploiting science and technology for the preservation of natural resources and the environment.
10. Creating social awareness of the importance of science and technology in realizing national security and sustainable development.

The National Policy for Science and Technology further defined ten "Strategic Underpinnings" that are compatible with the above-mentioned goals and objectives. The national policy goals and objectives, as well as the key needs of the Kingdom outlined in Subsection 2.1, form the starting point and foundation for developing the program's strategy, goals, and projects, as will be outlined in this plan.

Advanced Materials R&D Needs of the Kingdom

The Advanced Materials Program planning process put a strong emphasis on identifying the most critical advanced materials research and innovation needs for the Kingdom. Emphasis was placed on areas where there are special needs in the Kingdom due to the Kingdom's unique environment, culture, and existing industries, or where there are opportunities for KSA industry to have a competitive advantage. The following strategic areas were identified as priorities for advanced materials applications.

Water

Water is a critical need in Saudi Arabia. Saudi Arabia has the world's largest sea water desalination industry. There are many needs for advanced materials in water desalination, water treatment, water resources and conservation. The Kingdom has competencies in water technologies, such as in the Saline Water Conversion Corporation, which has a research institute, holds patents, and operates pilot plants and test facilities. The Kingdom needs to build on these capabilities to develop successful technology-based businesses.

Key advanced materials needs for water include:

- Membranes: These include reverse osmosis, nano filtration, ultra filtration, and micro filtration. These membranes are currently used but not produced in the Kingdom.
- Anti-scaling materials: Various anti-scaling materials are currently used in thermal processes. Product performance is temperature-delimited and breakthroughs are needed.
- Corrosion-resistant materials: Materials are required for preventing corrosion, especially in high-temperature environments. Advanced materials are also required to strengthen corrosion-resistant pipelines.
- Additives: Additives are used to reduce pollution. New additives with better performance are required.
- Water source identification: Advanced materials can play a critical role in developing tracers.

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Oil & Gas

The Kingdom is the world's leading producer of petroleum. A wide variety of advanced materials are needed in petroleum production. Key needs include:

- Corrosion: Materials are needed that can survive the sour (high sulfur content) service.
- Sulfur utilization: The KSA oil and gas industry needs better materials for use in converting or using sulfur.
- Composites: Composites are needed for construction, oil pipelines, optical fibers, and water services (such as pipelines, storage, processing, and disposal). Major technical challenges relate to joining, manufacturing, and installation. There are also issues with training and standards that limit applications.
- Non-destructive testing (NDT): NDT methods applied to composites and advanced materials are a key focus area.
- Welding Technologies: Although welding is viewed as a mature technology, there are many materials-related problems that need to be addressed.
- Oil Recovery: There is a strong need for polymers and other additives to enhance oil recovery.
- Drilling processes: Advanced materials are needed for non-vertical drilling.
- Coatings: Coating materials are required to reduce corrosion failures, especially those related to high-temperatures. Materials are needed to reduce wear in gas turbines.
- Anti-scaling materials: Anti-scaling materials are of great demand in the petroleum sector.

Petrochemicals

The Kingdom has a major petrochemicals industry. Many of this industry's materials needs are similar to those in the oil and gas industry but there are additional needs for:

- Advanced polymers: Some key areas include additives such as flow enhancers, fillers, ultraviolet stabilizing polymers, and fire-resisting polymers.
- Polymer processing technologies: such as those used to produce molds, coatings, and paints.
- Catalysts: including catalyst materials, regeneration, and catalyst support.
- Materials for environmental protection: including biodegradable materials.

Health, Biomedicine, and Pharmaceuticals

The Kingdom has an active health research and services sector and includes some generic pharmaceutical manufacturers. There are a number of advanced materials needs in this sector:

- Radioactive materials are needed for a wide variety of diagnostics, therapeutics, and sterilization purposes. There are also special packaging needs for radioactive materials.
- Genetic materials, including biomolecules with specific genetic compositions for diagnostics.
- Medical implants and prosthetics, which require specialized materials and coating and machining technologies.
- Tissue engineering, requiring polymeric biodegradable and non-biodegradable materials.
- Selective drug delivery, requiring new bioactive molecules.
- Membranes for dialysis.
- Specialized materials for biofacilities.

Mining and Metals

Saudi Arabia is a significant producer of minerals and metals. Some key needs are for:

- Mining and production processes.
- New technologies and processes for characterization of alloys.
- KSA-specific development of alloys for lamination and high-temperature conditions.
- Powder technologies.

Strategic Context

Agriculture and Food

The KSA agriculture and food industry has some specialized material needs, including:

- Polymer-coated fertilizers for longer life.
- Degradable pesticides.
- Materials for food packaging.
- Additives to prevent ultraviolet rays from penetrating food or beverages.

Defense

There are a variety of defense needs for advanced materials, including sulfur resistant materials and titanium based materials for aircraft, radar materials, light weight fiber reinforced (FR) composites for vehicles and gap crossings (e.g., bridges), radiation shielding, and erosion resistant materials.

Other needs

There are a number of other advanced material needs for the KSA construction, power, and electronics industries, including:

- Smart glass and smart windows for the construction industry.
- Silicon based materials including (poly/mono crystalline silicon), silicon wafers, semiconductor processing materials, silicon nano-particles, and silicon oxide nano-particles, for applications in electronics and other industries, Silane; Silicones.
- Heat transfer materials, to both aid and reduce heat flow, with applications in many industries.
- Photovoltaic and thermal technologies and materials for the solar industry, including thin films, solar cell, and coatings such as electro-catalytic coatings.
- Coating materials, including pre-coating surface preparation, inorganic (metal deposition, nano crystalline materials etc.), and organic (especially high temperature offshore coating or fast-cure coating), and coatings materials used in electro/ thermal/ photo chromic applications.
- Advanced ceramics for several industries.
- Composite materials, carbon-fiber composites and fiber glass composites for civil and infrastructural needs.

These are all areas where the Advanced Materials Program can provide benefits to the Kingdom through development, transfer and adaptation of advanced materials.

Strategic Context

Stakeholders Roles

The major program stakeholders include KACST, other government agencies, KSA universities, and industry. Their roles are as shown in table 1.

Table 1: Advanced Materials Stakeholder Roles

Stakeholders	Roles
KACST	■ Coordinate and manage Kingdom wide advanced material initiatives
	■ Manage and participate in national and international projects
	■ Provide materials research user facilities
	■ Provide consultation and advice to government on issues related to advanced materials and relevant technology transfer
Universities	■ Create new basic and applied scientific knowledge
	■ Train students in material science, engineering and relevant technical fields
	■ Participate in national and international collaborative projects
Independent or Specialized Government Research Centers	■ Create new applied scientific knowledge and operational prototypes
Government Agencies	■ Provide oversight of operations and implementation of relevant projects
Private Sector	■ Develop and commercialize products and processes resulting from the program
	■ Participate in national and international collaborative projects
	■ Participate in Technology Innovation Centers

Kingdom's Industry Status

The status of the Kingdom's industry related to advanced materials affects the Kingdom's strategy to succeed in the technologies. The Kingdom has several industries that are either users of advanced materials, producers of materials, or performers of materials R&D.

The major industrial entities are:

- Saudi Aramco and its suppliers are significant users of advanced materials, and Aramco's R&D center has materials scientists working on problems of interest to the industry.
- The Saline Water Conversion Corporation (SWCC) has an R&D center that conducts research on corrosion, scaling, and other materials problems.
- Saudi Arabia Basic Industries Corporation (SABIC) is a major producer of basic materials, especially petrochemicals but also minerals. It recently acquired GE Plastics, and so is a major producer of plastics, although not in Saudi Arabia. SABIC conducts a significant amount of R&D, but predominately outside of the Kingdom.
- The King Faisal Specialist Hospital and Research Centre, although not typically thought of as industry,

conducts research and produces specialized medical materials, such as radioactive materials.
Other industries that could potentially play a significant role in advanced materials in the Kingdom are aerospace/defense, electronics, solar energy, and construction. At present, these are either relatively small, not involved in the materials sector of their industry, or, as in the case of construction, are not significantly involved in technology development.

