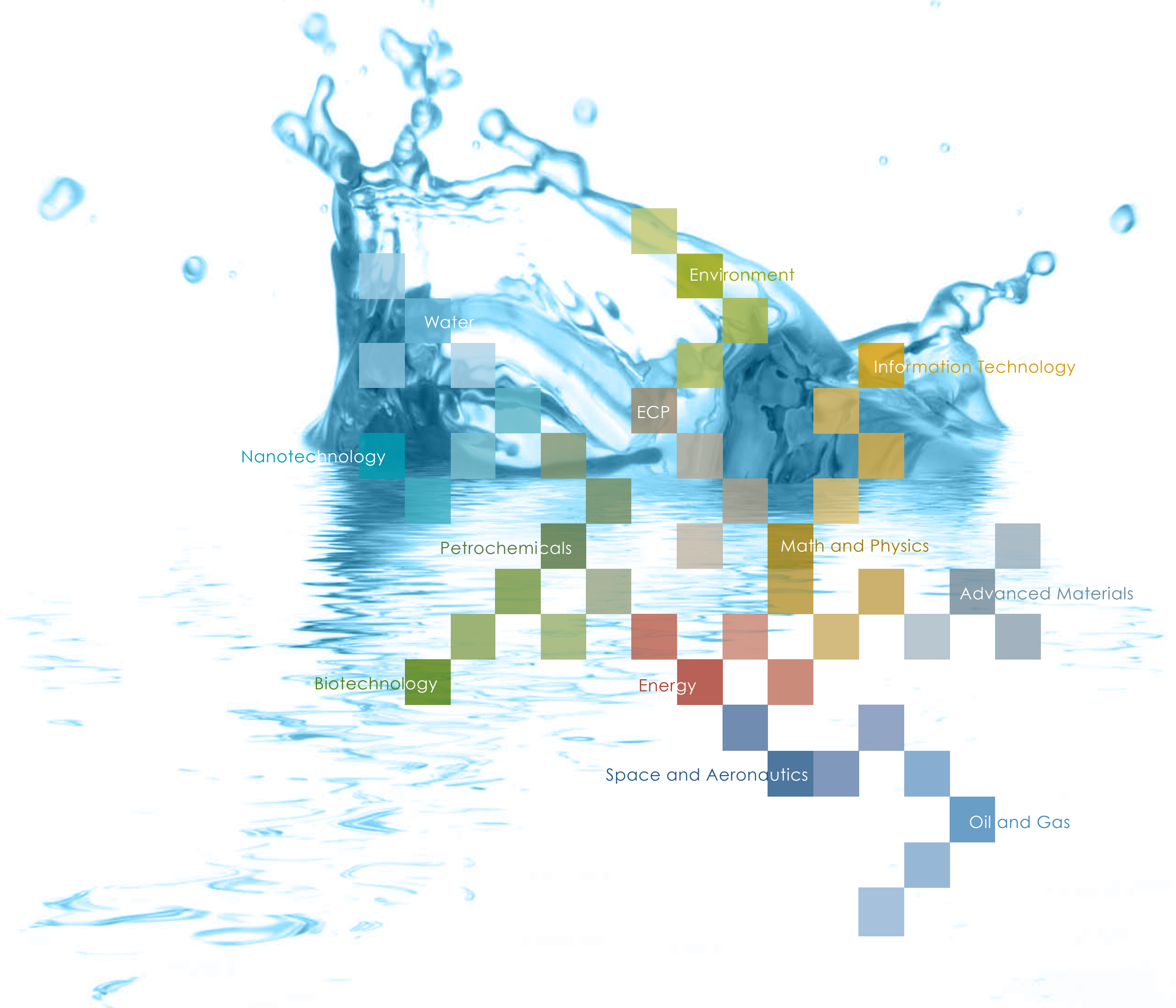
Kingdom of Saudi Arabia



Strategic Priorities for Water Technology Program

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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 future development of the Kingdom of Saudi Arabia (KSA). This plan is for one of these programs, the Water Technology Program.

The main motivation of the program is to promote and support Saudi economic, social, security, developmental and other national interests through localizing (including initial transfer) and developing properly selected strategic and advanced technologies in the water area.

The impetus for the water technology program stems from the specific needs of the Kingdom. The Kingdom faces a number of water resources limitations. It also stems from the role that water plays in the Kingdom's development plans, as well as the importance of water issues and policies internationally. This plan is based on input from the users and stakeholders of water technology in the Kingdom, including government agencies, industry and universities that have a role in water technology. The plan was derived from a process that:

- identified the key needs of the Kingdom for water technology research
- assessed the strengths, weaknesses, opportunities, and threats of the program.
- analyzed KSA water technology publications and patents and reviewed the works of some international research institutes.
- defined a vision and mission for the Kingdom's water technology program.
- defined the key technologies and other program areas needed to address the Kingdom's needs in water technology research.

Executive summary

This process concluded that improved KSA water technologies are needed to:

- Provide adequate water supplies for human, agricultural and industrial use.
- Support national self-reliance in water-related research and development and reduce dependence on foreign technology.
- Improve the price/value efficiency of water production and treatment.
- Develop a domestic water technology industry that will contribute to national economic performance and will provide employment opportunities.

In addition to the technical needs, the planning process identified several areas where policies need to be changed or barriers removed to facilitate development and localization of water technologies. These include:

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

The technology areas of highest priority are the following:

- Water Desalination:
  - Thermal Desalination.
  - Membrane Desalination.
  - Hybrid Desalination.

- Drinking Water Treatment:
  - Membrane Treatment.
  - Chemical Treatment.
  - Ionic Exchange.
  - Disinfection.
  - Filtration.

- Wastewater Treatment:
  - Biological Treatment.
  - Biological Membrane Treatment.
  - Chemophysical Treatment.
  - Advanced Treatment.

- Water Resources Management:
  - Water Conservation.
  - Water Reuse and Recycling.
  - Groundwater Recharge.
  - Rain Harvest.
  - Cloud Seeding.

The water technology program will be directed by a Program Manager who will be responsible for the overall execution of the plan. The Water 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 report to the National S&T Plan Supervisory Committee, which will oversee all of the Strategic Technology Programs.

