Kingdom of Saudi Arabia

Strategic Priorities for Petrochemicals Technology Program

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Strategic Priorities Plan for Petrochemical Technology Program

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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 roadmap is the plan for one of these programs, the Petrochemicals Technology Program. The program is designed to promote the development of petrochemical technologies in support of economic, social, and other critical national needs in the Kingdom of Saudi Arabia. Particular emphasis is placed on the development of local capacity supported by strategic technology adoption.

Saudi Arabia is the largest oil producer in the world. It is projected that ethylene, the most important basic petrochemical, will be produced at a capacity of greater than 18 million tons in 2012. Saudi Arabia is considered among the largest producers of polymers in the world at annual production of greater than 8 million tons. Hence it is essential for Saudi Arabia not only to export primary petrochemicals but also to make value added products from basic petrochemicals with innovative technologies for economic prosperity.

In this connection, and in order for Saudi Arabia to efficiently utilize its natural resources from oil and gas in the petrochemical industry, it is necessary for all stakeholders (i.e., governmental and private sectors, universities, research centers, and petrochemicals manufacturers) to collaborate jointly in the following areas:

Oil Processing

- Hydro-treatment (e.g. Deep hydrodesulphurization of petroleum fractions)
- Clean fuel (e.g. production of high octane components, conversion of heavier crude oil to higher quality hydrocarbons, development of refining catalysts and additives for clean fuel target, and desulphurization of crude oil).

Petrochemicals Synthesis

- Light paraffin activation (e.g., gas to liguid (GTL), selective oxidation, utilizing novel catalytic reactors such as membrane reactors for selective oxidation and oxidative coupling).
- Polymers (e.g., producing engineering and high performance polymers, polymeric membranes, and conductive polymers).

The priority technology areas that emerged from this process are the following:

1. Gas &Oil Processes.
2. Refining Processes.
3. Clean Fuel.
4. Process Development.

Executive summary

Specific fields of interest within these areas include

1. Cracking.
2. Isomerization.
3. Dehydrogenation.
4. Polymerization.
5. Alkylation.

This plan was developed by KACST's with the input from stakeholders in petrochemical technologies including government agencies, industry and universities.

The planning process was based on the following steps:

- identifing the key needs of the Kingdom for petrochemicals technology.
- assessing the strengths, weaknesses, opportunities, and threats for the program, including an analysis of KSA petrochemicals publications and patents and an assessment of international research institutes.
- defining a vision and a mission for the Kingdom's petrochemicals program.
- defining the key technologies and other program areas needed to address the Kingdom's needs in petrochemicals technology.

Among the key needs in the Kingdom identified in process are:

- satisfying the increasing demand for petrochemical products.
- supporting national self-reliance in petrochemical and refining-related research and development and reducing dependence on foreign technology.
- enhancing price/value efficiency in the petrochemical industry.
- contributing to national economic diversification by developing petrochemical technology industries and export.
- providing new investment and employment opportunities.

In addition to the technical needs, stakeholders identified a large number of areas where policies need to be changed or barriers removed to facilitate petrochemicals innovation. These needs include:

- Policies to facilitate R&D collaboration between KACST, universities, and industry.
- Policy and organizational changes in universities to improve the ability of faculty members to conduct research.
- Expanded human resources for petrochemicals R&D
- Improved knowledge of international technology developments.
- Expanded international collaboration, including cooperation between Saudi universities and world universities.
- Small business contracting preferences to support innovative small companies.

The Petrochemicals Technologies Program consists of a program leadership function, responsible for overall planning, management, and cross-cutting issues, and 5 priority technical areas corresponding to the abovementioned fields. The Petrochemicals Technology Program will be directed by a Program Manager, who will be responsible for the overall execution of the plan.

The Petrochemicals Strategic Technology Advisory Committee, with stakeholder membership, will oversee the implementation of the plan. It will establish and review performance metrics and provide advice on the portfolio of projects. The Committee will advise the Program Manager and will also report to the National S&T Plan Supervisory Committee, which will oversee all of the Strategic Technology Programs.

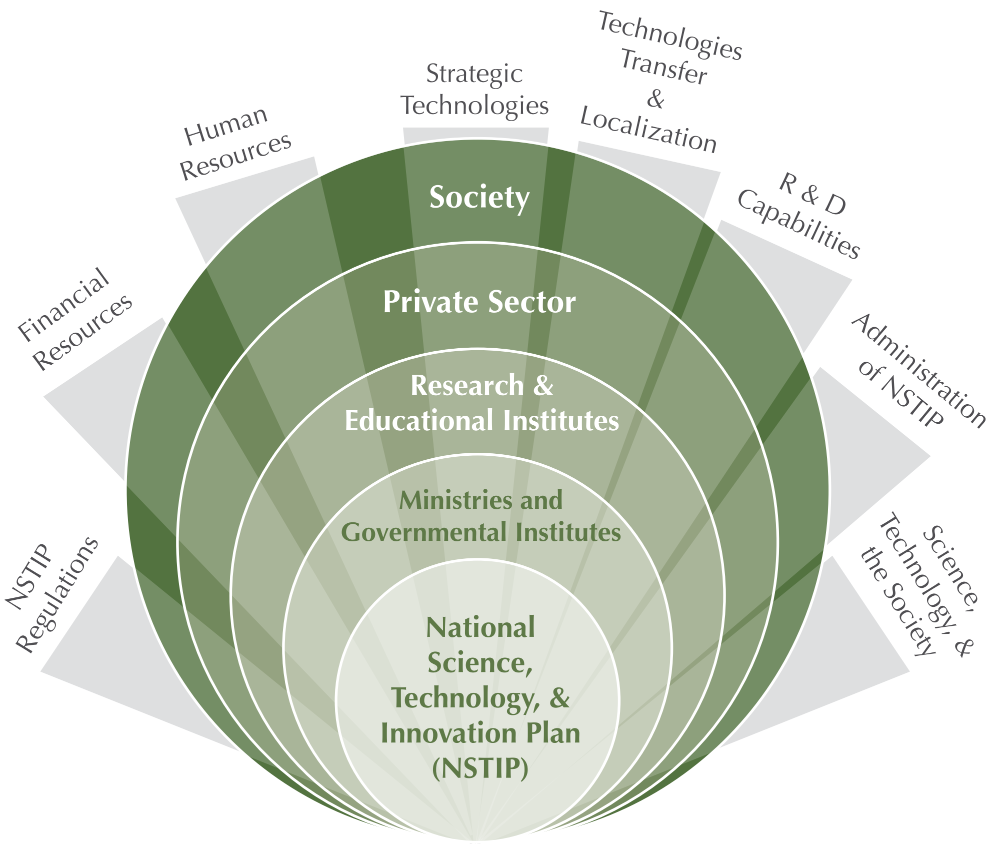
Introduction

Background

KACST was directed by a 1986 Royal Decree to "propose a national policy for the development of science and technology and to devise the strategy and plans necessary to implement them." In July 2002, the Council of Ministers approved the national plan for science and technology, which drew up the broad lines and future direction of science, technology, and innovation (STI) in the Kingdom, considering the role of KACST as well as that of universities, government, industry, and society at large. The plan, depicted in figure 1, encompasses:

1. Strategic and advanced technologies
2. Scientific research and technical development capabilities
3. Transfer, development and localizing technology
4. Science, technology and society
5. Scientific and technical human resources
6. Diversifying financial support resources
7. Science, technology and innovation system
8. Institutional structures for science, technology and innovation

Figure 1: Science and Technology Programs



In the "Strategic Technologies" area, KACST is responsible for 5-year strategic and implementation plans for 11 technologies:

1. Water
2. Oil & Gas
3. Petrochemicals
4. Nanotechnology
5. Biotechnology
6. Information Technology
7. Electronics, Communication, & Photonics
8. Space and Aeronautics
9. Energy
10. Environment
11. Advanced Materials

Each plan establishes a mission and vision, identifies stakeholders and users, and determines the highest priority technical areas for the Kingdom.