While the Kingdom is not a major producer of advanced materials, there is a strong domestic demand for advanced materials in several industries, very strong production of basic materials, and some industrial R&D capacity in advanced materials. These characteristics create the potential for establishing a successful domestic advanced materials industry.

Materials Research at Selected KSA Research Organizations

To better understand the current research capabilities of KSA research institutions in materials, the Advanced Materials Advisory Committee collected information from several universities and KACST regarding their areas of technical focus and number of researchers. These are shown in table 2.

Table 2: Materials research at selected KSA institutions

Organization	Materials field	Staff size
King Fahd University of Petroleum and Minerals	1. High temperature thermal barrier coatings 2. Atmospheric corrosion of Al alloys 3. Materials related problems in local industry 4. Corrosion inhibition of construction materials 5. Sea water corrosion of Al alloys 6. Development of corrosion and wear resistant coatings 7. Development of catalyst materials 8. Polymeric materials 9. Development of carbon nanotubes 10. Development of nanocomposite coatings 11. Concrete corrosion	10 PhDs 20 MSc.

Organization	Materials field	Staff size
King Abdulaziz University	1. Smart functional materials 2. Polymer science and technology 3. Coating science and technology 4. Semiconductor materials and devices 5. Catalysis 6. Multi-scale computation, simulation and design of materials 7. Applications of lasers in advanced materials	30 PhD 10 MSc. 10-15 graduate students
King Saud University	1. Characterization of materials and their performance and improvement in their properties. 2. Materials corrosion and protection 3. Polymer characteristics, improvement and processing	10 faculty; 4-8 graduate students
KACST	1. Metals and alloys. 2. Coating 3. Semiconductors and solar cells 4. Membranes 5. Polymers and polymer technology 6. Ceramics 7. Corrosion 8. Catalyst 9. Petrochemical	10 PhD 5 MSc.

Review of International Advanced Materials Research Institutes

The Advanced Materials Program also reviewed the activities of several research institutions around the world that have a significant focus on advanced materials. These were selected to provide examples of government research institutes that are similar in scope and purpose to that of KACST's. The five institutions reviewed are shown in table 3.

Table 3: Select Advance Materials Institutions

Selected Advanced Materials Institutions	
Institute	**Country**
Commonwealth Scientific and Industrial Research Organization (CSIRO) Manufacturing & Materials Technology (CMMT) Division	Australia
National Institute for Materials Science (NIMS)	Japan
Institute of Materials Research and Engineering (IMRE), Agency for Science, Technology and Research (A*STAR)	Singapore
Materials Science and Engineering Laboratory (MSEL), National Institute of Standards and Technology (NIST), U.S. Department of Commerce	United States
Oak Ridge National Laboratory (ORNL), U.S. Department of Energy	United States

The five research institutes conduct R&D in similar areas of advanced materials, but they each have a slightly different focus, depending on the national needs of their country. The research focus and priorities of the five organizations are summarized in table 4.

Table 4: Materials Research Focus

Organization	Materials Research Focus
CSIRO CMMT (Australia)	Ceramics (e.g., coatings, membranes, electronic ceramics)
	Chemicals (e.g., biocompatible, biofunctional, membranes, nanoscale, highly porous materials with nanoscale pores)
	Materials characterization and performance
	Metals (light metals and also development of new alloys)
	Advanced and composite materials (e.g., wood and polymer composites, nanocomposites, nanomaterials, geopolymers)
	Plastics and polymers
	Renewable and biodegradable materials
	Textiles
	Wood

Organization	Materials Research Focus
NIMS (Japan)	Key nanotechnologies (e.g., nano system functionality, advanced nano characterization, among others)
	Nanoscale materials
	Nanotech-driven materials research for information technology
	Nanotech-driven materials research for biotechnology
	Materials research for the environment and energy
	Materials research for reliability and safety
A*STAR IMRE (Singapore)	Micro- and nano-systems
	Molecular and performance materials
	Opto- and electronic systems
	Materials science and characterization
NIST MSEL (USA)	Materials measurement and standards infrastructure
	Advanced manufacturing processes
	Biomaterials
	Materials for electronics
	Nanometrology
	Carbon nanotubes
	Safety and reliability
ORNL Center for Nanophase Materials Sciences (USA)	Catalysis and nano-building blocks
	Functional nanomaterials
	Macromolecular complex systems
	Nanofabrication
	Nanomaterials theory
	Nanoscale structure and dynamics: neutrons, electrons, X-rays
	Nanophysics: magnetism, transport, and scanning probes

The institutes have several other common characteristics. All of the organizations emphasize a commitment to technology transfer to industry, and most have integrated this priority into their organizational structures. All of the research institutes in this report have collaborative linkages with other organizations, public, academic and private. For example, CSIRO has a light metals Flagship research initiative, involving an extensive partnership with many industry players, to develop ultra-light, ultra-strong recyclable metals.

Most of the research institutes have a staff size of between 200 to 500 materials researchers of varying credentials. To develop human capital, the institutes have strong partnerships with universities to mentor and train postgraduate research students, as well as guest researcher programs. NIMS, for example, has an International Center for Young Scientists, which gives young researchers from various countries and diverse research field opportunities to conduct research.

Most of the institutes have facilities that they promote for external use. Users can often book the equipment online. Of note are ORNL's Spallation Neutron Source and High Flux Isotope Reactor, NIST's Center for Neutron Research (NCNR), and NIST's Center for Theoretical and Computational Materials Science.

All five research institutes receive direction for their strategic plans from their respective overarching national strategic plans and/or agencies. The research institutes may also receive external guidance from industry and academia, as in the case of CSIRO, NIMS, and NIST.

Advanced Materials R&D Indicators

Overview

This section provides indicators of advanced materials R&D based on publication and patent data. Publication and patents are widely used as indicators of science and technology, although publication and patent counts alone do not fully represent the quality or scope of research.[1] Several commonly used indicators include the numbers of publications and patents, the forward citations of publications and patents (the frequency at which publications and patents are cited by other publications and patents), and the co-authoring relationships of publications. These provide indicators of research and inventive output, impact, and collaboration.

For this analysis, the field of "advanced materials" and its subfields were defined in close consultation with KACST researchers and other KSA stakeholders. KACST researchers identified seven subfields relevant to KSA strategic priorities and provided detailed lists of keyword terms that were used to develop search queries for publication and patent databases.[2] Advanced materials R&D is a multidisciplinary field that spans many research areas, including applied physics, physical chemistry, condensed matter physics, chemical engineering, and nanoscience. The seven KSA advanced materials subfields are: membranes, composite and hybrid materials, polymers and polymer processing technologies, metals and alloys, ceramics, smart materials, and coatings. The scope of this study was restricted to only recent publication (2006-2007) and patent (2002-2006) activity in the seven KACST defined fields.