Introduction

Background

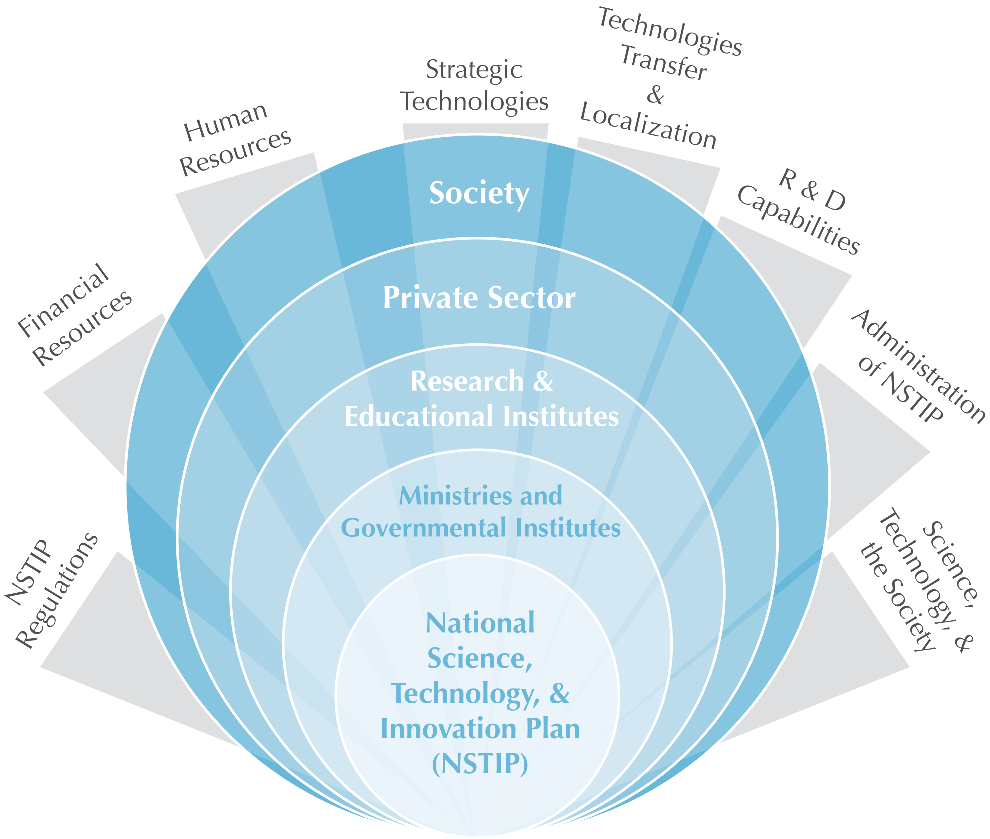
King Abdulaziz City for Science and Technology (KACST) was directed by its charter of 1986 to "propose a national policy for the development of science and technology and to devise the strategy and plans necessary to implement them." In accordance with this charter, KACST launched a comprehensive effort in collaboration with the Ministry of Economy and Planning (MoEP), to develop a long-term national policy on science and technology. In July 2002, the Council of Ministers approved the national policy for science and technology, entitled "The Comprehensive, Long-Term, National Science and Technology Policy."

Under the framework of this policy, KACST and MoEP, in collaboration with relevant stakeholders, developed the national plan for science, technology and innovation (STI). The plan outlined the focus and future direction of science, technology, and innovation in the Kingdom, with special consideration of the role of KACST, universities, government, industry, and society. The plan encompasses eight major programs, depicted in figure 1, as follows:

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.

Introduction

Figure 1: Science and Technology Plan



In the "Strategic and Advanced 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.

Scope

The scope of the water program includes all water technology research and development within the Kingdom of Saudi Arabia. The program involves KACST, universities, industry, and government stakeholders. KACST has overall responsibility for the development and execution of the program.

The program's sphere of activity involves water-related fields of technology that are significant to the Kingdom's interests as expressed in the National Policy for

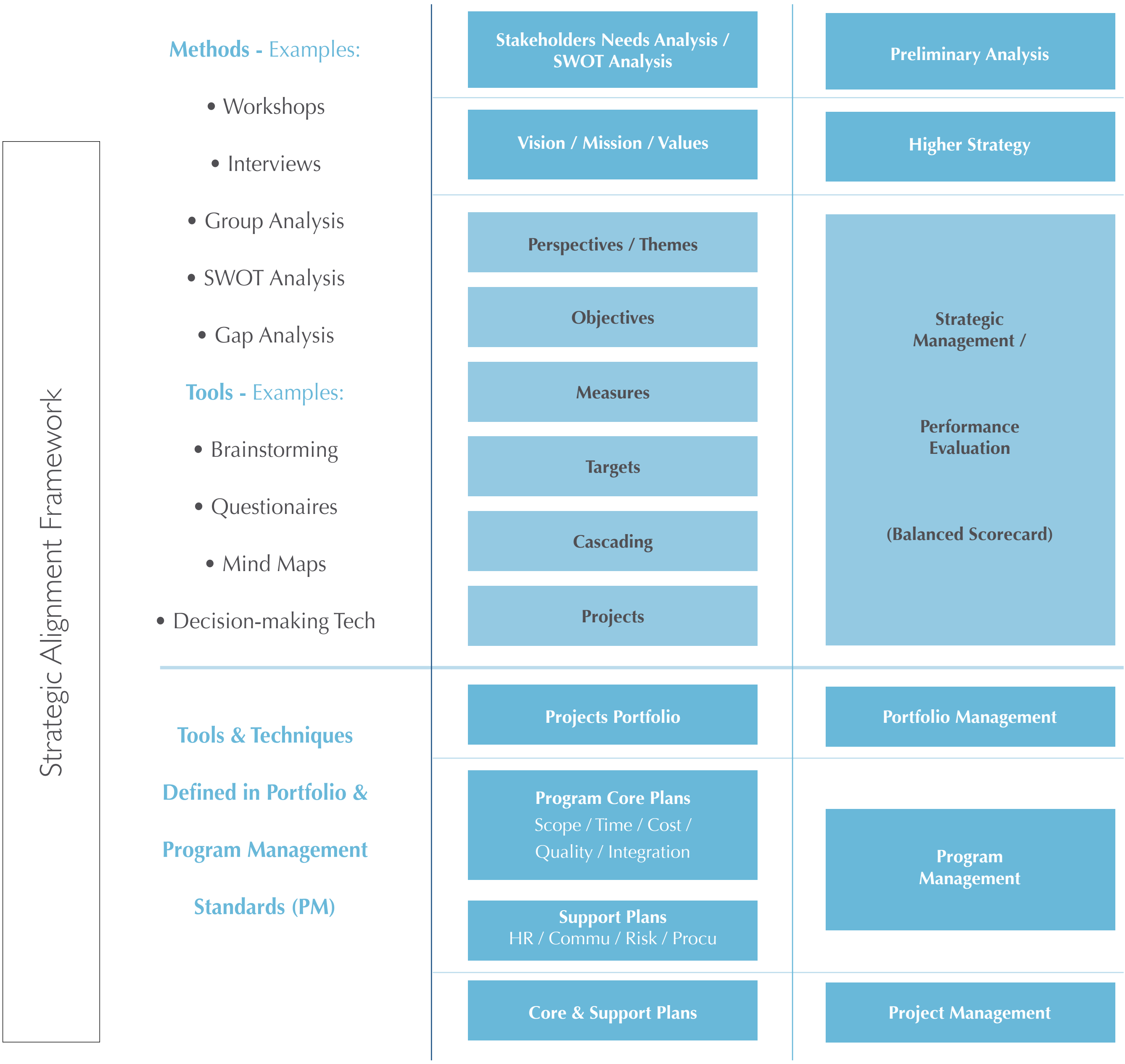
Science and Technology. The program will also maintain a perspective on worldwide developments and movements in the water technology field. For implementation, the program will concentrate on areas of application and projects that represent optimal utilization of resources with realistic chances of successful outcomes. The program scope includes technology transfer and localization, and R&D needed to follow-on to or enhance the localization. Although program products may include contributions to knowledge, the emphasis is on applied R&D rather than basic research. The program's technology areas and research and development (R&D) projects are outlined in this plan. The program's main deliverables are water technologies and the establishment of international collaborative networks to enhance the research capacity within the Kingdom.