Introduction

Program Scope

The scope of this plan is national: it is a Petrochemicals Technology Strategic plan for the Kingdom of Saudi Arabia. The plan involves KACST, universities, industry, and government stakeholders. KACST has overall responsibility for the development and execution of the plan.

The program's sphere of activity involves petrochemicals and refining-related fields of technology that are significant to the Kingdom's interests and concerns as expressed in the National Policy for Science and Technology. The program's main deliverables are petrochemicals and refining technologies. These technologies are to be developed within the Kingdom and through strategic technology transfers to benefit users in the Kingdom as well as incubators and Technology Innovation Centers. The program will also maintain a perspective on international developments in petrochemicals technologies. The program will concentrate on applications and projects that most closely meet the Kingdom's needs.

The primary focus of the program is applied research and development (R&D), including development related to localization and technology transfer. The program conducts basic / fundamental research only if and when needed to support applied research and development.

The principal concepts employed by the program are the following:

- **Technology Development:** involves developing new technologies that are non-existent, or currently unavailable in the Kingdom. Technology development may involve strategic basic research to generate new knowledge needed for technology development.

- **Technology Localization:** involves research and education required to strengthen the absorptive capacity of the Kingdom. It emphasizes the development of local technical human resources and policy structures to promote the importation of beneficial foreign technologies and the creation of spin-off technologies in the Kingdom.

- **Technology Transfer:** involves scientific and technical support for transferring "off the shelf" technologies into the Kingdom. The program will emphasize the development of local capacity to prevent a dependence on foreign technologies.

Introduction

Plan Development Process

The development of this plan began with identifying the stakeholders and users of petrochemicals technology in the Kingdom, creating vision and mission statements, and conducting background research on the current position of the Kingdom in petrochemicals technology and on the role of other petrochemicals technology research institutes around the world. Appendix-B provides a full description of the development process.

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 transfer and 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 societal 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 these goals and objectives. The goals and objectives, the needs of the Kingdom in petrochemical technologies, and the current position of the kingdom in petrochemical technology are the starting point and foundation for developing the program’s higher strategy (vision, mission, values, strategic goals) and implementation strategy (technology selection criteria, program objectives, performance indicators and projects).

KSA Petrochemicals R & D Needs

The following key needs of the Kingdom were identified through a National Stakeholder workshop:

- Satisfying the increasing demand for petrochemical products.
- Supporting national self-reliance in petrochemical and refining-related research and development and reducing dependence on foreign technology.
- Enhancing price/value efficiency in the petrochemical industry.
- Contributing to national economic diversification by developing petrochemical technology industries and export.
- Providing new investment and employment opportunities.

In addition to the technical needs, workshop participants identified a number of areas where policies need to be changed or barriers removed. These needs include:

- Policies to facilitate R&D collaboration between KACST, goverment agencies, universities, and industry.
- Expanded human resources for petrochemicals technology R&D .
- Improved knowledge of international technology developments.
- Expanded international collaboration, including cooperation between Saudi universities and world universities.
- Small business contracting preferences to support innovative small companies.

Stakeholders Roles

The stakeholders for the Petrochemicals Technology Program include KACST, KSA universities, various independent or specialized research institutes, other government agencies, and private companies. Table 1 shows the roles of these stakeholders in the program.

Table 1: Stakeholders and their roles

Stakeholder	Role
KACST	■ Plan, coordinate and manage the program ■ Conduct applied research, technology transfer and prototype applications development ■ Manage and participate in national projects ■ Provide support for university and industrial participation in national projects ■ Provide and manage national research facilities ■ Provide advice and services to government on science and technology.
Universities	■ Create new basic and applied scientific knowledge ■ Train students in science and engineering ■ Host and participate in Technology Innovation Centers ■ Participate in collaborative projects
Independent or Government Specialized Research Centers	■ Create new applied scientific knowledge ■ Participate in collaborative projects
Ministries and Government Agencies	■ Operational and implementation projects ■ Provide input to program on government R&D needs ■ Reduce regulatory and procedural barriers to R&D and innovation ■ Support R&D in universities and industry
Private Sector	■ Develop and commercialize products & processes resulting fromthe program. ■ Communicate company needs to program ■ Support and participate in collaborative R&D projects. ■ Support and participate in the Technology Innovation Centers

Analysis of Petrochemical Publications and Patents

Overview

Petrochemical technology is a multidisciplinary field that draws tools and techniques from a variety of fields including chemical engineering, physical chemistry, energy & fuels, environmental sciences and materials science. The overall field, "petrochemical technologies", as well as sub-topics, were defined in close consultation with KACST researchers and other KSA stakeholders, who provided detailed lists of keyword terms that were used to query publication and patent databases.[1] The KSA petrochemical technologies program identifies two research tracks-oil processing and petrochemicals-relevant to KSA strategic priorities. The scope of this study was restricted to only recent publication (2005-2007) and patent (2002-2006) activity in those two 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.[2] Several indicators, including forward citations (the frequency at which publications and patents are cited by others), a measure of impact, and co-authoring relationships, an indicator of scientific collaboration, are presented below. Together, these indicators provide measures of collaboration, globalization and impact of science and technology research in fields related to the KSA petrochemical technologies program.