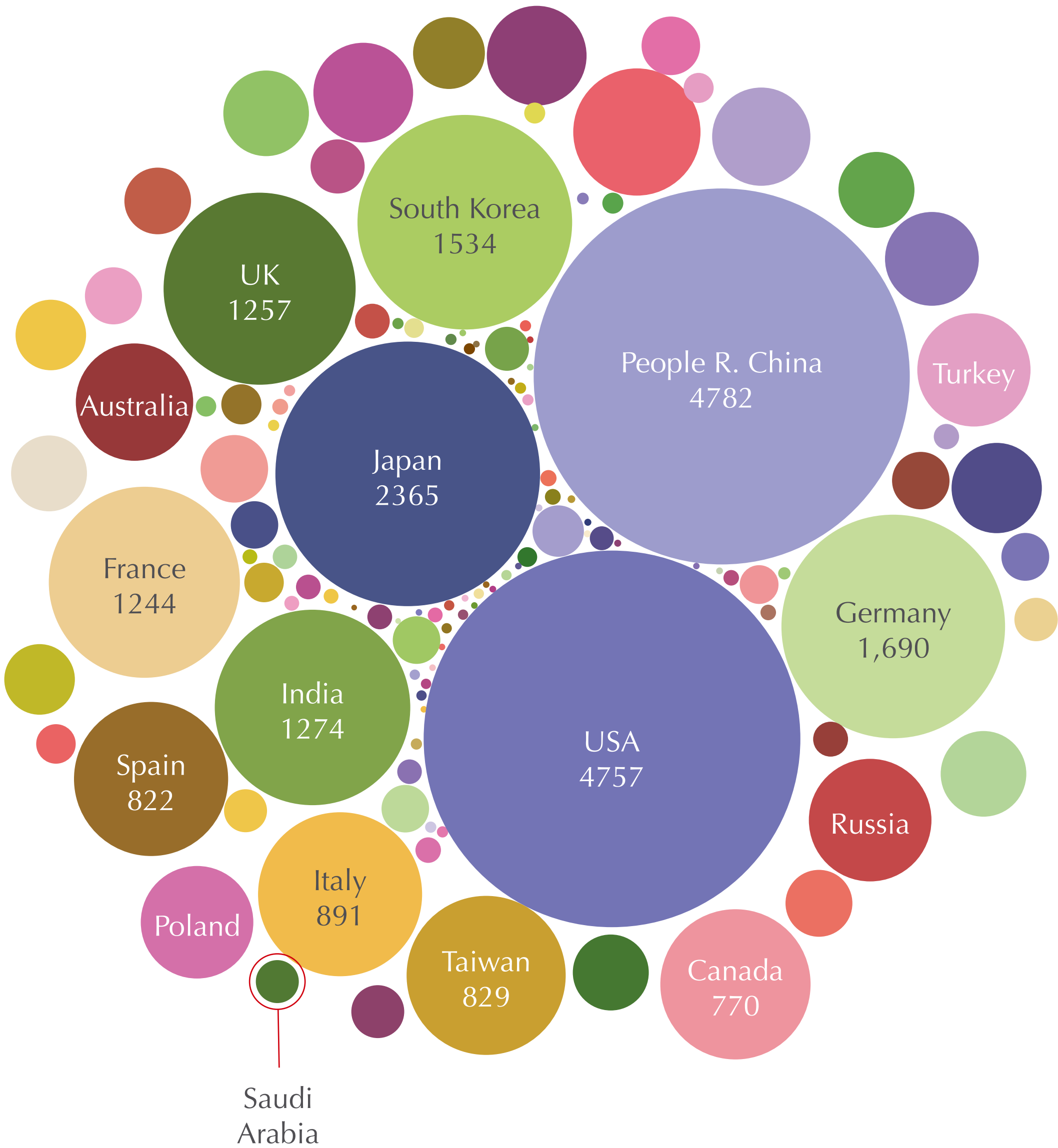
1 Seminal research in the use of publications as a measure of scientific productivity includes A.J. Lotka, "The frequency distribution of scientific productivity," Journal of the Washington Academy of Sciences, vol 16 (1926); D. Price, Little Science, Big Science, (New York: Columbia university Press, 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.

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.

Global Advanced Materials Publication Activity

Between 2006 and 2007, there were 25397 articles published worldwide related to KSA research priorities in advanced materials.[3] Figure 1 shows the number of publications produced by countries over this time period.[4] The People's Republic of China was the world's largest producer of related articles, generating 4782 articles over this time period. The United States was second, producing 4757 articles followed by Japan and Germany with 2365 and 1690 articles respectively. Saudi Arabia was the 46th largest producer of publications, producing 67 articles in ISI-indexed journals.

Figure 1: Advanced Materials Publications



3 Throughout this report, "advanced materials" refers only to the subset of advanced materials defined by the KSA advanced materials program.

4 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.

Strategic Context

As shown in table 5, composite and hybrid material R&D accounts for the majority of advanced materials related publications (7886) followed by polymers and polymer processing technologies (5283), metals and alloys (3540), smart materials (3296), membranes (2878), ceramics (2382) and coatings (1423).

Table 5: Advanced Materials Sub-topics (2006-2007)

Sub-Topic	Publications
Composite and Hybrid Materials	7886
Polymers and Polymer Processing Technologies	5283
Metals and Alloys	3540
Smart Materials	3296
Membrane	2878
Ceramics	2382
Coatings	1423

Publication Impact

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 1.81 followed by Singapore (1.53) and the United Kingdom (1.43). The average publication impact for Saudi Arabia was 0.42 with 28 citations of 67 articles. The table 6 presents publication and citation counts for benchmark countries.[5]

5 Benchmark countries include global leaders in terms of total advanced materials output in addition to a list of specific countries provided by KACST.

Table 6: Benchmark Country Publication Impact (2006-2007)

Country	Publications	Total Citations	Average Publication Impact
USA	4757	8607	1.81
Singapore	329	504	1.53
UK	1257	1795	1.43
Israel	177	247	1.40
Oman	8	11	1.38
Germany	1690	2307	1.37
France	1244	1697	1.36
South Korea	1534	1894	1.23
Peoples R China	4782	5001	1.05
Japan	2365	2316	0.98
South Africa	73	69	0.95
India	1274	1136	0.89
Kuwait	19	10	0.53
Malaysia	99	42	0.42
Saudi Arabia	67	28	0.42
UAE	22	5	0.23

Advanced Materials Research Organizations

Advanced materials R&D publications are produced at thousands of research institutions in 120 countries. As shown in table 7, the three institutions producing the largest number of publications related to advanced materials R&D are the Chinese Academy of Sciences (806), the Indian Institute of Technology (336), and Tsing Hua University (333). The Chinese Academy of Sciences is the largest producer of publications in all advanced materials sub-topic areas except ceramics. The Russian Academy of Sciences is the largest producer of ceramics related publications.