Plan Development Process

The development of this plan began with identifying the stakeholders and users of water technology research and innovation in the Kingdom, creating vision and mission statements, and conducting background research on the current position of the Kingdom in water technology and on the role of other water technology research institutes around the world. Figure 2 illustrates the elements of this process.

Introduction

Figure 2: Roadmap Development Methodology



KSA Water Technology R&D Needs

The workshops conducted during the development of this plan identified a wide number of water technology research and innovation needs for the Kingdom. These included needs from the water technology sector, water industry, several government agencies, and universities. Improved KSA water technologies are needed to:

- Provide adequate water supplies for human, agricultural and industrial use
- Support national self-reliance in water-related research and development and reduce dependence on foreign technology.
- Improve the price/value efficiency of water production and treatment.
- Develop a domestic water technology industry that will contribute to national economic performance and will provide employment opportunities.

Because water is so vital to the Kingdom, having a strong technological capability in domestic water industry is both a national security and economic imperative.

A number of areas were identified where policies need to be changed or barriers removed to facilitate the development and localization of water technologies. These include:

- Policies to facilitate R&D collaboration between KACST, government agencies, universities, and industry.
- Expanded human resources for water 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.

Strategic Context

Stakeholders Roles

The stakeholders for the water technology program include KACST, universities, various independent specialized research institutes, and other government agencies.

Table 1: Stakeholders and their roles

Stakeholders	Role
KACST	Program management and coordination, including developing an integrated program management system
	Program technical development
	Conducting infrastructure research and studies
	Providing qualified human resources, including researchers and experts
	Providing financial resources
	Providing equipments and laboratories
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	Creating new applied scientific knowledge
	Participating 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 from the program.
	Communicate company needs to program
	Support and participate in collaborative R&D projects.
	Support and participate in the Technology Innovation Centers

Analysis of Comparable Water R&D Institutes

As part of the background work for this plan, the planning team reviewed several other water research laboratories around the world, which were selected to include a mix of government-supported laboratories with functions similar to those of the KACST's water program. These included:

- The National Water Research Institute, Canada.
- The Japan Water Research Center.
- The National Hydraulic Research Institute of Malaysia.
- The Institute for Water Research, South Africa.
- The U.S. Department of the Interior, Bureau of Reclamation, and Sandia National Laboratories.
- Various water related R&D activities in Australia.

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

- Thermal desalination.
- Membrane desalination.
- Hybrid desalination.
- Membrane treatment.
- Chemical treatment.
- Ionic exchange.
- Disinfection.
- Filtration.
- Biological treatment.
- Biological membrane treatment.
- Chemophysical treatment.
- Advanced treatment.
- Water conservation.
- Water reuse and recycling.
- Groundwater recharge.
- Rain harvest.
- Cloud seeding.

A full description of these laboratories' programs can be found in a separate document.[1]

Analysis of Water Technologies Publications and Patents

The overall field, "water 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 develop search queries for publication and patent databases.[2] Water technologies R&D is a multidisciplinary field that spans many research areas, including environmental engineering, chemical engineering, civil engineering, geosciences, microbiology, meteorology, and materials sciences. The KSA water technologies program identifies four major application sub-topics: water desalination, drinking water treatment, wastewater treatment, and water resources management. The scope of this analysis was restricted to only recent publication (2005-2007) and patent (2002-2006) activity in the four KACST-defined fields.

There is general agreement that publications and patents strongly correlate with scientific research capacity, although publication and patent counts alone do not fully represent the quality or scope of research. Nonetheless, publication and patent activity have long been used as indicators for knowledge creation and research output.[3] Several indicators, including forward citations (the frequency

1 Strategic Review: Information Technology. Report prepared by SRI International for KACST.

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 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. Because the U.S. market is large, most important inventions from around the world are patented there.

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

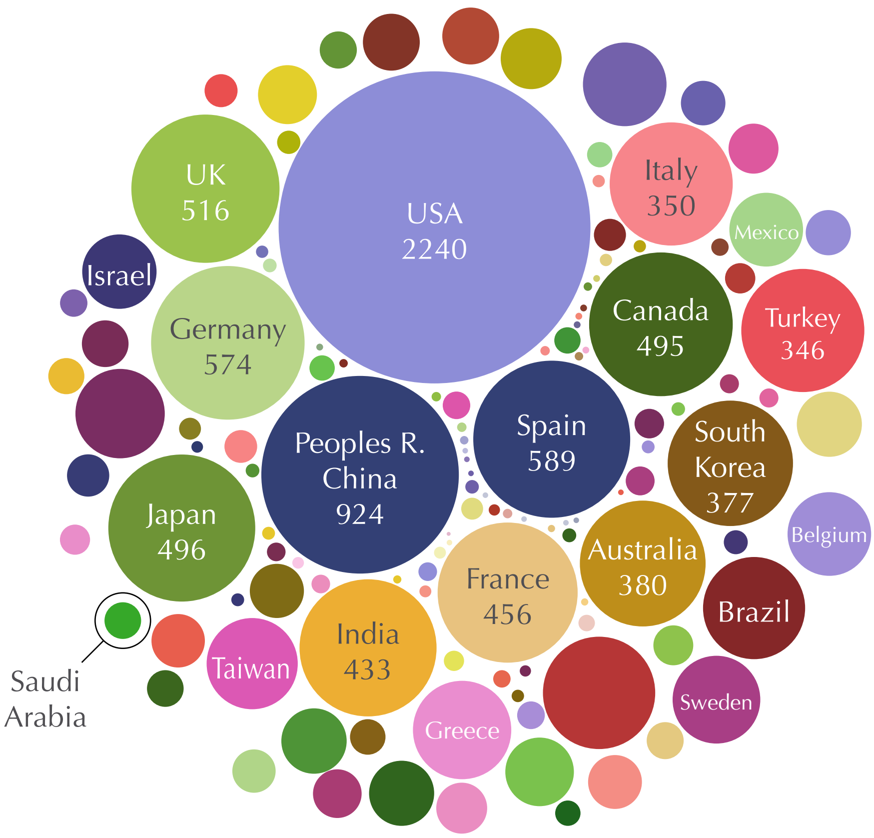
at which publications and patents are cited by others), a measure of impact, and co-authoring relationships, an indicator of scientific collaboration, are presented below. Together, these indicators provide measures of collaboration, globalization and impact of science and technology research in fields related to the KSA water technologies program.