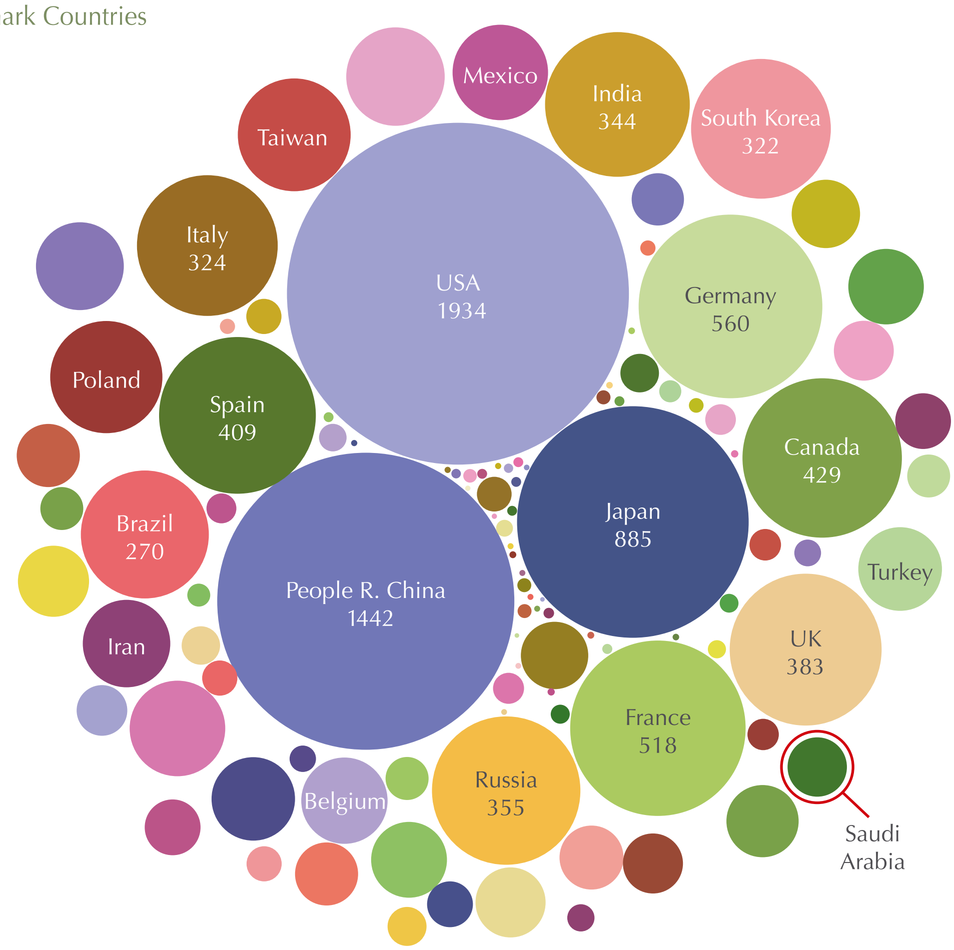
1 ISI Web of Science and Delphion were queried for scientific publication and U.S. patent application data, respectively. The ISI Web of Science is a database of peer-reviewed articles in major scientific journals from around the world. Delphion is a searchable database of global patent activity, including 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.

2 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.

Global Petrochemical Technologies Publication Activity

Between 2005 and 2007, there were 9541 articles published related to KSA priorities in oil processing and petrochemicals.[3] As shown in figure 2, the United States was the world's largest producer of related articles, generating 1934 articles over this time period. The People's Republic of China was second, producing 1442 articles followed by Japan, Germany, and France with 885, 560, and 518 articles respectively.[4] Saudi Arabia was tied for the 35th largest producer of publications, producing 53 articles in ISI-indexed journals.

Figure 2: Benchmark Countries



3 Throughout this report, "petrochemical technologies" refers only to the fields of research defined by the KSA petrochemical technologies research 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.

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 example, a country that published 50 articles that were cited 100 times would have an average publication impact of two. Between 2005 and 2007, Germany had the highest average publication impact of all countries at 3.35 followed by the US (3.31), the UK (2.74), and Spain (2.35). The average publication impact for Saudi Arabia was 0.74 with only 39 citations of 53 articles. Table 2 presents publication and citation counts for benchmark countries.[5]

Table 2: Petrochemical Technologies Publication Impact (2005-2007)

Country	Publication	Total Citations	Average Publication Impact
Germany	560	1875	3.35
Usa	1934	2496	3.31
Uk	350	986	2.74
Spain	409	963	2.35
France	518	1199	2.31
Japan	885	1928	2.18
Canada	429	829	1.93
P.R. Of China	1442	2496	1.73
India	344	474	1.38
Russia	355	392	1.10
Saudi Arabia	53	39	0.74

Petrochemical Technologies Research Organizations

Petrochemical technologies R&D publications are produced at many research institutions. As shown in table 3, the three institutions producing the largest number of publications related to petrochemicals technologies R&D are the Chinese Academy of Sciences, the Russian Academy of Sciences, and CSIC (The Spanish National Research Council). This top-three is the same when split into the separate topics of petrochemicals and oil processing.

5 Benchmark countries include global leaders in terms of total petrochemical technologies publication output in addition to a list of specific countries provided by KACST.ISI Web of Science and Delphion were queried for scientific.

Table 3: Petrochemical Technologies R&D Organizations (2005-2007)

Institution	Total Publications	Average Impact	Oil Processing	Petrochemicals
Chinese Acad Sci	345	2.34	263	195
Russian Acad Sci	199	0.88	131	126
CSIC	105	2.63	83	67
Tsing Hua University	101	2.20	74	47
Nat'l Inst Adv Ind Sci & Technol Seto	84	2.40	62	40
Univ Texas	80	3.74	56	36
Tokyo Institute Technol	75	2.31	42	50
Indian Inst Technol	70	1.20	52	28
CNR	65	1.77	48	34
Inst Mexicano Petr	65	1.57	56	20
Tianjin Univ	62	1.15	47	30
Zhejiang Univ	61	1.72	35	42
Penn State University	58	5.17	46	16
Univ Tokyo	57	1.96	33	32
Inst Francais Petr	57	1.25	41	28

International Collaboration and Publication Impact

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

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

KSA Collaboration Activity

Table 4 shows the countries of co-authors of KSA authored papers. Authors affiliated with KSA institutions collaborated on more than one article with authors from: the Pakistan (3 publications), the United Kingdom (2), and the United States (2). KSA-affiliated authors collaborated on individual publications with authors from: Canada, Germany, Ireland, Oman, UAE, and Venezuela.

Figure 3: Petrochemical Technologies Collaboration and Publication Impact (2005-2007)