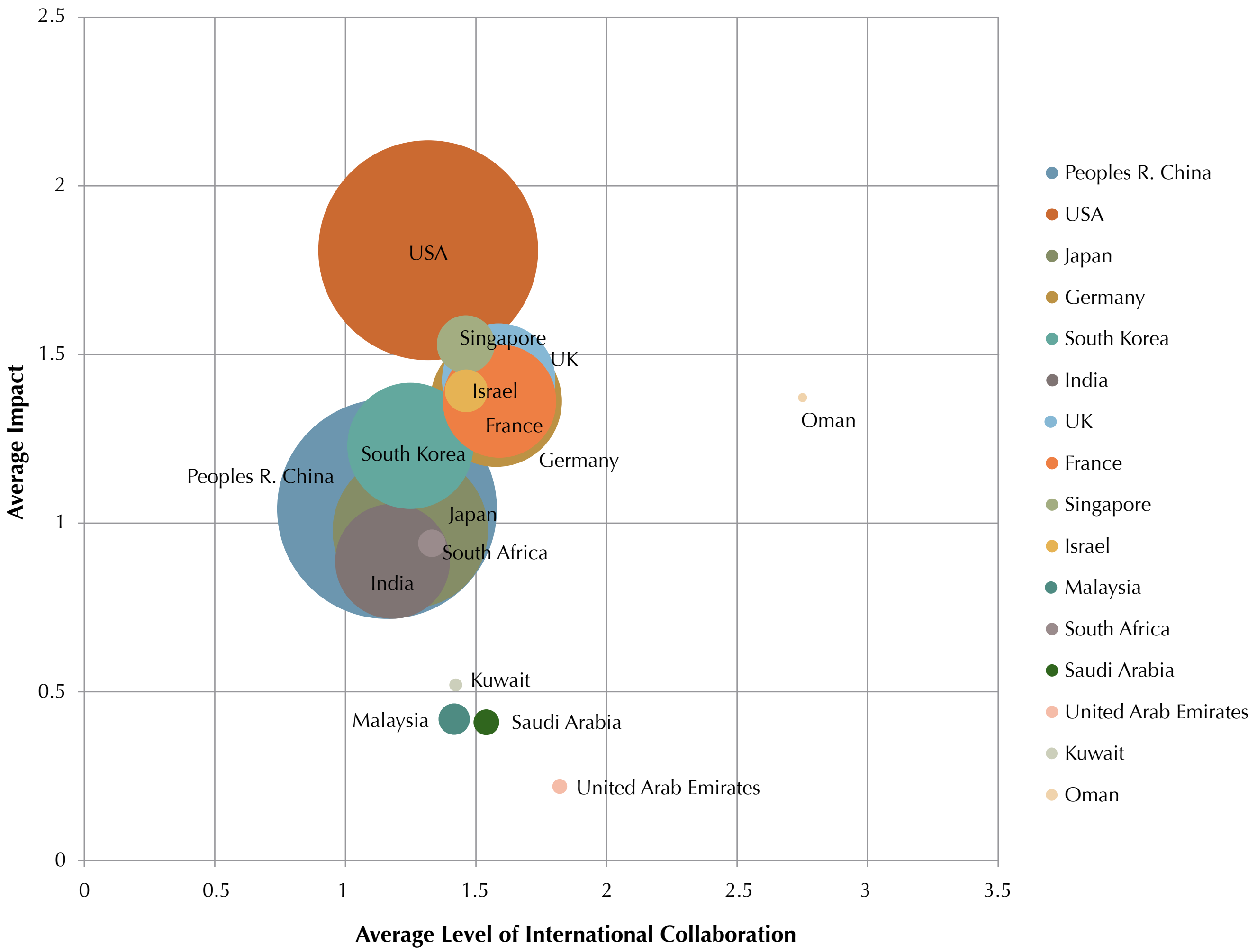
Table 7: Global Advanced Materials R&D Organizations (2006-2007)

Institution	Total	Average Impact	Composite and Hybrid Materials	Polymers and Polymer Processing Technologies	Metals and Alloys	Smart Materials	Membrane	Ceramics	Coatings
Chinese Acad Sci	806	1.61	235	122	146	152	85	48	56
Indian Inst Technol	336	0.78	113	46	91	34	19	33	25
Tsing Hua University	333	1.33	93	50	46	69	42	30	14
Univ Sci & Technol China	295	1.26	74	72	39	62	19	29	11
Russian Acad Sci	253	0.59	68	47	27	33	28	52	12
Harbin Inst Technol	220	0.46	103	13	68	10	11	13	9
Seoul Natl Univ	214	1.47	59	41	13	60	29	16	8
Univ Texas	194	1.99	69	56	14	13	29	11	10
Tohoku Univ	191	0.99	44	14	95	17	13	9	11
Natl Univ Singapore	188	1.82	39	56	11	20	56	10	4

International Collaboration and Publication Impact

In this study, international collaboration is calculated as the average number of countries represented per publication, based on authors' addresses. Figure 2 plots a country's level of international collaboration (horizontal axis) against the average impact of its publications (vertical axis).

Figure 2: Advanced Materials Collaboration and Publication Impact (2006-2007)



KSA Collaboration Activity

In the advanced materials field, as shown in table 8, authors affiliated with KSA institutions collaborated on a significant number of articles with authors from: Egypt (8 publications), Lebanon (5), and the United States (5). KSA-affiliated authors also collaborated with authors from: Ireland, Italy, Turkey, the United Kingdom, Yemen, and Qatar.

Table 8: KSA Publication Collaborators (2007)

Country	Number of Publications
Egypt	8
Lebanon	5
USA	5
Ireland	4
Italy	4
Turkey	4
United Kingdom	3
Yemen	2
Qatar	1

Advanced Materials Journals

Table 9: presents journals with a significant level of publication activity related to KSA advanced materials sub-fields from (2005 - 2007).

Table 9: Advanced Materials Journals

	Journal	Publications
Composites	JOURNAL OF APPLIED POLYMER SCIENCE	233
	COMPOSITES SCIENCE AND TECHNOLOGY	204
	COMPOSITE STRUCTURES	151
	COMPOSITES PART A-APPLIED SCIENCE AND MANUFACTURING	125
	JOURNAL OF MATERIALS SCIENCE	122
	JOURNAL OF COMPOSITE MATERIALS	112
	MATERIALS LETTERS	111
	JOURNAL OF COMPOSITES FOR CONSTRUCTION	109
	JOURNAL OF REINFORCED PLASTICS AND COMPOSITES	101
	MATERIALS SCIENCE AND ENGINEERING A-STRUCTURAL MATERIALS PROPERTIES MICROSTRUCTURE AND PROCESSING	99

	Journal	Publications
Coatings	SURFACE & COATINGS TECHNOLOGY	150
	JOURNAL OF APPLIED POLYMER SCIENCE	30
	APPLIED SURFACE SCIENCE	28
	LANGMUIR	26
	NANOTECHNOLOGY	26
	THIN SOLID FILMS	23
	ELECTROCHIMICA ACTA	21
	MATERIALS SCIENCE AND ENGINEERING A-STRUCTURAL MATERIALS PROPERTIES MICROSTRUCTURE AND PROCESSING	18
	APPLIED PHYSICS LETTERS	17
	JOURNAL OF APPLIED PHYSICS	17
Ceramics	JOURNAL OF THE EUROPEAN CERAMIC SOCIETY	101
	JOURNAL OF THE AMERICAN CERAMIC SOCIETY	68
	SURFACE & COATINGS TECHNOLOGY	47
	RARE METAL MATERIALS AND ENGINEERING	46
	MATERIALS SCIENCE AND ENGINEERING A-STRUCTURAL MATERIALS PROPERTIES MICROSTRUCTURE AND PROCESSING	41
	JOURNAL OF MATERIALS SCIENCE	37
	APPLIED PHYSICS LETTERS	31
	CERAMICS INTERNATIONAL	29
	JAPANESE JOURNAL OF APPLIED PHYSICS PART 1-REGULAR PAPERS BRIEF COMMUNICATIONS & REVIEW PAPERS	28
	JOURNAL OF APPLIED PHYSICS	28

	Journal	Publications
Metals and Alloys	SURFACE & COATINGS TECHNOLOGY	252
	MATERIALS SCIENCE AND ENGINEERING A-STRUCTURAL MATERIALS PROPERTIES MICROSTRUCTURE AND PROCESSING	212
	CORROSION SCIENCE	150
	RARE METAL MATERIALS AND ENGINEERING	108
	TRANSACTIONS OF NONFERROUS METALS SOCIETY OF CHINA	104
	ELECTROCHIMICA ACTA	83
	MATERIALS TRANSACTIONS	75
	JOURNAL OF ALLOYS AND COMPOUNDS	75
	SCRIPTA MATERIALIA	62
	APPLIED SURFACE SCIENCE	61
Membrane	JOURNAL OF MEMBRANE SCIENCE	380
	DESALINATION	157
	SEPARATION AND PURIFICATION TECHNOLOGY	60
	INDUSTRIAL & ENGINEERING CHEMISTRY RESEARCH	44
	JOURNAL OF POWER SOURCES	41
	LANGMUIR	40
	NEPHROLOGY DIALYSIS TRANSPLANTATION	35
	JOURNAL OF APPLIED POLYMER SCIENCE	33
	NANOTECHNOLOGY	30
	PERITONEAL DIALYSIS INTERNATIONAL	30
Polymer	JOURNAL OF APPLIED POLYMER SCIENCE	304
	ELECTROCHIMICA ACTA	113
	POLYMER	111
	SYNTHETIC METALS	92
	POLYMER DEGRADATION AND STABILITY	90
	MACROMOLECULES	88
	JOURNAL OF POLYMER SCIENCE PART A-POLYMER CHEMISTRY	78
	BIOMATERIALS	73
	EUROPEAN POLYMER JOURNAL	71
	JOURNAL OF POWER SOURCES	67