Global Water Technologies Publication Activity

Between 2005 and 2007, there were 10587 articles published worldwide related to KSA research priorities in wastewater treatment, drinking water treatment, water resources management, and water desalination.[4]

The United States was the world's largest producer of related articles, generating 2240 articles over this period. The People's Republic of China was a distant second, producing 924 articles followed by Spain and Germany with 589 and 574 articles respectively. Figure 3 shows the number of publications produced by selected countries over this period.[5] Saudi Arabia was tied for the 48th largest producer of water technologies publications, producing 31 articles. Overall, Saudi Arabia produces a small fraction of the world's water technologies publications.

Figure 3: Water Technologies Publications (2005 - 2007)



4 Throughout this report, "water technologies" is defined by the keyword and sub-topic definitions provided by KACST.

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

As shown in table 2, wastewater treatment accounts for the majority of water technologies related publications worldwide (4,551) followed by drinking water treatment (2,666), water resources management (2,624) and water desalination (746). Desalination publications account for almost half of Saudi Arabia's water technologies publication output and Saudi Arabia is ranked 24th in the production of desalination technology publications.

Table 2: Water Technologies Sub-Topics 2005 - 2007)

Sub-Topic	Publications
Wastewater Treatment	4551
Drinking Water Treatment	2666
Water Resources Management	2624
Water Desalination	746

Benchmark Countries

Average publication impact is calculated as the number of citations of articles from a particular country divided by the total number of articles published by authors from that country. For instance, a country that published 50 articles that were cited 100 times would have an average publication impact of two. Between 2005 and 2007, Switzerland had the highest average publication impact

of all countries at 4.96 followed by Germany (3.40), France (2.63), and the Netherlands (2.55). The average publication impact for Saudi Arabia was 0.55 with 17 citations of 31 articles. Table 3 presents publication and citation counts for benchmark countries. [6]

7 Benchmark countries include global leaders in terms of total water technologies publication output in addition to a list of specific countries provided by KACST.

Table 3: Water Technologies Publication Impact (2005 - 2007)

Country	Publications	Total Citations	Average Publication Impact
Switzerland	176	873	4.96
Germany	574	1,949	3.40
France	456	1,201	2.63
Netherlands	287	733	2.55
USA	2,240	5,614	2.51
UK	463	1,137	2.46
Argentina	52	120	2.31
Spain	589	1,284	2.18
Sweden	176	377	2.14
Australia	380	762	2.01
Saudi Arabia	31	17	0.55

Water Technologies Research Organizations

Water technologies R&D publications are produced at thousands of research institutions in nearly 130 countries. As shown in table 4, the three institutions producing the largest number of publications related to water technologies R&D are the Chinese Academy of Sciences (192), the United States Environmental Protection Agency (107), and the University of Florida (92). The Chinese Academy of Sciences is the number one producer of wastewater treatment and water resources management, publications while the US EPA is the number one producer of drinking water treatment publications. Kuwait University is the leading producer of water desalination publications.

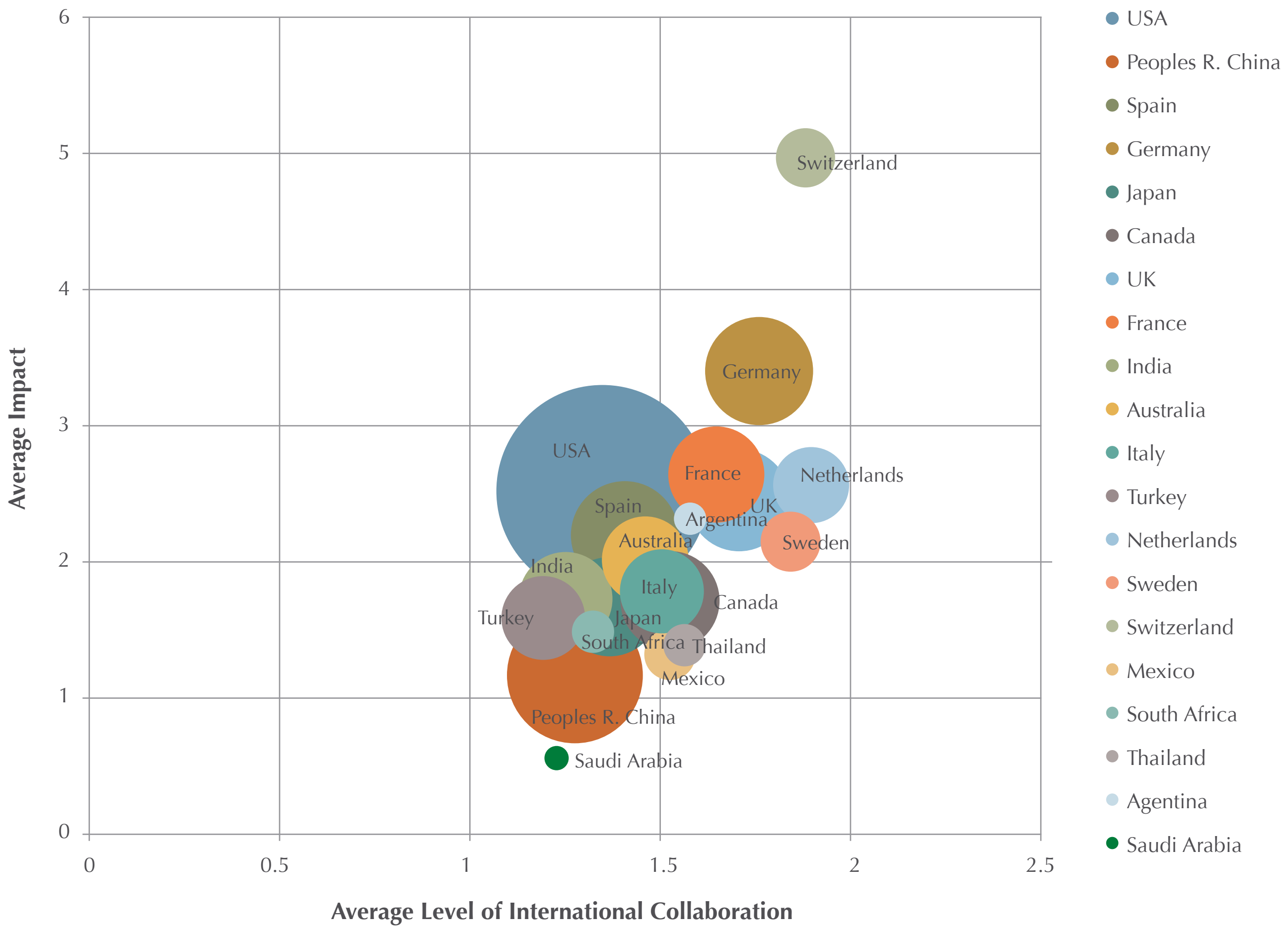
Table 4: Global Water Technologies Research Organizations (2005 - 2007)