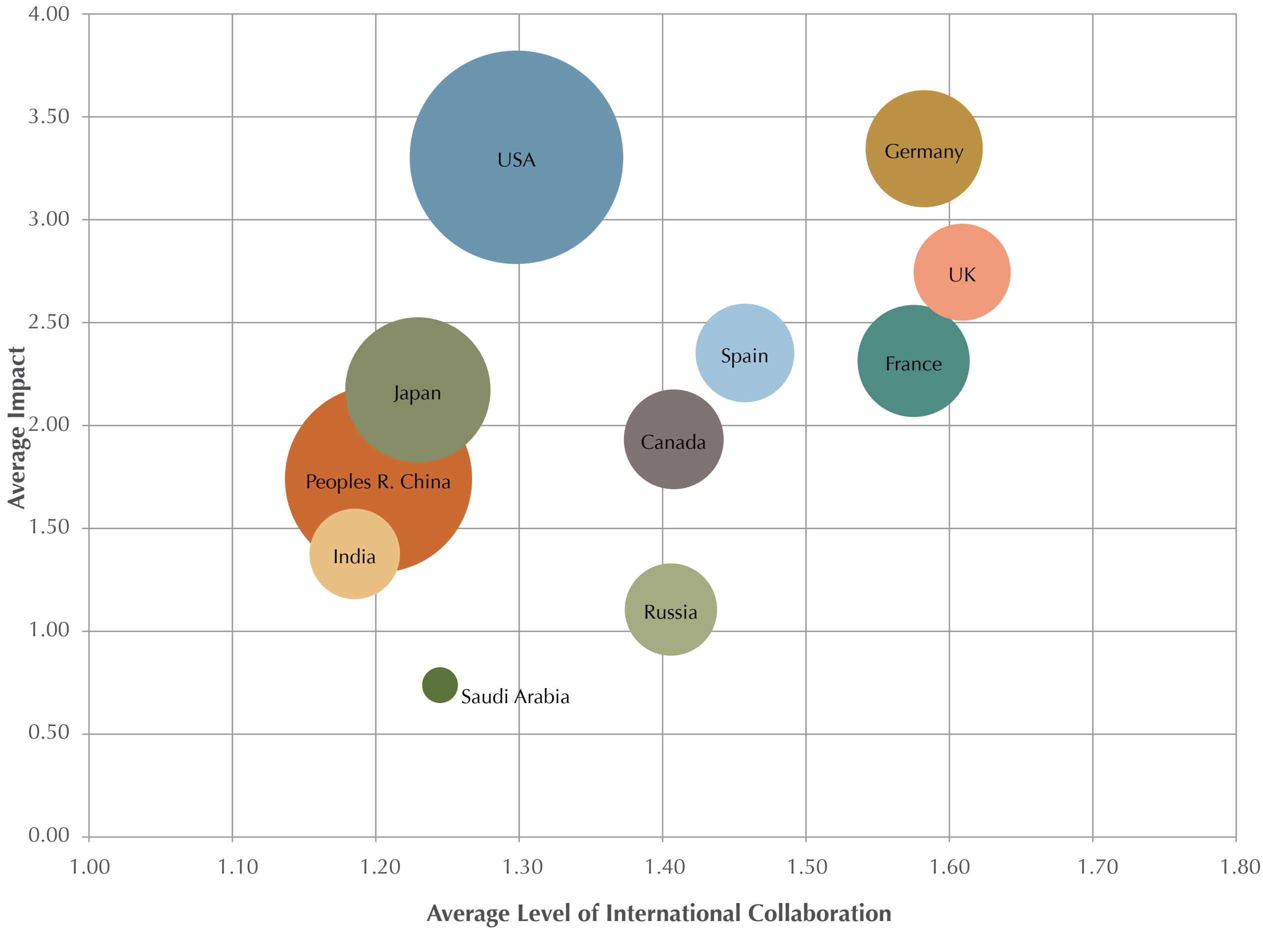


Table 4: KSA Publication Collaborators (2005-2007

Country	Number of Publications
Pakistan	3
UK	2
USA	2
Canada	1
Germany	1
Ireland	1
Oman	1
United Arab Emirates	1
Venezuela	1

Petrochemical Technologies Journals

Table 5 shows the journals with a significant number of articles in the KSA petrochemical technologies sub-fields from 2005-2007.

Table 5: Petrochemical Technologies Journals (2005-2007)

	Journal	Publications
Petrochemicals	Catalysis Today	199
	Applied Catalysis A-general	177
	Industrial & Engineering Chemistry Research	135
	Journal Of Catalysis	110
	Journal Of Molecular Catalysis A-chemical	105
	Applied Catalysis B-environmental	99
	Journal Of Physical Chemistry B	97
	Journal Of Power Sources	87
	Catalysis Letters	83
	Energy & Fuels	67
Oil Processing	Catalysis Today	266
	Applied Catalysis A-general	247
	Energy & Fuels	223
	Industrial & Engineering Chemistry Research	213
	Journal Of Catalysis	159
	Applied Catalysis B-environmental	135
	Journal Of Molecular Catalysis A-chemical	120
	Journal Of Power Sources	118
	Fuel	115
	Journal Of Physical Chemistry B	96

Petrochemical Technologies Patents Activity

Table 6 shows petrochemical patents. Between 2002 and 2006, there were 305 petrochemical technology-related patent applications filed with the United States Patent Office (USPTO). The majority of these (509) listed at least one inventor from the United States. Other countries with a significant number of inventors include: Japan (81 applications), France (24 applications), Belgium (23 applications), and South Korea (23 applications). Two petrochemical technologies related patent applications listed an inventor from Saudi Arabia: "Fluid catalytic cracking process for heavy oil"[6] and "Heavy oil fluid catalytic cracking process."[7] Both of these involve collaboration of KSA inventors with inventors from Japan.

Table 6: Petrochemical Technologies Patents (2002-2006)

Country	Oil Processing	Petrochemicals	Total
United States	62	48	110
Japan	24	57	81
France	15	9	24
Belgium	1	22	23
South Korea	5	18	23
China	7	10	17
Germany	6	2	8
India	4	4	8
Canada	5	1	6
United Kingdom	5	0	5
Russia	0	4	4
Saudi Arabia	2	0	2
Spain	0	0	0

6 Ino, Takashi, Okuhara, Toshiaki, Abul-Hamayel, Mohammad, Aitani, Abdullah, Maghrabi, Abdulgader, U.S. Patent Application # 20030006168, 2003.

7 Ino, Takashi, Okuhara, Toshiaki, Redhwi, Halim Hamid, Abul-Hamayel, Mohammad, Aitani, Abdullah, Maghrabi, Abdulgader, U.S. Patent Application # 20020195373, 2002

While the majority of the petrochemical technology-related patent applications are defined as individually owned patent applications (180 applications) by the United States Patent Office, some institutions, shown in table 7, are designated as the patent assignee on a significant number of applications. These institutions, with demonstrated innovative activity in the petrochemical technology fields related to KSA strategic priorities, could be targets for future collaborations. Huntsman Petrochemical Corporation is listed as the patent assignee on 18 petrochemical technologies applications followed by Idemitdu Petrochemical Co. (13 applications), Korea Kumho Petrochemical Co. (13 applications), and China Petroleum and Petrochemical Corporation (10 applications).

Table 7: Leading Petrochemical Technologies Patent Assignees (2002-2006)

USTPO Assignee	No. of Patents Apps.
Individually Owned Patents	180
Huntsman Petrochemical Corporation	18
Idemitdu Petrochemical Co.	13
Korea Kumho Petrochemical Co.	13
China Petroleum and Petrochemical Corporation	10

The Current Status of the Petrochemical Industry in the Kingdom

The Saudi Petrochemical Industry

The Saudi petrochemical industry relies essentially on petroleum and natural gas (associated and non-associated) as well as liquefied petroleum gas, to obtain various raw and intermediate materials. These products can be in turn utilized to manufacture finished materials such as organic and plastic materials, synthetic fibers, solvents, paints, adhesive materials, various kinds of rubber, pesticides, detergents, in addition to many other products. Natural gas is one of the most important raw materials used in the petrochemical industry, which boomed in the mid-1970s, and continued to grow approximately tenfold over the last two decades, from an estimated 3.7 to 36 million tons/year. Production is estimated to further grow to 70 million tons/year by 2010. Since natural gas is the main supply of the petrochemical sectors, production currently focuses on:

1. Basic materials: Methane, ethane, propane and butane are the main supplies used to manufacture primary petrochemicals such as olefins (ethylene, propylene and butanes) and aromatics.
2. Intermediate chemicals: such as methanol, methanol, ethylene glycol, polyterphthalic acid (PTA), 2-Ethyhexanoic Acid (2-EH), dioctylphtalte(DOP), Vinyl Chloride Monomer (VCM) Styrene, etc…
3. Basic polymers- Poly Ethylene (PE), Polypropylene (PP), polystyrene (PS), Poly Vinyl Chloride (PVC) and polyethylene terphthalte (PET).