	Journal	Publications
Smart Materials	APPLIED PHYSICS LETTERS	301
	THIN SOLID FILMS	122
	JOURNAL OF APPLIED PHYSICS	93
	SOLAR ENERGY MATERIALS AND SOLAR CELLS	90
	JAPANESE JOURNAL OF APPLIED PHYSICS PART 1-REGULAR PAPERS BRIEF COMMUNICATIONS & REVIEW PAPERS	89
	JOURNAL OF MATERIALS CHEMISTRY	73
	ADVANCED FUNCTIONAL MATERIALS	64
	JOURNAL OF POLYMER SCIENCE PART A-POLYMER CHEMISTRY	56
	MOLECULAR CRYSTALS AND LIQUID CRYSTALS	53
	CHEMISTRY OF MATERIALS	51

Advanced Materials Patent Activity

Between 2002 and 2006, there were 8973 advanced materials-related patent applications filed with the United States Patent Office (USPTO). As shown in table 10, the majority of these (4988) listed at least one inventor from the United States. Other countries with a significant number of inventors include: Japan (1551 applications), Germany (721 applications), and South Korea (386 applications). There was one advanced materials-related patent application that listed an inventor from Saudi Arabia over this time period. "Highly luminescnt color-selective nanocrystalline materials"[6] involved the collaboration of inventors from Saudi Arabia, Spain, and the United States.

6 Bawendi, Moungi, Jensen, Klaus F., Dabbousi, Bashir O., Rodriguez-Viejo, Javier, Mikulec, Frederic Victor. U.S. Patent Application # 20040033359, 2004.

Table 10: Advanced Materials Patents (2002-2006)

Country	Membranes	Composite and Hybrid Materials	Polymers & Polymer Processing Technologies	Metals and Alloys	Ceramics	Smart Materials	Coatings	Total
United States	179	321	2844	123	232	439	964	4988
Japan	83	110	774	119	196	75	222	1551
Germany	28	71	321	19	62	64	171	721
South Korea	17	4	278	9	15	46	26	386
Taiwan	8	8	99	11	17	132	47	316
United Kingdom	13	19	191	5	11	25	34	295
France	11	22	154	17	5	14	39	257
Canada	19	11	115	11	6	25	32	214
Netherlands	5	0	100	2	3	9	7	123
Italy	12	8	47	7	17	3	16	108
Saudi Arabia	0	0	0	0	0	0	1	1

While the majority of advanced materials related patent applications are defined as individually owned patent applications (5,986 applications) by the United States Patent Office, some institutions are designated as the patent assignee on a number of applications. These institutions, which have a record as inventors, could be targets for future collaboration. As shown in table 11, Eastman Kodak Co. is listed as the patent assignee on 93 advanced materials applications followed by Samsung Electronics Co., Ltd. (85 applications), Polymer Group, Inc. (55 applications), and 3M Innovative Properties Company (54 applications). The single patent with an inventor from Saudi Arabia lists Massachusetts Institute of Technology as the patent assignee.

Table 11: Leading Advanced Materials Assignees (2002-2006)

USTPO Assignee	No. of Patents Apps.
Individually Owned Patents	5986
Eastman Kodak Co.	93
Samsung Electronics Co., Ltd.	85
Polymer Group, Inc.	55
3M Innovative Properties Company	54

SWOT Analysis

This section represents a SWOT (strengths, weaknesses, opportunities, and threats) analysis of the Saudi Arabia Advanced Materials Program relative to achieving its vision. In a SWOT analysis, terms are defined as follows:

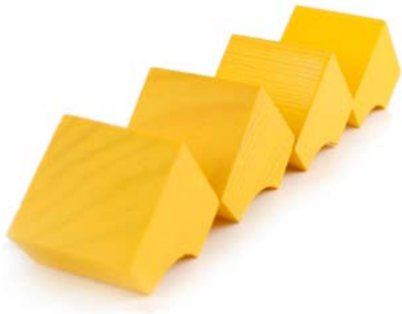
- **Strengths:** attributes of an organization that are helpful to achieving the objective.
- **Weaknesses:** attributes of an organization that are harmful to achieving the objective.
- **Opportunities:** external conditions that are helpful to achieving the objective.
- **Threats:** external conditions that are harmful to achieving the objective.

Strengths and weaknesses are internal to the organization, while opportunities and threats are external to the organization. For the purpose of this analysis, the "organization" is the Saudi Advanced Materials Program, including KACST, universities, other government agencies, and companies. The SWOT analysis is summarized in table 12.

Table 12: Advanced Materials SWOT Analysis

	Helpful	Harmful
Internal	**Strengths:** ■ Major petroleum and petrochemical and minerals producers that provide feedstock for advanced materials and have advanced materials needs. ■ Ample financial resources. ■ Domestic customers for advanced materials in water, health, defense, transportation and construction. ■ Some research capability in universities, industry, and KACST.	**Weaknesses:** ■ Weak overall position in materials research and technology. ■ Weak human resources base -- no material science departments in universities. ■ Poor mobility and adaptability of human resources (once a physicist, students remain tied to physics). ■ Inflexibility in human resource regulations (e.g. difficult to hire and retain good people in government. ■ Logistics in obtaining research supplies. ■ Insufficient international linkages. ■ Weak industry-government- university linkages. ■ Weak culture and history of R&D and successful innovation. ■ Weak implementation of planning. ■ Weak manufacturing sector (outside of petroleum and petrochemicals) to make use of advanced materials.
External	**Opportunities:** ■ Potential to produce high-value added materials based on KSA raw materials. ■ Growing domestic and international markets for water and solar technologies. ■ National strategy of investing in science and technology. ■ Potential to collaborate domestically and internationally. ■ Education of future scientists.	**Threats:** ■ International competition -- other countries are moving faster (see Appendix 2). ■ Constraints on needed reforms. ■ Instability in financial support and policies. ■ Saudization of education and research.

Strategic Context



The overall strengths of the Kingdom in advanced materials are its large natural resource-based firms, its financial resources, and its domestic market for advanced materials. The Kingdom has several weaknesses with respect to advanced materials. Research institutes, including universities, government, and industry, do not rank among the top worldwide institutions. Human resources for advanced materials research are generally weak. There are no materials science departments or curricula in universities. There is poor mobility and adaptability of human resources -– it is difficult for physicists or chemists to move into materials science. Human resource regulations are inflexible, making it difficult to hire and retain good people in government.

Saudi researchers have insufficient collaboration with others in the Kingdom, their counterparts in industry, or in other countries. There is little track record of successful innovation or of successful implementation of planning initiatives. Another weakness is that it is difficult to obtain research supplies. Finally, outside of the petroleum and petrochemical industries, the manufacturing sectors that provide the demand for advanced materials are relatively weak.

There are opportunities to take advantage of the Saudi national strategy to invest more heavily in science and technology, combined with the potential to leverage the Kingdom's strength in natural resources to compete in higher value added products. The main threat is that international competitors are not standing still, and, indeed, seem to be moving faster than Saudi Arabia.

The initiatives in this plan have been designed to take advantage of the KSA strengths and to address the weaknesses, while keeping aware of the opportunities and threats. To take advantage of the KSA strengths, programs have been designed to focus on areas of special KSA needs and markets, and to build on existing capabilities. To counteract the weaknesses, programs have been designed to expand government-university-industry collaboration, to focus on innovation, and to train students and researchers in materials science.

Higher Strategy

The Program higher strategy is represented by its Vision, Mission, Values and Strategic Goals. These are derived with consideration of the goals and objectives of the National Policy for Science and Technology and Key Needs of the Kingdom.