Institution	Total	Average Impact	Wastewater Treatment	Drinking Water Treatment	Water Resources Management	Desalination
Chinese Acad Sci	192	1.35	88	46	64	4
US EPA	112	2.38	19	86	15	
Univ Florida	92	1.83	26	29	36	7
Univ Texas	92	1.99	24	27	40	4
Indian Inst Technol	88	2.26	33	22	25	10
Swiss Federal Institute Aquatic Science & Technology	87	5.40	42	39	13	
CSIC	87	2.87	52	13	25	2
USDA ARS	83	1.99	21	21	42	
Tsing Hua University	77	0.97	41	22	6	11
Harbin Inst Technol	74	0.74	59	13	3	1

International Collaboration and Publication Impact

For countries with a similar level of publication activity, those countries with a high level of international collaboration also tend to produce publications with a high level of impact. In this study, international collaboration is calculated as the average number of countries represented per publication, based on authors' addresses. Figure 4 plots a country's level of international collaboration (horizontal axis) against the average impact of its publications (vertical axis). Countries such as Switzerland and Germany, which show significant international collaborative activity, also tend to produce papers with a higher average impact.

Figure 4: Water Technologies Collaboration and Publication Impact (2005 - 2007)



KSA Collaboration Activity

As shown in table 5, authors affiliated with KSA institutions collaborated on more than one article with authors from Egypt (3 publications). KSA-affiliated authors collaborated on individual publications with authors from: India, Pakistan, Sweden, and the United Kingdom.

Table 5: KSA Publication Collaborators (2005 - 2007)

Country	Numbers of Publications
Egypt	3
India	1
Pakistan	1
Sweden	1
United Kingdom	1

Water Technologies Journals

Table 6 presents journals with a significant level of publication activity related to KSA water technologies sub-fields from 2005-2007.

Table 6: Water Technologies Journals (2005 - 2007)

	Journal	Publications
Desalination	DESALINATION	408
	JOURNAL OF MEMBRANE SCIENCE	42
	FILTRATION & SEPARATION	11
	JOURNAL AMERICAN WATER WORKS ASSOCIATION	10
	INDUSTRIAL & ENGINEERING CHEMISTRY RESEARCH	9
	SEPARATION AND PURIFICATION TECHNOLOGY	8
	APPLIED THERMAL ENGINEERING	7
	RENEWABLE ENERGY	6
	SEPARATION SCIENCE AND TECHNOLOGY	5
	WATER RESEARCH	5
Drinking Water Treatment	WATER RESEARCH	194
	DESALINATION	153
	ENVIRONMENTAL SCIENCE & TECHNOLOGY	128
	JOURNAL AMERICAN WATER WORKS ASSOCIATION	52
	JOURNAL OF WATER SUPPLY RESEARCH AND TECHNOLOGY-AQUA	48
	JOURNAL OF HAZARDOUS MATERIALS	45
	CHEMOSPHERE	43
	JOURNAL OF MEMBRANE SCIENCE	41
	APPLIED AND ENVIRONMENTAL MICROBIOLOGY	40
	WATER SCIENCE AND TECHNOLOGY	36
Wastewater Treatment	WATER SCIENCE AND TECHNOLOGY	397
	WATER RESEARCH	296
	DESALINATION	251
	JOURNAL OF HAZARDOUS MATERIALS	184
	CHEMOSPHERE	168
	ENVIRONMENTAL SCIENCE & TECHNOLOGY	136
	WATER ENVIRONMENT RESEARCH	119
	ENVIRONMENTAL TECHNOLOGY	105
	PROCESS BIOCHEMISTRY	105
	BIORESOURCE TECHNOLOGY	96

	Journal	Publications
Water Resources Management	DESALINATION	154
	JOURNAL OF HYDROLOGY	67
	AGRICULTURAL WATER MANAGEMENT	65
	WATER SCIENCE AND TECHNOLOGY	64
	JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES	48
	HYDROGEOLOGY JOURNAL	47
	ATMOSPHERIC CHEMISTRY AND PHYSICS	41
	JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION	36
	WATER RESOURCES RESEARCH	31
	HYDROLOGICAL PROCESSES	29

Water Technologies Patent Activity

Between 2002 and 2006, there were 795 water technologies-related patent applications filed with the United States Patent Office (USPTO). As shown in tabl e 7, the majority of these (509) listed at least one inventor from the United States. Other countries with a significant number of inventors include: Japan (59 applications), Germany (40 applications), and Canada (32 applications).

Table 7: Water Technologies Patents (2002 - 2006)

Country	Water Desalination	Drinking Water Treatment	Wastewater Treatment	Water Resources Management	Total
United States	52	53	174	236	509
Japan	11	7	28	13	59
Germany	6	10	3	21	40
Canada	2	2	16	12	32
Republic of Korea	0	1	16	9	25
Taiwan	5	1	6	13	24
France	2	3	3	15	22
Israel	3	2	2	11	18
United Kingdom	0	7	3	7	17
China	1	1	3	6	11

While the majority of the water technologies related patent applications are defined as individually owned patent applications (518 applications) by the United States Patent Office, some corporations are designated as the patent assignee on a number of applications. These organizations have demonstrated their involvement in water technology innovation and could be future targets for collaborative outreach efforts. As shown in table 8, General Electric Company is listed as the patent assignee on six water technologies applications, followed by Aqua-Aerobic Systems Inc. (4 applications), Eastman Kodak Company (4 applications), and CH2M Hill Inc. (3 applications).

Table 8: Leading Water Technologies Patent Assignees (2002 - 2006)

USTPO Assignee	No. of Patents Apps.
Individually Owned Patents	518
General Electric Company	6
Aqua-Aerobic Systems Inc.	4
Eastman Kodak Company	4
CH2M Hill Inc.	3

SWOT Analysis for Water Technology Program

This section presents a SWOT (strengths, weaknesses, opportunities, and threats) analysis of the Saudi Arabian Water Technology Program. In a SWOT analysis strengths and weaknesses are defined as internal to the organization while opportunities and threats are defined as external to the organization. For the purpose of this analysis, the "organization" is the water technologies program, including KACST, universities, and other government agencies.