SABIC, the Saudi Basic Industries Corporation is credited for the development of most of the Kingdom's petrochemical sector. It currently produces 95% of Saudi petrochemicals. KSA is dedicating great efforts to decrease this percentage to 75% by 2010, aiming to raise private investments to accelerate the growth of the downstream petrochemical sector. In addition, Saudi ARAMCO is currently planning to enhance competition in the petrochemical market, by being the first in the Kingdom and the Middle East to manufacture new petrochemicals, such as phenol, cumene and aromatics, including xylene and toluene. The abundance of raw materials holds great potential for the Kingdom, as it can produce every kind of natural gas, naphtha, benzene and others, thus accelerating and supporting the development of the petrochemical sector in the Kingdom. Furthermore, negotiations between Saudi Aramco and Sabic, the largest petrochemical company in the world in terms of market value, have reached an advanced stage to develop a petrochemical complex along the coast of the Red Sea, in the Western region.

Saudi Private Companies

The first plants developed by the private sector came onstream in the early 1980s and were small units for the production of finished petrochemicals, such as PVC pipes and polyurethane. Since then, however, larger facilities have been built for the production of bulk chemicals and petrochemicals, including solvents, butadiene, formaldehyde, polystyrene materials, polyester, epoxy resins, latex, and titanium dioxide. In addition, projects are underway or planned for the production of propylene and polypropylene, methyl tertiary butyl ether (MTBE), paraxylene, sodium triphosphate, chlorine, caustic soda, butanediol, maleic anhydride, cumene, linear paraffin, and linear alkyl benzene.

Analysis of Comparable Petrochemical R&D Institutes

As part of the background work for this plan, the planning team reviewed several other petrochemical technology research laboratories/centers around the world, selected to include a mix of government supported laboratories with functions similar to that of the petrochemical technology program. These centers include:

- Commonwealth Scientific and Industrial Research Organization (CSIRO), Manufacturing & Materials Technology (CMMT), Australia
- Leibniz Institute for Catalysis at the University of Rostock (LIKAT), Germany
- College of Polymer Science and Polymer Engineering, University of Akron, United States
- University of Delaware Center for Composite Materials (UD-CCM), United States

The research foci and scope of the four institutions reflect interesting and useful approaches regarding strategies and options for development of petrochemical research and related technology. From a national planning perspective, the consideration of national government research institutes (Australia) and university-based research institutes (Germany and United States) provides a continuum of policy and institutional understanding in regard to the strategic role and activities of research institutes.

These institutes are working in a range of technical areas related to those considered for this plan, including:

- Renewable and biodegradable materials
- Coordination chemistry and catalytic processes
- Processes to improve organic and inorganic synthesis
- Advanced material characterization and performance benchmarking

A full description of these laboratories' programs can be found in a separate document.[8]

8 SRI International. Strategic Review: Petrochemicals. August 2007

SWOT Analysis for KSA Petrochemicals Strategic Technology Program.

This section presents a SWOT (strengths, weaknesses, opportunities, and threats) analysis of the Saudi Arabia Petrochemicals Strategic Technology program relative to achieving its vision. In a SWOT analysis, terms are defined as follows:

Strengths: attributes of the organization that are helpful to achieving the objective.

Weaknesses: attributes of the 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 defined as external to the organization. Following are the main items identified through SWOT analysis sessions:

Strengths	Weaknesses
■ Extensive experience of Sabic and Saudi Aramco and related opportunities available to the Program ■ Saudi Aramco's interests in petrochemicals market and the competitiveness created ■ Possibility of licensing commodity technologies through international strategic partnerships	■ Inadequate qualified human resources ■ Difficulty of obtaining value-adding specialty technologies ■ Weak program sponsorship by some stakeholders
Opportunities	**Threats**
■ Facilities granted to technology localization organizations in obtaining feedstock ■ Availability of financial incentives for value-adding specialty technologies ■ Globalization and WTO encourages investors with advanced technologies ■ Availability of research centers in both public and private sectors	■ Possibility of developing alternative feedstock to oil and gas ■ Possibility of developing competitive petrochemical products ■ Energy and carbon taxations ■ Negative effect of some governmental regulations on investment in technology

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, Technology, and Key Needs of the Kingdom.

Vision

The vision for the Kingdom's Petrochemical technologies program is:

To reach a prominent strategic position internationally through a broad national sponsorship of petrochemical technology transfer, localization and development.

This vision focuses on the establishment of an effective innovation system in which research and invention need to lead to economic and social benefits for the Kingdom. To achieve this, it is essential to have strong and mutually beneficial linkages between universities, government, and industry.

Mission

The program's Mission is:

Working on developing, transferring and localizing petrochemical technologies in the Kingdom through qualifying distinguished human resources and developing the methods and applications of scientific and technological research. This will support competitive local production and facilitate new investment opportunities and markets. We pursue a robust economic base, comprehensive development and efficient use of available resources in our field.

Program Values and Culture

To achieve excellence, the program will develop an effective internal culture through training, sponsorship of the program's 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 strategic goals of the program are:

1. To support and develop domestic capacity in critical petrochemicals and refining technologies.
2. To optimize the use of abundant available natural resources.
3. To support the local refining and petrochemicals industry with technology solutions that facilitate new product development, improve production efficiency, price/value efficiency, environmental protection and similar concerns.
4. To develop innovative high quality petrochemical technologies and applications to meet specialized industrial and commercial needs in the Kingdom such as in oil and gas.
5. To adapt and localize petrochemical technologies to support the development of national capability.
6. To support societal and cultural development towards optimal exploitation of technology and transformation from a consumption to a production culture.
7. To enhance the Kingdom's competitiveness in regional manufacturing through transfer and development of advanced petrochemical technologies.
8. To improve the national ranking in science and technology capabilities.

Technology Areas

Selection Process

An initial list of technology areas in the petrochemicals field was developed by stakeholders with consideration of the program's strategic goals and the higher strategy. Based on this input, KACST staff and consultants refined the list of critical technology areas for the Kingdom. The technology areas were reviewed by the KACST Petroleum and Petrochemical Research Institute (PAPRI) and a final list of targeted technologies areas was selected.

Selected Technology Areas

The program's Technology Areas were selected based on meeting the Kingdom's needs in the following critical areas:

1. Gas & Oil Processes.
2. Refining Processes.
3. Clean Fuel.
4. Process Development.

Specific fields of interest within these areas include:

1. Cracking.
2. Isomerization.
3. Dehydrogenation.
4. Polymerization.
5. Alkylation.

Program Structure

Work in each Technology Areas will be achieved through a program structure that starts with identifying specific Objectives within three major program domains: Infrastructure, Core Operations and Value Delivery. Performance Indicators (and target levels) are defined for each Objective and then Projects are identified to satisfy the Indicators. Stakeholders participated throughout the Objectives, Indicators and Projects definition process, using a Balanced Scorecard development process).

Program Objectives

To achieve the programs strategic goals, the following implementation objectives were considered:

Infrastructure

- Developing Human Resources:
  - removing barriers to hiring/retaining key staff.
  - advocating changes to pre-college education, advocating improvements to college training in relevant science, technology, engineering and mathematics courses.
  - expanding the role of women in petrochemical research and innovation.
- Developing a collaborative culture:
  - expand R&D collaboration between KACST, universities, and industry, and make policy changes to improve the ability of university faculty members to conduct research.
  - improve KSA knowledge of international technology developments and KSA participation in international research.
- Effective financial management.
- Developing work processes and systems.
- Provision of Laboratories and Equipment.
- Developing knowledge management system.