Vision

The vision for advanced materials science and technology in the Kingdom is:

The Kingdom will leverage its unique strengths and needs to become a world leader in specific advanced materials technologies and an exporter of high value-added advanced materials. The Kingdom shall have an effective innovation system that has strong linkages between research and education and between industries, universities, and government.

A key aspect of this vision is that it is focused on innovation in areas of particular importance to the Kingdom. The near-term vision for the Kingdom is not to be strong in all areas of materials or to be a world leader in fundamental research, but rather to focus on the areas where the Kingdom has potential competitive advantages and can apply technology to the Kingdom's economic and social needs.

Mission

The mission of the Advanced Material Program is to support an effective innovation system for advanced materials in the Kingdom through:

- research, development, technology transfer, and localization in areas of national need;
- collaborations among national and international research institutions;
- actions to develop human resources for advanced materials; and
- the planning, developing, and operating of major materials research facilities.

Values and Program Culture

To achieve excellence, the program will develop an internal culture through both the sponsorship of its leadership and commitment of its operational teams, based on the following values:

- Excellence of work.
- Professional integrity and ethical behavior.
- Openness and transparency.
- Commitment to achieving objectives.
- Support of creativity and innovation.
- Teamwork and collaboration.

Program Strategic Goals

The Program Strategic Goals are to:

- Improve the contribution of advanced materials to the critical national needs and the competitiveness of KSA industry.
- Enable a domestic technology-based advanced materials industries in key areas (such as membranes and catalysis).
- Raise KSA's international position of advanced material.
- Improve the Kingdom's human resources and institutions for advanced materials R&D.

Technology Areas

Selection Process

The Advance Materials program selected technologies based on input from the program's stakeholders through the stakeholder's workshop and the program's advisory committee. The main criteria were the needs of industry or other stakeholders. The advisory committee also considered the potential for the Kingdom to develop a strong position in the technology, based on the presence or absence of existing R&D capabilities, the Kingdom's current position in the technology, and the market impact of the technology.

Selected Technology Areas

The following are key advanced materials technologies for the Kingdom grouped into major categories, although there is some overlap among the categories.[7]

Membranes

- Advanced function membranes for use especially in water treatment as well as other industrial applications. Relevant technologies include developing non-biofouling materials, chemical and scale resistant membranes, high reverse osmosis rejection and permeability membranes, and gas separation and sterilization membranes.
- Filtration membranes. Nano-, micro-, and ultra-filtration membranes are vital for the water sectors and also have applications in the petroleum, petrochemical, and biomedical sectors in the Kingdom.

Composite and Hybrid Materials

- Corrosion-resistant materials, especially for high temperature and high sulfur environments, are critical to the petroleum, petrochemical, and water sectors. Sulfur resistant materials are also important for aircraft.

7 There is no single clear taxonomy of materials technologies, since materials are commonly grouped by both functional purpose (e.g. corrosion resistance, catalysis), application field (e.g. biomedical materials, electronic materials), or by type of material (e.g. ceramics, metals).

Technology Areas

- Composites are needed for construction, pipelines, optical fibers, and water services (such as pipeline, storage, processing, disposal etc.). Major technical challenges relate to design, joining, manufacturing processes, and installation. There are also issues with training and standards that limit applications.
- Non-destructive testing (NDT) technologies, especially applied to composites and other advanced materials are important in the petroleum, petrochemical and water sectors.
- Welding Technologies are important for petroleum and water sectors.

Polymers and Polymer Processing

- Advanced polymer technologies have broad industrial uses including oil and natural gas drilling, pipeline and storage tanks, electronics, textiles, agriculture, water, dentistry, and drug delivery.

- New classes of polymers and polymer processes including resin systems and high temperature ablative resins, nanostructured polymers, water soluble and biodegradable polymers, flame retardants, UV light stabilizers, and nanoparticles for polymer reinforcement.

Metals and Alloys

- Advanced functions include duplex and ferritic steels for thermal plants, materials for desalination plants, materials to reduce high temperature stress corrosion cracking, and materials for specialized uses in medical applications.
- Specialized alloys include corrosion and erosion resistant and high temperature and strength alloys for use in water treatment, construction, and oil and gas industries, defense and aerospace applications.

Ceramics

- Development of specialized ceramics such as aluminum oxide, tungsten carbides, and refractory oxide dispersion strengthened alloys for use in insulation, medical implants, and new building materials.

Smart Materials

- Advanced functional materials include photo-, thermo-, piezo-, tribo-, and electro-chromatic materials, and smart glass for use in construction. Other smart materials include multifunctional materials and switchable systems for use in textiles, food packaging, and solar applications.
- Silicon based materials including (poly/mono crystalline silicon), silicon wafers, semiconductor processing materials, silicon nano-particles, and silicon oxide nano-particles, for applications in electronics and other industries, Silane; Silicones.
- Heat transfer materials, to both aid and reduce heat flow, with applications in many industries

Coating

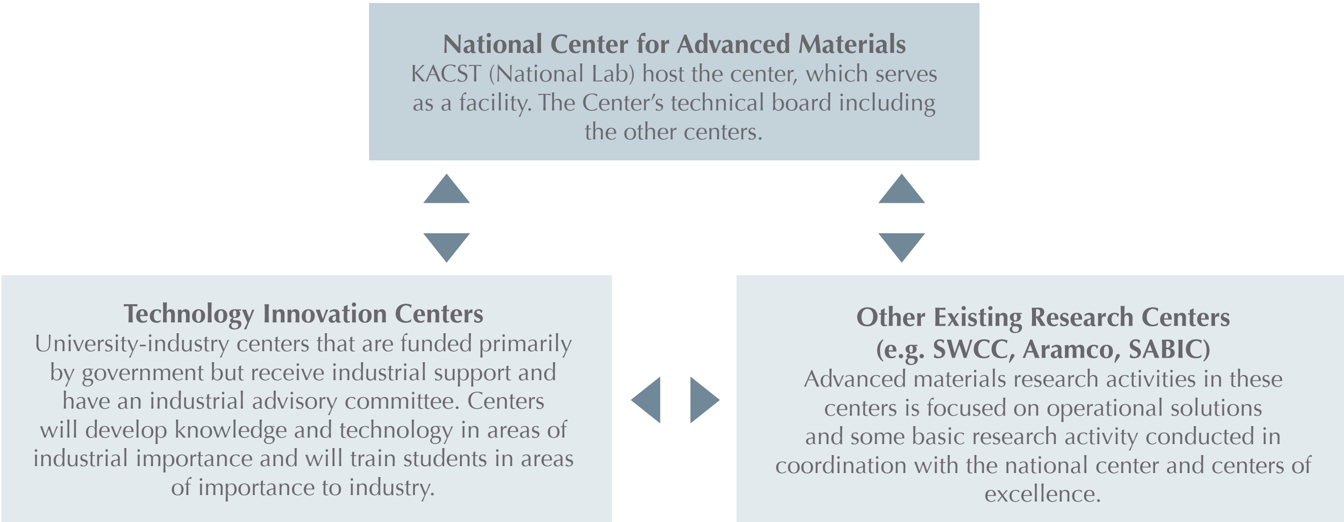
- Corrosion resistant, self-cleaning, and healing coatings; light, heat, and pressure switchable coatings for various industrial applications.
- Development of UV light resistant coatings and metallic and thermal barrier coatings also for use in textiles, food packaging, and oil and gas drilling and transport.

Program Structure

Overview

Figure 3 provides a schematic diagram of the proposed Advanced Materials Program. It consists of three main subprograms: KACST, university-based Technology Innovation Centers (TIC), and other existing research centers. The activities of other existing research centers, while coordinated as part of the overall program, are not presented in detail in this plan.

Figure 3: Structure of Advanced Materials Program



Role of KACST in Advanced Materials

KACST will be responsible for (1) advanced materials planning and policy leadership; (2) conducting applied research and development on problems of national importance, and (3) providing high quality research facilities and technical support to university and industry researchers.