Table 9: SWOT Analysis

	Helpful	Harmful
Internal	**Strengths**: ■ High national priority given to water-related issues (e.g. First among Strategic Technologies) ■ Availability of local multi-discipline expertise ■ Availability of a viable national water industry	**Weaknesses**: ■ Lack of experience with technology localization ■ Low equipment and laboratory readiness ■ Inadequate technical human resources
External	**Opportunities:** ■ Increasing need for water resources due to expanding population and industry ■ Availability of energy at favorable prices ■ Availability of vast shorelines ■ Need for advanced technology to address remote areas water necessities	**Threats**: ■ Decreasing ground water levels ■ High rate of technological change & obsolescence in the field ■ Price and quality competition from international products

Higher Strategy

Vision

KACST's vision for the water technologies plan is to achieve a distinguished international position in developing, acquiring, and localizing water technologies through the development of a comprehensive knowledge and economic infrastructure.

Mission

To develop and localize water technologies in the Kingdom by building qualified human resources and integrating local and international partners. This will enhance performance, reduce costs and provide investment opportunities. The program aims at increasing national water security and economic growth, as well as contributing to society at-large.

Values

To achieve excellence, the program will develop an internal culture through sound leadership and commitment to its operational teams that is rooted in the following values:

- Integrity.
- Sincere drive for excellence & proficiency.
- Creativity and innovation.
- Teamwork and collaboration.
- Loyalty.

Program Strategic Goals

The strategic goals of the program are:

- Developing advanced local technologies for water desalination and treatment at economical and competitive costs.
- Developing lab bench-scale prototypes for technology products in the selected areas.
- Acquiring equipment and facilities in KACST Institutes for each strategic project to support prototype development.
- Establishing specialized work teams in desalination and treatment technologies related to approved projects.

Higher Strategy

- Integrating the efforts of related organizations, which is a program management prerequisite for success.
- Enhancing the performance of key public and private sector players.
- Reducing costs of water desalination, purification and sewage treatment.
- Providing new investment opportunities to the private sector.
- Promoting the role of science and technology in the water sector.
- Developing high-quality human resources

Technology Areas

Selection Process

Technology areas were selected according to criteria that were defined by the stakeholders in alignment with the strategic goals of the water technology program and in keeping with the key needs of the Kingdom. The primary selection criteria were:

- The extent of dependence on the technology locally and regionally.
- Ease of design and manufacturing.
- Ease of use.
- Potential for further technology development.
- Future competitiveness.
- Economy of energy consumption.
- Availability of qualified human resources.
- Low operation and maintenance costs.
- Contribution to environmental protection.
- Low cost of technology development.
- Ability to form strategic partnerships as required.
- Ability to attract investors.
- High technology sustainability.

Selected Technology Areas

The technology areas selected were those that best met the criteria and have the greatest potential for developing the scientific and technical capacity of the Kingdom as well as meeting the urgent water needs. The following are the selected technology areas:

- Water Desalination:
  - Thermal Desalination:

Technology Areas

- Developing high temperature scale control anti scalants.
- Development of high temperature corrosion resistant materials for evaporators.
- Development an innovative intake system.
- Improving performance of heat transfer surfaces of thermal desalination process.
- Development of new design for thermal desalination plants (multi stage flash, multi effect distillation , electro dialysis).
- Developing commercially viable solar assisted desalination plants.

□ Membrane Desalination:
- Develop a feedwater recovery system for membrane desalination.
- Develop a process to reduce/ recover energy.
- Development of membranes with high resistance to organic and inorganic fouling.
- Development of anti corrosion membrane materials.

□ Hybrid Desalination:
- Develop a cost effective hybrid multi-stage flash and multi-effect evaporation system.
- Develop a cost effective hybrid multi-stage flash and reverse osmosis system.
- Develop a cost effective hybrid reverse osmosis and electrodialysis system.
- Develop a cost effective hybrid reverse osmosis and nanomembrane system.
- Develop a cost effective hybrid reverse osmosis and solar energy system.

■ Drinking Water Treatment:

□ Membrane Treatment:
- Development of reverse osmosis pretreatment processes.
- Development of micro, ultra, and nano filtration membrane material and processes.

□ Chemical Treatment:
- Development of local chemicals for hardness removal.
- Exploring the use local material for production of activated carbon.

□ Ionic Exchange:
- Synthesis organic or inorganic ion-exchange materials.
- Process improvements.

□ Disinfection:
- Developing disinfection processes using chlorine dioxide, ozonation, and UV.

□ Filtration:
- Exploring and use of local naturally occurring filtration material.
- Developing filtration processes.
- Process efficiency improvement.

■ Wastewater Treatment:

□ Biological Treatment:
- Activated sludge process improvement.
- Development of biological biofilter processes.
- Process efficiency improvement.

□ Biological Membrane Treatment:
- Development of anaerobic membrane bioreactor processes.
- Development of efficient aeration system.
- Development of membrane material.
- Process efficiency improvement.

Technology Areas

- Chemophysical Treatment:

- Development of coagulation chemicals.
- Exploring the development of innovative electro-coagulation and electro-oxidation processes.
- Improvement of process design.

- Advanced Treatment:

- Development of biological nitrogen and phosphorus removal.
- Development of chemical/physical nitrogen and phosphorus removal processes.

- Water Resources Management:
- Water conservation.
- Water reuse and recycling.
- Groundwater recharge.
- Rain harvest.
- Cloud seeding.

Program Structure

The R&D in each of the technology areas will be conducted within the parameters of a specific program structure. The governance of the research work will be based on (1) program objectives, (2) performance indicators, and (3) project categories. The process of selection projects began by considering the program objectives and then performance indicators and target levels for each objective. Projects were then selected to meet the targets.

Work on the aforementioned technology areas is achieved through a program structure that starts with identifying specific implementation objectives within three major program domains/perspectives; namely 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 (Balanced Scorecard development process).

Program Objectives

To achieve the program's strategic goals, the following implementation-oriented objectives were defined by the stakeholders:

Infrastructure

- Develop human resources.
- Develop organizational culture.
- Develop effective financial management.
- Develop work processes and systems.
- Provide laboratories and equipment.
- Develop knowledge management system.

Core Operations

- Select technologies.

- Establish strategic partnerships.
- Develop technologies:
  - Conduct fundamental research.
  - Conduct applied research.
  - Build pilot plants.
- Localize technology:
  - Conduct localization research & studies.
  - Build localization pilot plants.
- Transfer technology:
  - Assess ready technologies.