Program Structure

Core Operations

- Technology Selection.
- Establishing Strategic Partnerships.
- Technology Development.
- Conducting Fundamental Research.
- Conducting Applied Research.
- Building Pilot Plants.
- Technology Localization.
- Conducting Localization Research & Studies.
- Building Localization Pilot Plants.
- Technology Transfer.
- Assessment of Ready Technologies.

Delivery of Program Value

- Working with the Incubators.
- Working with the Technology Innovation Centers.
- Working with the Program Beneficiaries:
  - Providing Cost/Value Efficiency.
  - Providing Job Opportunities.
  - Providing Investment Opportunities.
  - Supporting Environmental Protection.
  - Effective Use of National Resources.
- Supporting National Goals:
  - National Self-Reliance and Security.
  - Continuous Development.
  - Economic Growth.

Performance Indicators

Several performance indicators will be used to gauge the progress of the broad program functions. Major performance indicators include:

- Percentage of HR requirements fulfillment.
- Program return on investment.
- Level of strategic objectives fulfillment by projects and work processes.
- Size of used knowledge assets (documented and acquired).
- Level of strategic objectives fulfillment by selected technologies.
- Percentage of activated strategic partnerships to total required.

- Number of innovations leading to new applications through fundamental research.
- Percentage of applied research resulting in prototypes, pilot plants or applied solutions.
- Percentage of pilot plants leading to production line or solution.
- Percentage of applied research resulting in localized technologies.
- Percentage of by-product technologies resulting from localized technologies.
- Percentage of localization pilot plants leading to production line or solution.
- Percentage of ready technologies leading to production lines or solutions.
- Number of ready technologies passed on to localization and development.
- Percentage of technologies, prototypes and pilot plants adopted by incubators from total offered.
- Percentage of pre-incubation and production prototypes developed with TIC's to total offered.

Program Project Categories

To fulfill the program objectives and achieve satisfactory levels in the performance indicators for each objective, initial program projects were identified by stakeholders which can be divided into the 3 main categories that correspond to the the three major program domains: infrastructure projects, core operation projects (including research and development), and value delivery projects. These projects will be subject to evaluation during implementation and possible cancellation or replacement, if not satisfactory (portfolio management).

Operational Plans

Operational plans include a portfolio management plan, a technology transfer plan, a quality management plan, a human resources plan, a communications plan, and a risk management plan.

Portfolio Management

Initial Portfolio Formation

Potential R&D projects were entered into a project portfolio formation process to form an **initial** portfolio based on best utilization of available resources to achieve the program's strategic objectives. This included the following main phases:

- **Phase 1:** Evaluate with respect to strategic goals

In this phase, only projects aligned with the Program's strategic goals were selected. These projects were distributed into strategic groups and the total available resources were allocated to the strategic groups based on their strategic significance. The Program adopted a Project Distribution Matrix technique for defining the strategic groups. Nine groups resulted from the intersection of two dimensions having 3 elements each. These are **Strategic Technology Paths** (Development, Localization and Transfer) and **Research & Development Types** (Basic Research, Applied Research / Pilot Plants, and Product Dev't / Added Value).

- **Phase 2:** Prioritization for resources:

In this phase, projects competing for the same resources within each group are prioritized. The Program adopted a Paired Comparison technique for this purpose. Accordingly, nine paired comparison tables were developed.

Projects were selected to the portfolio one by one starting from the top of the prioritized list in each group down until the initially allocated resource for that group is consumed.

- **Phase 3:** Select vs. Balancing Factors

In this phase, further selection or elimination is made to the projects selected in Phase-2 to balance the selection in terms of some balancing factors such as:

- Research vs. Development.
- Long-Term vs. Short-Term.
- High Risk vs. Low Risk.
- Growth vs. Sustainability.
- Outsourced vs. In-sourced.
- Local / National vs. International.

Portfolio Management Process

Following the initial formation of the portfolio, projects are then activated and the portfolio is managed over the life of the Program. Active projects will be evaluated, completed, postponed or cancelled based on their performance in:

- Achieving the strategic objectives they were selected for, and/or
- Achieving satisfactory implementation progress (in terms of scope, schedule, budget and quality).

At the same time, strategic objectives may be adjusted and resources may be varied, which results in a requirement for portfolio reformation as well. This portfolio management process is designed to ensure that projects implemented in the program always represent the best means of achieving program strategies with best utilization of available resources. Without such objective and methodical process, project initiation and resources utilization is usually subject to personal preferences, organizational political pressures and subjective factors.

Technology transfer plan

The Petrochemical Technology Program will follow internationally recognized best practices in technology transfer. Key elements of the program that are designed to facilitate technology transfer are:

- Involvement of users in the program design. This occurs through user participation in the planning workshop and user involvement in the petrochemical advisory committee. It is well recognized that user involvement in the research design leads to research and outcomes that are more likely to meet the needs of users, and thus are more likely to lead to successful innovation.

- The national programs focused on the development of advanced pilot application projects. The projects involve universities as well as companies, and knowledge is transferred to the companies in the course of the project. This is a proven method for developing technologies that serve a need and can be transferred readily to government or commercial users.

- The use of university/industry centers as a major research mechanism throughout the plan. Industry involvement in these centers (providing advice and funding) will encourage university research to be focused on user needs, increasing the likelihood of technology transfer. These centers will also transfer knowledge to industry though the training and graduation of students (who have been trained on problems of interest to industry), who then take jobs in companies or form their own companies.

- The linkage between the petrochemical program and technology business incubators and other programs to aid the start-up of new petrochemical companies.

Quality management plan

The Petrochemical Technology program will follow international best practice quality management processes 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) subprogram evaluations 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.

Human resources plan

As noted in the SWOT analysis, human resources are a critical barrier for the success of the Petrochemicals Technology Program. The availability of skilled people, including both researchers and technical managers and leaders, is likely to limit the growth and success of KSA Petrochemicals programs. The plan will require substantial numbers of Petrochemicals professionals, including additional researchers, technical managers, and technical leaders at KACST, at universities and at companies.

A central task of the program management function will be to address this issue.

To achieve the goals of the program, KACST will need to hire or develop additional program managers with the skills to lead national programs. To do this KACST will need additional flexibility with respect to compensation packages, speed of hiring, and ability to hire international staff.

Universities and companies will need additional researchers and software engineers with the skills to develop innovative technologies. This will require broader changes, some of which are outside of the scope of this plan. As part of the activities in this plan, the Petrochemicals Technology Program will:

- Analyze petrochemicals human resource issues and advocate changes to improve the quality of math and science education in primary and secondary education
- Work with the other agencies to improve the quality of undergraduate petrochemicals education, especially at regional universities.
- Work with new universities to develop research and education programs that especially match the kingdom's petrochemicals strategic technology needs.
- Work to change policies to allow more international hiring, to bring specialized expertise to the Kingdom.
- Support training for researchers to become R&D managers and leaders.

At the undergraduate and especially graduate level, this plan is designed to help increase the numbers of petrochemicals researchers through its emphasis on university-industry centers. These centers are designed to train new students with research and innovation skills needed by research organizations and industry.

Communications management plan

The purpose of the communications management plan is to provide appropriate information to the program participants and stakeholders. One element of the communications plan is to improve communication throughout the KSA Petrochemicals research and innovation community and to expand collaboration among members of the community. Aspects of this include:

- There will be a public website with information on program goals, accomplishments, funding opportunities, and other news.
- Periodic workshops will be held with users and stakeholders to define future program needs.
- Requests for proposals (for university centers, grants, and pilot application development programs) will be announced to the public.