1. Planning and Policy Leadership.

The planning and policy leadership function will be especially important in the early years of the advanced materials program. It will have several objectives. In this function, the national center will:

- Provide direct and ongoing ways for material users to provide input to R&D priorities such as through workshops organized by sector (oil and gas, medical, defense, etc.) and by technology area (membranes, polymers, composites, etc.)
- Develop technology roadmaps in key areas of advanced materials that define the technical advances needed in specific time frames, and define the roles of university, industry, and government.
- Prioritize and organize advanced materials R&D programs.
- Develop a national plan for materials research facilities (see below).
- Support an advisory board, made up of key stakeholders, that will oversee the development of the plan, budget and resource allocations, and execution of the plan.
- Develop an advanced materials human resource plan that will estimate the need for researchers and technicians

and the skills needed, and determine how to meet these needs through education, training, and international hiring.

- Promote a material science curriculum in universities.
- Support an advanced materials professional society to exchange knowledge and build trust among members of the KSA advanced materials research community.
- Advocate changes in national policies that affect many areas of technology, including:

- Legal framework to support technology partnerships
- Procedures for sharing of research equipment
- Incentives and accountability for researchers to improve research productivity
- Policies on employment of non-Saudis and women researchers
- Improved primary and secondary school education in math and science

2. Applied Research and Development

Most specific areas of applied research and development conducted by KACST, in collaboration with universities and other research institutes, will be determined as an outcome of the detailed planning and technology platforms described above. R&D conducted at the national center will typically differ from university work as follows:

- more applied and time-urgent.
- larger scale.
- require specialized (e.g, nuclear materials) facilities

KACST will conduct a combination of independent and client (either government agency or industry) funded work. Independent projects will be prioritized according to their potentially beneficial economic or humanitarian impact on the Kingdom. For each project, there will be a clear path or paths through which the project is likely to provide evident, desirable, and timely benefits to the Kingdom. This may be through solving important problems in existing industries, enabling a technological advancement in an emerging or needed industry, or meeting an unmet need that will result in a new KSA industry of significant size (either homegrown or through foreign investment). Programs will involve both KACST R&D and extramural funding of existing research centers

3. Research Facilities and Related Human Resources

The objective in this area is to provide KSA researchers with access to state-of-the-art research equipment. An important role for national laboratories is to provide for advanced research facilities that can be shared by many users. Examples around the world include light sources (synchrotrons or accelerators), advanced microscopes, magnet laboratories, ion beam facilities, neutron sources, high temperature facilities, clean rooms, pilot processing plants, and many other types of facilities. Such facilities are expensive and may be technically challenging to build and operate; many have had significant cost and time overruns. Careful planning is important.

KACST work in this area will begin with the development of both a near- and a long-term plan to acquire, or acquire access to, the modern analytical equipment needed to conduct the research needed to meet current and emerging national R&D needs in materials.[8] The plan will begin by developing an inventory of current experimental and test facilities in the Kingdom and an inventory of the types of equipment needed in the priority research

[8] Examples of such plans include European Strategy Forum on Research Infrastructures (2006). European Roadmap for Research Infrastructures Report 2006, and U.S. Department of Energy (2003). Facilities for the Future of Science:A Twenty-Year Outlook.

fields. The plan will identify which needs can be met adequately through arrangements with existing regional and international centers. The plan will then prioritize and design to acquire the new facilities needed for the Kingdom. The plan will also consider the training needed for KSA scientists and technicians to build and operate the facilities. This planning will be conducted jointly with groups in related areas that share needs for research equipment, including physics, nanotechnology, petroleum and petrochemicals, and water, because of their mutual need for similar instrumentation.

Based on this plan, KACST will establish a "National User Facility" containing a comprehensive and integrated array of up-to-date scientific equipment, supported by a well-trained technical staff. The facilities and technical staff will support university and industrial researchers as well as KACST researchers. KACST will develop policies and procedures for prioritizing the use of these facilities by various parties. KACST will also develop policies to facilitate the flow of research supplies including solvents, resins, chemicals, etc. needed in materials research.

A major national technology project to be managed by KACST, in conjunction with SWCC and universities, is R&D in membrane technology. This project will transfer membrane manufacturing techniques and develop new technologies with the goal of supporting membrane manufacturing and innovation in the Kingdom. This project will also support the water scarcity plan that relies on desalination as a strategic option.

Another proposed national project is the development of advanced materials in the field of medical applications, to be conducted primarily at the King Faisal Specialist Hospital and Research Centre. This would strengthen the research activities and tools for the applications of molecular imaging and treatment by using the proton/carbon method. This will contribute to new methods of diagnosis, prevention, and treatment of disease.

University TICs in Advanced Materials

The University TICs in Advanced Materials Program will include financial support for several university-industry research centers in advanced materials, coordinated with KACST activities, in such key areas as:

- Engineering materials – corrosion, biomedical, composites, ceramics.
- Membranes - water, medical, petrochemical.
- Materials processing – catalysts, etc.
- Coatings & smart materials.

The goals of these centers are to:

- Develop a critical mass of expertise at universities in areas of research that are important to industry.
- Expand human resources for advanced materials by training students in technical fields of direct relevance to industry.
- Build trust and collaboration among industry and academia.
- Change the culture of universities to emphasize systems level work and work on important problems.

Each academic center will primarily be funded by government but will be expected to obtain partial funding from industry, which will serve to ensure that the center's studies are focused on real industrial needs. Each center will also have an industrial advisory board. Each center will involve both undergraduate and graduate students in research, preparing them for employment in areas of industrial need. The output will be new knowledge and technology, but equally important, students who are trained in conducting research on projects with direct relevance to industry and other users.

KACST will run a competition for the multi-year support of such centers, and an external review committee will evaluate their performance over time, recommending continuation or termination, as appropriate. The universities will be free to define the technical focus of their centers, but the involvement of industrial advisors and the requirement of significant industrial cost-sharing should help ensure that relevant and useful results are produced. The Centers will be intimately involved in the KACST planning process described above. From this process, the Centers will receive guidance about user needs. The Centers will also be an important source of technical input to the processes.

Current Research Centers

The third element of the Advanced Materials Program is made up of the existing research centers that have some advanced materials activities. There are several existing university materials centers, including:

- The King Saud University (KSU) Center of Excellence on engineering materials.
- The KSU SABIC Polymer Research Center.
- Various centers at King Fahd University of Petroleum and Minerals (KFUPM) and the KFUPM Research Institute, which is a contract research institute affiliated with the university.

Although not yet established, the King Abdullah University of Science and Technology (KAUST) is also expected to have significant materials research activities, starting in 2009.

In addition to the university centers, there are several industrial and medical research centers that conduct materials related research, including:

- King Faisal Specialist Hospital and Research Centre (KFSHRC).
- Saline Water Conversion Corporation (SWCC) Saline Water Desalination Research Institute.
- Aramco Research and Development Center, which includes a materials science division
- Saudi Arabian Basic Industry Corporation (SABIC)

In addition, several KACST institutes or technology programs have activities related to advanced materials. These include:

- Petrochemicals.
- Water.
- Aerospace.
- Nanotechnology.
- Math and Physics.
- Atomic Energy.
- Energy.

All of these research centers currently receive their main funding from a variety of sources, and will continue receive the major funding from outside of the Advanced Materials Program. But all of these centers will be involved in the Advanced Materials Program in several ways. They may receive funding from the Materials Program to support the centers' participation in national advanced materials projects. They will also participate in the planning activities, and members of these centers will participate in the Advanced Materials Advisory Committee. The centers will share information to ensure that they collaborate in areas where it is beneficial and appropriate for them to do so.