Value Delivery

- Work with the incubators.
- Work with the Technology Innovation Centers.
- Work with the program beneficiaries:
  - Provide cost/value efficiency.
  - Provide job opportunities.
  - Provide investment opportunities.
  - Support environmental protection.
  - Use national resources effectively.
- Support 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 fulfilled.
- 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 Technology Innovation Centers (TIC) 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 that can be divided into the three main categories outlined below. These projects will be subject to evaluation during implementation and possible cancellation or replacement, if not satisfactory (portfolio management):

- **Infrastructure Projects:** these are projects to plan, establish, and manage the infrastructure required for the success and efficiency of the program including its

human capital, knowledge capital, organizational capital, financial capital, and other systems / resources.

- **Research & Development Projects:** stakeholder's representatives were divided into groups representing each of the technology areas according to their personal research activity and expertise. They considered worldwide technological trends as well as local needs, resources and conditions in suggesting these projects. The link to national goals and needs is achieved through the alignment of the technology areas with those goals and needs. These are projects to develop new knowledge and technology in each of the selected technology areas.

- **Value Delivery Projects:** these are projects to assist the program in delivering value to beneficiaries or in working with incubators and Technology Innovation Centers (TIC's).

Operational Plans

As highlighted in other sections, the Water Technologies Program encompasses a large number of projects including water-related research and development projects, infrastructure projects and value delivery projects. Success of the program is dependent on success in accomplishing these projects. At the program level, high-level functions are carried out, but the most important role of the program is to support the individual projects.

This section discusses the actions that will be undertaken at the project and program level.

Project Level

To maintain a high success rate in achieving the Program's projects, the following actions will be taken:

1. Achieving the required maturity level at the program level by managing and delivering projects according to internationally recognized project management standards.
2. Establishing a Project Management Office (PMO) structure with multiple tiers including the program level, organization level (stakeholders / implementers), and the project level (PMO's).
3. Developing an effective process/methodology for project management to be used by all projects. This process could be customized as necessary by individual projects, but this will provide a standard level of excellence across projects. The unified process will cover all core project functions including scope, time, cost and quality management as well as project facilitating functions such as human resources, risk, communication and vendor management.
4. Training and developing the skills of project managers and supporting them with implementing PM functions.
5. Ensuring that the Knowledge Management function identified among the Program's infrastructure objectives (mentioned above) takes into account learning and building knowledge assets across projects, both sequentially and in parallel, and in both technical and project management domains.

6. Providing resource utilization efficiencies, such as pooling human resources, facilities, equipment, labs and automated tools among projects.

Program Level

At the program level, a fundamental question that will guide decisions and actions is "why is a program level needed?" Areas in which program level management is needed include:

- Portfolio management provides benefits that cannot be obtained by managing the multiple projects individually. Examples of benefits include:
  - Actions with effects across several projects; positive effects to be sought and negative effects to be avoided.
  - Decisions that can be exposed and handled only with a program perspective.
  - Risks that can be best addressed at a shared program level.
  - A Benefits Statement will be compiled for the Program and a Benefits Monitoring and Management scheme will be applied.
- Governance that will be provided by the Program to the higher national level(s) to ensure program performance and progress monitoring.
- Stakeholders management, to include:
  - Higher stakeholders that cannot be managed/coordinated at the individual project level.
  - Assisting project managers, especially startups, in managing their project stakeholders.
  - Covering stakeholder interdependencies across projects.

One of the most important aspects of Program stakeholder management will be to facilitate, realize and manage the successful and effective "change" that the Program should produce.

The following sections provide specific examples of concerns that will be addressed at the program level through the portfolio management plan, technology transfer plan, quality management plan, human resources plan, communications plan, and risk management plan.

Technology Transfer Plan

The water technology program will follow internationally recognized best practices in technology transfer. Key elements of the program 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 water 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.

- National programs focused on the development of advanced pilot application projects: these projects involve KACST, government agencies, universities, and industry. Knowledge is transferred to companies in the course of the project. This is a proven method for developing technologies wich fulfill a specific need and can be easily transferred to government or commercial users.

- 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.

- Linkage between the water program and technology business incubators and other programs will aid the start-up of new water technology companies.

Quality Management Plan

The water technology program will follow international accepted 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 to the success of the water 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 water programs. The plan will require substantial numbers of water 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.

Stakeholders 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 water technology program will:

- Work with the other agencies to improve the quality of undergraduate water technology education, especially at regional universities.
- Work with new universities to develop research and education programs that especially match the Kingdom's water technology research 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 water researchers through its emphasis on university-industry centers. These centers are designed to train new students with research and innovation skills that are 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 water research 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 risks.

One source of technical 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:

- Adopting 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 cannot be hired.
- Expanding the pool of people with needed skills through education and training programs, such as university water research centers (see human resources plan).

Another cause of technical risk is overly ambitious goals. To address this risk the program should 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 funding shortfalls 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 water 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.

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 quickly initiate 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 Water Technology Advisory Committee will oversee the implementation of the plan. It will meet approximately four times a year and review progress in the program, which can be evaluated according to the:

- Growth or establishment of technology-based businesses due to the water program.
- Amount of revenue and jobs created.
- Successful importation of technology resulting in new businesses or applications.
- Movement of projects to incubators.
- Water-related patents.

Implementation of the Plan

- Private sector funding of university and KACST water research (indicates the value private sector places on university or KACST water R&D).
- Number and level of presentations in international conferences.
- Changes in policies (described previously) to improve water innovation
- Number and impact of publications.
- Extent of domestic and international R&D collaborations.
- Number of water advanced degrees awarded.

The advisory committee will also sponsor and oversee studies of emerging areas of water technology, 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 water research and innovation network in the Kingdom.

Appendix A: Plan Development Process

Stakeholders Participants

The program thanks the following stakeholder participants for their contributions to the development of this plan.

However, They, do, however, bear responsibility for the contents of the final plan.