- The program advisory board will review and comment on the program, and advisory board reports will be made public on the website.
- The program will sponsor workshops, conferences, and professional society activities to expand communication and networking throughout the community.
- Presentations on the program will be made at national and international conferences.

Another element of the plan is to define appropriate communications within the management structure of the plan. It is especially important that information about risks or difficulties in the program, such as delays, lack of resources, or non-attainment of goals be rapidly communicated to higher levels of management. A general principle is that management should never be surprised by bad news.

Risk management plan

The program presented here is an ambitious program that will challenge the capabilities of the Kingdom. There are several types of risks that could prevent attainment of program goals, including technical risks, market risks, and financial risk.

One source of technical risk-risk to attainment of technical goals-is, as described above, the lack of adequate human resources to implement the program. Approaches to managing this risk are:

- Changing policies to attract people with the needed skills. This may involve raising salaries and recruiting internationally.
- Delaying or phasing in some program elements if people are cannot be hired.
- Expanding the pool of people with needed skills through education and training programs, such as university petrochemicals research centers (see human resources plan).

Another cause of technical risk is overly ambitious goals. The approaches to addressing the risk are to have an independent review of technical goals to ensure they are feasible, and to adjust technical goals if milestones are not being met.

Market risk is that projects, while technically successful, do not lead to successful products because of poorly understood or changing market conditions, such as the development of other technical approaches. A way to address this risk is through:

- Designing programs based on carefully considered market needs.
- Monitoring international technology and market developments.
- Continual readjustment of plans in responses to changes in the environment.

Financial risk is the risk of unavailability of funds or of cost overruns. The way to address risks in this area is through careful program planning and monitoring, and early identification of possible cost overruns. Another financial risk is due to changes in the plan or funding due to political or policy changes. It will be important for the plan management to maintain communication with policy leaders to ensure they are aware of the accomplishments of the program and to get early warning of any policy changes that may affect the program.

Implementation of the Plan

Within KACST, the Petrochemicals program manager will be responsible for the overall execution of the plan. Some portions of the plan may be managed by other parts of KACST. For example, the technology innovation centers and technology incubators may be managed by the Technology Development Center, which may specialize in the management of these kinds of programs. In this case, the program manager's role will be to provide technical input to the design and evaluation of these programs rather than to manage.

Many aspects of the plan represent new functions, especially in developing and managing national technology programs that include industry and universities and may involve international collaborations. A major task for the first year of the program will be, in addition to detailed program planning, for KACST to acquire or develop the necessary skills through hiring or training. Although it is critical to rapidly start new research programs, it is essential to build the skills necessary to lead and develop these programs, and to plan them carefully. As part of the initial activities under this plan, KACST staff members will visit programs of a similar nature elsewhere in the world to discuss their management practices and lessons learned.

The Petrochemicals Strategic Technology Advisory Committee will oversee the implementation of the plan. It will meet approximately four times a year and review progress in the program.

Key performance indicators will be established for each subprogram. General performance indicators include:

- Growth or establishment of technology-based businesses due to Petrochemicals program.
- Amount of revenue and jobs created.
- Successful importation of technology resulting in new businesses or applications.

Implementation of the Plan

- Movement of projects to incubators.
- Contribution to OSS applied in Kingdom.
- Licenses and licensing revenue to universities and research institutes.
- Petrochemicals-related patents and copyrights.
- Private sector funding of university and KACST petrochemicals research (indicates the value private sector places on university or KACST petrochemicals R&D).
- Number and level of presentations in international conferences.
- Changes in policies (described previously) to improve petrochemicals innovation.
- Number and impact of publications.
- Extent of domestic and international R&D collaborations.
- Numbers of petrochemicals advanced degrees awarded.

The advisory committee will also sponsor and oversee studies of emerging areas of petrochemicals, 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, industry and other stakeholders will also contribute to both a continual evolution of the plan as well as a stronger petrochemicals research and innovation network in the Kingdom.

Appendix A: Stakeholders Participants

The program thanks the following stakeholder participants for their contribution. The development of this roadmap was assisted valuably by their joint input. They are held free of any responsibility resulting from the plan's content.

Representatives	Stakeholders
Dr. Ahmed AL-Shafiea	Royal Commission for Jubail and Yanbu
Dr. Abdulwahab AL-Sadoon Eng. Raed AL-Humaid	SAGIA
Dr. Abdullaziz AL-Jodai	SABIC
Dr. Aydh AL-Shihri	King khalid University
Dr. Abdullah AL-Arifi	King Saud University
Dr. Abdullrahman Arabiah	
Dr. Yahia AL-Hamed	King Abdulaziz University
Dr. Suliman AL-Khataf	KFUPM
Dr. Mauyed Mehdi Eng. Adel AL-Ghamdi Eng. Mohamed AL-Tayyar Eng. Musaed AL-Ghamdi	Saudi Aramco Co.
Eng. Ahmed AL-Bassam	NIC

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Eng.Khalid S. AL-Ghamdi

Appendix B: Development Methodology

A strategic planning / strategic management methodology was designed and implemented for developing this program roadmap. Figure B-1 is a framework that shows the methodology's main stages and components. Major issues taken into consideration in developing this methodology include:

- Ensuring a comprehensive approach from higher strategy to implementation level with clear strategic alignment.
- Maximizing the opportunity that the strategic plan represented by this roadmap finds its way to actual implementation through clarity of «next step» and guidance towards execution.
- Emphasizing focus and conciseness in representation and avoiding verbose expression to improve understanding among all parties involved with developing and implementing the roadmap, especially given the program's scientific / engineering setting.
- Making use of proven methods and concepts in strategic planning as well as project/program management fields, including:

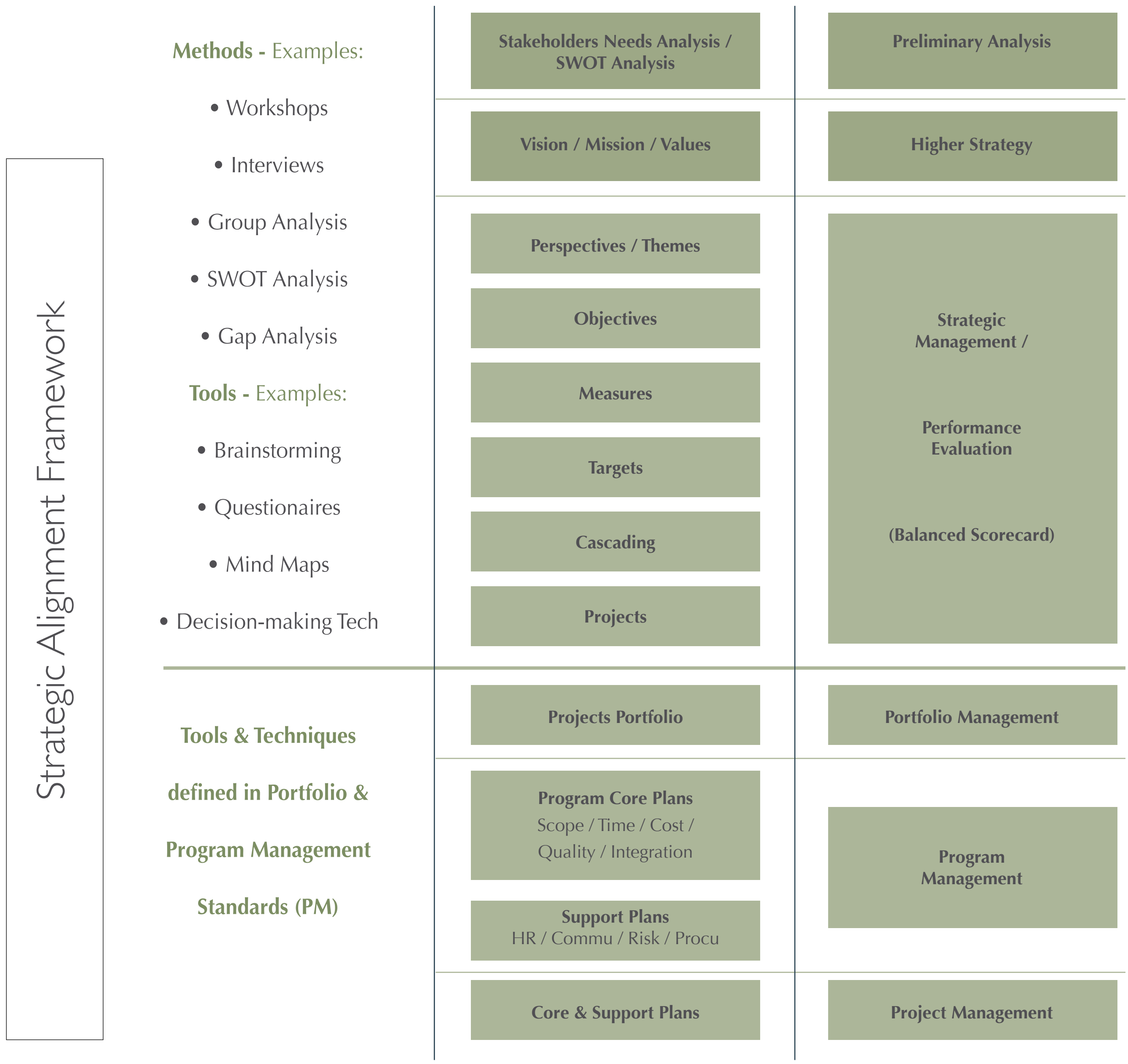
- Balanced Scorecards for linking the program's vision and mission to its projects, developing a performance oriented strategy and identifying program objectives, performance indicators and projects in a methodical and objective way. Figure B-2 shows the Strategy Map that guided scorecard development and is instrumental in depicting the structure of the program and relationships between important program elements.
- Portfolio Management for ensuring optimal utilization of available resources and proper selection and balancing of projects as a continuous mechanism throughout the life of the program. This is further explained in Section 5 of the roadmap.

Appendix B: Development Methodology

- Program Management to ensure that program-level benefits are identified and effectively captured as projects are implemented.

The above approach ensured that not only strategic planning, but also strategic management requirements and concerns are considered and addressed. The Petroleum and Petrochemicals Research Institute at KACST has a complete documentation of the roadmap development methodology and the processes that were applied with stakeholders over various workshops and functions to finalize the roadmap.

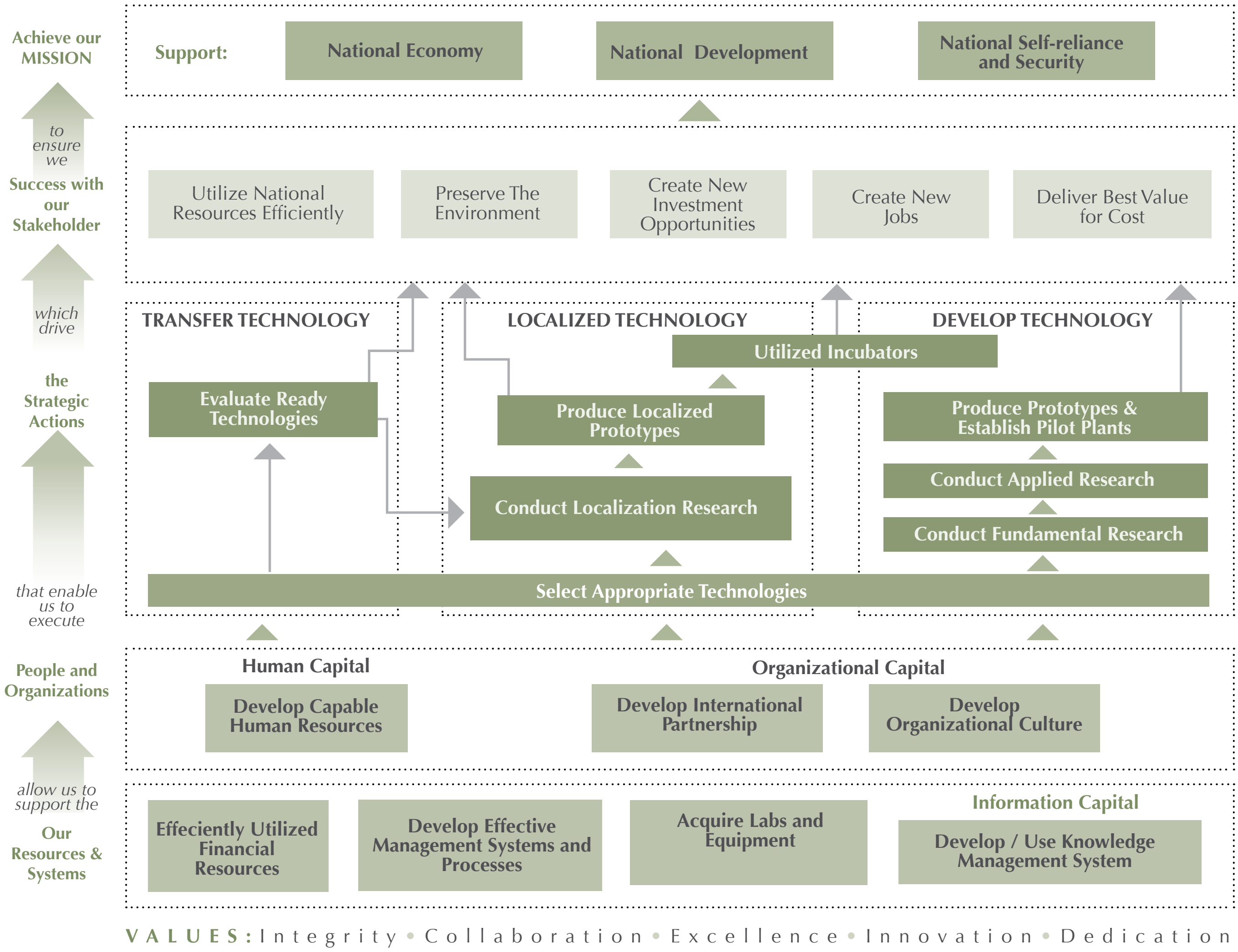
Figure B-1: Plan development Methodology



Appendix B: Development Methodology

VISION: To reach a prominent strategic position internationally through a broad national sponsorship of petrochemical technology localization and development.

Figure B-2: Program Strategy Map



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