Program Implementation

Portfolio Management

The Advance Materials Program will include a variety of projects with different goals and objectives. The program will be managed to achieve a balance across multiple objectives. Some factors to be considered in program balance include:

- The balance between projects to achieve an immediate objective versus building long-term capacity (especially human resources) for the program.
- The balance between meeting the needs of existing companies versus establishing new technology-based industries in the Kingdom.
- The balance between low risk incremental projects and high risk/high return projects.
- The balance among different national needs and major stakeholders (water, petroleum, petrochemical, medical, etc.).

The program manager and advisory committee will review the program to ensure that it maintains an appropriate balance among these factors.

Program Management

Organizational Structure and Performance Indicators

The Advance Materials Program will be directed by a Program Manager, who will be a KACST employee, and responsible for the overall execution of the plan. The Advanced Materials Advisory Committee will oversee the implementation of the plan. 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 Advance Materials Advisory Committee will meet approximately four times a year and review progress in the program and approve updates to the plan as necessary. Key

Program Implementation

performance indicators will be established for each subprogram. General long-term performance indicators include:

- Growth or establishment of technology-based businesses due to the Advanced Materials program.
- Amount of revenue or jobs created.
- Successful importation and adaptation of technology resulting in new businesses or applications.
- Number of licenses and amount of licensing revenue to universities and research institutes.
- Number of advanced materials-related patents.
- Private sector funding of university and KACST Advanced Materials research (indicates the value private sector places on university or KACST R&D).
- Number and level of presentations in international conferences.
- Changes in policies (described previously) to improve advanced materials R&D in the Kingdom.
- Number and impact of publications.
- Extent of domestic and international R&D collaborations.
- Numbers of materials science advanced degrees awarded.

In the near term, the program will be evaluated on the progress in implementing this plan, including the establishment of the national facilities at KACST and the university-industry centers, the implementation of applied research programs, the development of technology roadmaps and the facilities plan, and the development of policies to improve advanced materials R&D.

The advisory committee will also sponsor and oversee studies of emerging areas of advanced materials 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 advanced materials R&D network in the Kingdom.

Program Implementation

Key Management Issues

Two key management issues are quality management and human resources. With respect to quality management, the Advanced Materials Program will follow international best practices for science and technology programs. Elements of this plan include:

- Advisory committee review of the overall program design and budget.
- Competitive, peer-reviewed selection processes for university-based research centers and projects.
- Annual reviews of technology development projects to ensure that milestones are being met.
- Periodic (every 5 years) evaluation of the Advanced Materials Program conducted by a review committee supported by an experienced evaluator.

Procedures will be developed for disclosing and managing potential conflicts of interest among reviewers. In many cases, some international experts will be used on review panels to reduce possible conflicts of interest and to provide an independent external assessment.

With respect to human resources, the availability of skilled people, including both researchers and technical managers and leaders, is likely to be a limiting factor in the growth and success of the KSA Advanced Materials program. The program will require substantial number of materials professionals, including additional researchers, technical managers, and technical leaders at KACST, universities, and companies. In the short-run, a critical need is to recruit people with appropriate skills to KACST for Advanced Materials to manage the various tracks of this plan. Without the ability to recruit people with adequate knowledge of advanced materials and program management skills, the plan will not meet its goals.

In the near term, other strategies to expand the human resources for the materials program are:

- Allow salary flexibility to be able to pay competitive, market-based salaries to attract key people.
- Change policies to allow more international hiring, to bring specialized expertise to the Kingdom.
- Train researchers to become R&D managers and leaders.

This plan is designed to help increase the number of materials researchers over the long term through its emphasis on university-industry centers and the development of material science curriculum for universities. These university-industry centers will be designed to train new students with the research and innovation skills needed by research organizations and industry.

Appendix A - Plan Development Process and Participants

The development of this plan was overseen by the Advanced Materials Advisory Committee. A one-day stakeholder workshop was held on June 17, 2007 to receive input from a wide range of stakeholders. The workshop focused on the needs of the Kingdom in Advanced Materials, outlined programs to meet the needs, and identify barriers to success. Following the workshop, the advisory committee met on a weekly or biweekly basis to provide input and review drafts of the plan. List below are the members of the advisory committee, as well as the participants in the workshop.

Advanced Materials Advisory Committee

Khalid A. Aleissa
Director of Institute of Atomic Energy Research
King Abdulaziz City for Science and Technology

Abdullah I. Almarshad
Prof. of Materials Eng &Corrosion Head, Corrosion Research Group
King Abdulaziz City for Science and Technology

Ahmed Alyamani
Deputy Director of Nanotechnology Center
King Abdulaziz City for Science and Technology

Gasem M. Fallatah
Non-Metallic Materials Specialist
Saudi Aramco

Abdullah M. Asiri
Prof. of Organic Chemistry
King Abdulaziz University

Ibrahim AlJammaz
Senior Scientist, Deputy Chairman Cyclotron Radiopharmaceuticals
King Faisal Specialist Hospital and Research Centre

luai Al-Hadhrami
Center Director for Engineering Research
King Fahd University of Petroleum and Minerals

Maher A. Alodan
Vice President for Research
Alfaisal University

Rafea F. AL-Shehri
Operation Research, R&D Department
Ministry of Defense and Aviation

Abdulrahman M. Abanmy
Reverse Osmosis Desalination Specialist
Saline Water Conversion Corporation

Tariq Shukri
Deputy Director of Institute of Atomic Energy Research
King Abdulaziz City for Science and Technology

Mohammed S. AlSuhybani
Scientific researcher
Atomic Energy Research Institute
King Abdulaziz City for Science and Technology

Participants in Advanced Materials Stakeholder Workshop

Table: A-1 Participants in Advanced Materials Stakeholder Workshop

Participant	Organization
Abdulaziz A. Alsugair	KACST
Abdullah A. AlMahadef	Ministry of Water and Electricity
Abdullah I. Almarshad	KACST
Abdullah M. Asiri	KAAU
AbdullrahmenA. Almuhanna	KACST
Abdulrahman M. Abanmy	SWCC
Ahmed A. Basfar	KACST
Ahmed AlSaya	KACST
Ahmed M. Hala	KACST
Asmail N. Andijani	SWCC
Gasem M. Fallatah	Saudi Aramco
Hamed F. Alharbi	KSU
Hamed N. Alwashmi	SWCC
HunJai Bae	KACST
Ibrahaim AlJammaz	KFSHRC
K.M. Idriss Ali	KACST
Khaled A. Aladeli	KACST
Khalid A. Aleissa	KACST
Magdi M. AlRayes	KSU
Maher A. Alodan	Alfaisal University
Maher Essahab	KSU
Mazen A. Babbad	KACST
Mohammed A. AlDosari	KACST
Mohammed A. Bahattab	KACST
Mohammed Husain	KACST
Mohammed Momen	Momen Consult Office
Mohammed S. AlSuhybani	KACST

Participant	Organization
Mohmoud S. Soliman	KSU
Nabil H. AlHarthi	KSU
Olgun Buven	Hacetlepa Univesitu, Ankare, Turkey
Osamah Draihem	KSU
Rabeh Elleithy	KSU
Rafa F. AlShahri	Ministry of Defense and Aviation
Sakhawat Hussain	KACST
Sultan A. AlMutari	Saudi Aramco
Suliman Alkhweiter	KACST
Syed Sabir	KACST
Tariq M. Shaukri	KACST
Zain H. Yammani	KFUPM

*KACST= King Abdulaziz City for Science and Technology

*KFUPM=King Fahd University of Petroleum and Minerals

*SWCC=Saline Water Conversion Corporation

*KFSHRC=King Faisal Specialist Hospital and Research Centre

*KSU= King Saud University

*KAAU=King Abdulaziz University

Appendix B - Supporting Analyses and References

Following are some of the references reviewed in the process of developing this roadmap:

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Tel 488 3555 - 488 3444
Fax 488 3756
P.O. Box 6086 Riyadh 11442
Kingdom of Saudi Arabia
www.kacst.edu.sa

King Abdulaziz City for Science and Technology

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