Table A-1: Stakeholders Participants

Stakeholders	Representatives
King Abdulaziz City for Science and Technology (KACST)	▪ Dr. Omar Al-Harbi ▪ Dr. Abdulaziz Al-Quizani ▪ Dr. Khaled Alam ▪ Mr. Abdulah Al-Khaled ▪ Mr. Hamad Safiran ▪ Mr. Obid Al-Harbi ▪ Eng. Yala Al-Aseeri ▪ Eng. Munther Al-Sudis
Prince Sultan Research Center for Environment, Water and Desert (King Saud University)	▪ Dr. Abdul Malek Al al-Shaikh ▪ Eng. Ali Abo-Rishah
Water Research Center (King Abdulaziz University)	▪ Dr. Omar Seraj Aburizaiza
Saline Water Conversion Corporation (SWCC)	▪ Eng. Ahmed Al-Arifi
Ministry of water and Electricity	▪ Dr. Salh Al-Mogrin ▪ Mr. Helal Al-Harthi ▪ Mr. Ibrahim Al-Shabibi ▪ Eng. Sami Al-Youssef ▪ Mr. Abdullah Al-Mouhaethef

Appendix A: Plan Development Process

Stakeholders	Representatives
King Saud University	▪ Dr. Ibrahim Al-Mutaz ▪ Dr. Abdulrahman Al-Dakheel ▪ Dr. Farj Abdulslam
King Abdulaziz University	▪ Dr. Mohamed Beirutty
King Fahd University of Petroleum & Minerals	▪ Dr. Alaadin Bukhari
Saudi ARAMCO	▪ Eng. Ahmad Al-Rammah

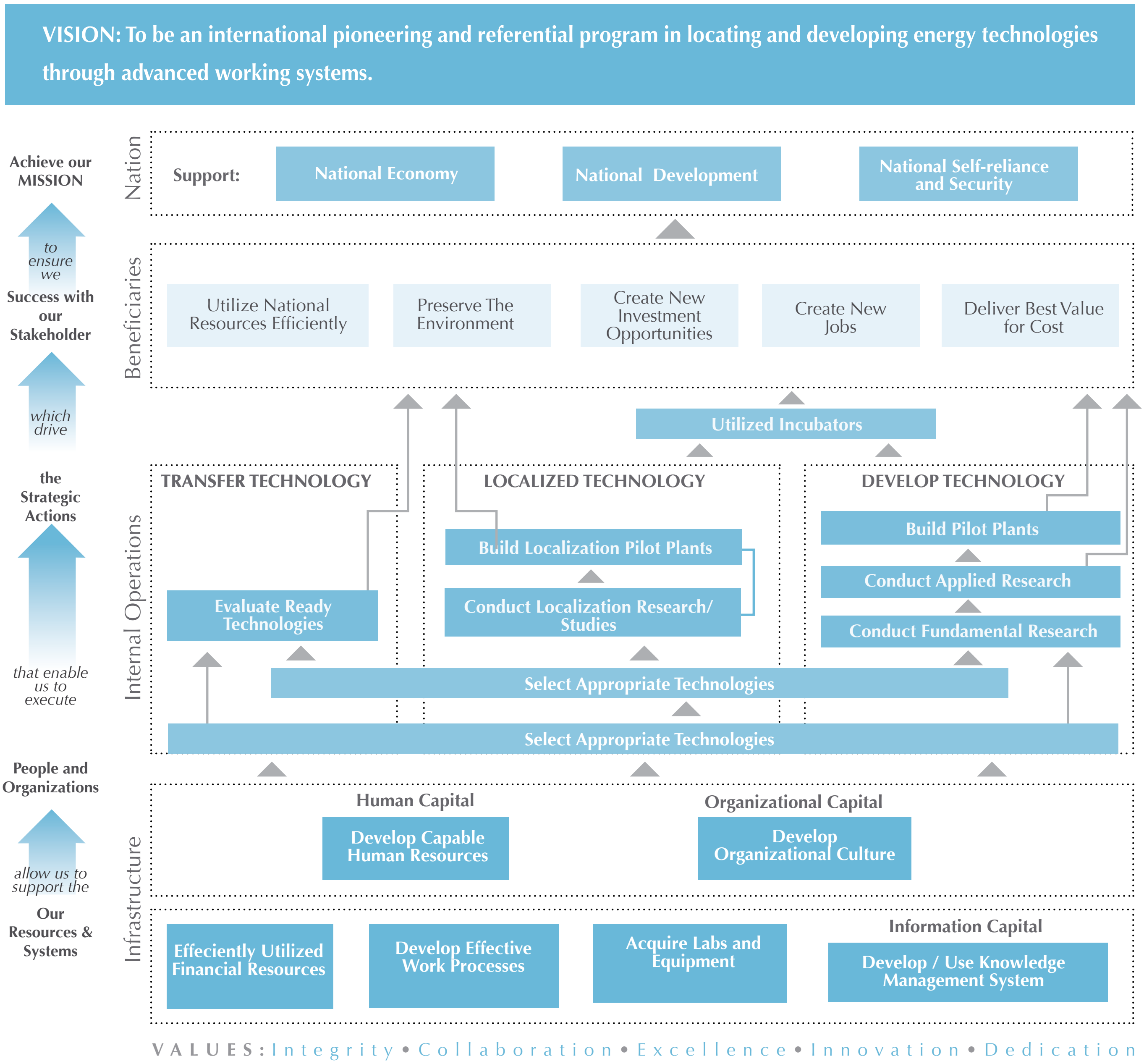
Planning Development Methodology

A strategic planning / strategic management methodology was designed and implemented for developing this program plan. Figure A-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 plan 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 plan, 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.
  - 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.
  - 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.

Figure A-1: Program Strategy Map



Appendix A: Plan Development Process

Portfolio Management

Initial Portfolio Formation

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

Phase 1: Evaluate vs. Strategy

In this phase, only projects aligning with the Program's strategic goals were selected. These projects were distributed into strategic groups (buckets), and the total available resources were distributed / allocated initially to the strategic groups based on strategic significance. The program adopted a Project Distribution Matrix technique for defining the strategic groups (buckets). Nine groups resulted from the intersection of two dimensions having three elements each. These are:

- Strategic Technology Paths:
  - Development.
  - Localization.
  - Transfer.
- Research & Development Types:
  - Basic Research.
  - Applied Research / Pilot Plants.
  - Product Development / Added Value.

Phase 2: Prioritization for Resources

In this phase, projects competing for the same resources within a group (bucket) were prioritized from a resource-related viewpoint. The Program adopted a paired comparison technique for this purpose. Accordingly, nine paired comparison tables were developed. These are not shown in this plan but can be provided by the Program/ERI if requested.

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 was exhausted. This resulted in formation of a portfolio, but it may be unbalanced.

Phase 3: Select vs. Balancing Factors

In this phase, some projects were eliminated and some new ones were added to those selected in Phase 2. The goal of this process is to balance the portfolio in terms of:

- 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

Phase 4: Execute and Review vs. Strategy

As indicated, the portfolio formed so far is the initial or start-up portfolio. Projects are then funded and the portfolio is managed over the life of the program through continuous reformation as active projects are evaluated, completed, postponed or cancelled based on their performance in:

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

At the same time, strategic objectives may be adjusted and resources may change, which will require portfolio reformation.

This portfolio management process ensures that the program is using its resources most efficiently. Without an objective and methodical process, project initiation and resources utilization is usually subject to personal preferences, organizational political pressures and subjective factors.

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