جامعة الملك فهد للبترول والمعادن
King Fahd University of Petroleum & Minerals

King Fahd University of Petroleum & Minerals

RESEARCH & INNOVATION ANNUAL REPORT 2021

CONTENTS

A Message from Dr. Muhammad Al-Saggaf
President of KFUPM

"We have been able to overhaul our research program by staying close to our strategic plans of research and innovation with the integration of multiple disciplines and working to improve human conditions and make an impact on the nation and the world."

As the President of King Fahd University of Petroleum & Minerals (KFUPM) since January 2020, I've been very fortunate to meet with many talented researchers and faculty members here. Many ideas were developed through sincere discussions and passion to make KFUPM an attractive scientific destination for talented researchers.

Year 2021 was overall a difficult but quite a satisfactory and rewarding year. In 2021, the goals and mission of the University were solidified more than ever to make a substantive impact on the economy of the Kingdom and to enable it to transform from a conventional, resource-monetizing economy primarily dependent on oil and gas to a diversified, knowledge -based economy that would propel the Kingdom to assume its rightful place, not only as a participant but as a competitor, in the new global digital age. This mission became an important driver for us in shaping the activities at the University.

We have been able to overhaul our research program by staying close to our strategic plans of research and innovation with the integration of multiple disciplines and working to improve human conditions and make an impact on the nation and the world. To achieve this goal, we implemented the requirement that every faculty member must be jointly affiliated in one of the 20 new or overhauled interdisciplinary or applied research centers. The number of faculty members currently enrolled in these centers is overwhelming (300), roughly half of our professorial-rank faculty. We also ensured the growth of research human capital, including postdoctoral fellows and graduate students, who are the backbone of any successful research program. Last year, we attracted 50 new postdoctoral fellows, up from nearly zero, resulting in a significant increase in the number of researchers who will assist our faculty and contribute to the overall research program of the University. We also admitted 350 international graduate students from different geographies to the PhD and MS programs - a significant growth of more than threefold.

Regarding enhancements in teaching and curriculum, KFUPM now speaks the language of tomorrow. We revolutionized our undergraduate curricula to have the strongest and most complete digital foundation, calling it the AI+X platform. All our students in 35 academic majors take Al courses in addition to those in their major. In addition, as the world is moving towards specialization,

our graduates are prepared for the job market with programs involving 20+ undergraduate concentrations (CX) in exciting disciplines. Addition of this specialization makes our graduates stronger and ready to hit the ground running and integrate directly and swiftly into the working environment of their employers.

KFUPM also activated industry leaders by introducing 15 new professional Master's degrees in exciting fields. The intent behind these programs, which the University is offering for the first time, is to establish a strong foundation for leaders and professionals who will go on to establish their own new startup ventures or will go back to their employers with a much more enhanced understanding of their discipline.

Regarding our global reputation, KFUPM is now ranked 7th worldwide in Petroleum Engineering, 16th in Mineral Engineering, 60th in Chemical Engineering, 86th in Electrical Engineering, 98th in Civil Engineering, and 14th in the number of US-registered patents.

I hope you enjoy reading the annual report and gain an insight into the transformations that are taking place at KFUPM. It sheds light on the efforts our management and researchers have made over the past year, and how it is important to have a powerful, connected, and supportive community to make dreams come true.

VISION

TO BE GLOBALLY RECOGNIZED FOR IMPACTFUL, INTERDISCIPLINARY, FORWARD-LOOKING, CUTTING-EDGE RESEARCH.

MISSION

TO STEER, ENABLE AND OVERSEE AN AMBITIOUS RESEARCH PORTFOLIO, AND TO FACILITATE ITS TRANSLATION TO TANGIBLE, KNOWLEDGE-BASED CONTRIBUTIONS TO THE ECONOMY AND SOCIETY OF THE KINGDOM AND BEYOND.

The full Strategic Direction for research and innovation can be found at www.ri.kfupm.edu.sa

A Message from Dr. Ali Al-Shaihki

Vice President Research and Innovation

"The new research structure has resulted in an environment that is more conducive than ever before for successful collaboration among our faculty from academic departments and researchers from research centers."

The research and innovation annual report for 2021 shows the commitment of King Fahd University of Petroleum & Minerals (KFUPM) to advance its research activities and respond to national and international needs aligned with achieving the goals of the Kingdom's Vision 2030 programs.

KFUPM's research centers and academic departments are its cornerstones of research activities, contributing to high-quality research and solving critical scientific and technical problems as well as converting knowledge into practice.

During the year 2021, KFUPM completely revamped its research structure and programs through a strategic transformation. The new research structure has resulted in an environment that is more conducive than ever before for successful collaboration among our faculty from academic departments and researchers from research centers. The emphasis now is on how to enhance the well-being of the society and overcome mega challenges. The proposed initiatives will enable impactful research, especially in challenging areas which directly benefit the Kingdom of Saudi Arabia in its transition to a knowledge-based and digital economy.

Hence, considering that answers and solutions to critical and challenging research problems can be best obtained at the interfaces of disciplines, interdisciplinary research is the focus of the new revamped structure. The expectation is that combined knowledge of multiple disciplines can make a substantial impact. To achieve this objective, 20 research centers plus a number of research and innovation programs have been established with expertise in multiple related disciplines, and the faculty from relevant departments have been encouraged to affiliate with them. Details of the above can be found in this report.

The annual report shows how resolute the University has been in its determination to improve KFUPM's research structure to demonstrate flexibility and strength. The report shares some of the most notable research accomplishments in 2021.

I take this opportunity to extend my thanks and appreciation for the efforts of all those involved in the successful research transformation. My special thanks are due to the President of the University for his leadership and continued support to all research activities, and to all University Deans, Directors of Research Centers, Department Chairpersons, faculty, researchers, and other individuals who contributed to the strengthening of our research sector.

KFUPM completely revamped its research structure and programs through a strategic transformation

2021 IN NUMBERS
RESEARCH DASHBOARD

DECADES OF EXCELLENCE AND RESEARCH GROWTH

World University Ranking

3rd IN ARAB WORLD

KFUPM is third among Arab countries, holding the following world rankings

163rd IN THE WORLD **QS 2022**

351-400 IN THE WORLD **THE (Times Higher Education) 2022**

401-500 IN THE WORLD **ARWU 2021**

Emerging Economies

KFUPM is ranked **40th** in the Emerging Economies University Ranking of 2022

Subject Rankings

5 Engineering Programs are in the Top 100 - 2021 QS World Subject Rankings

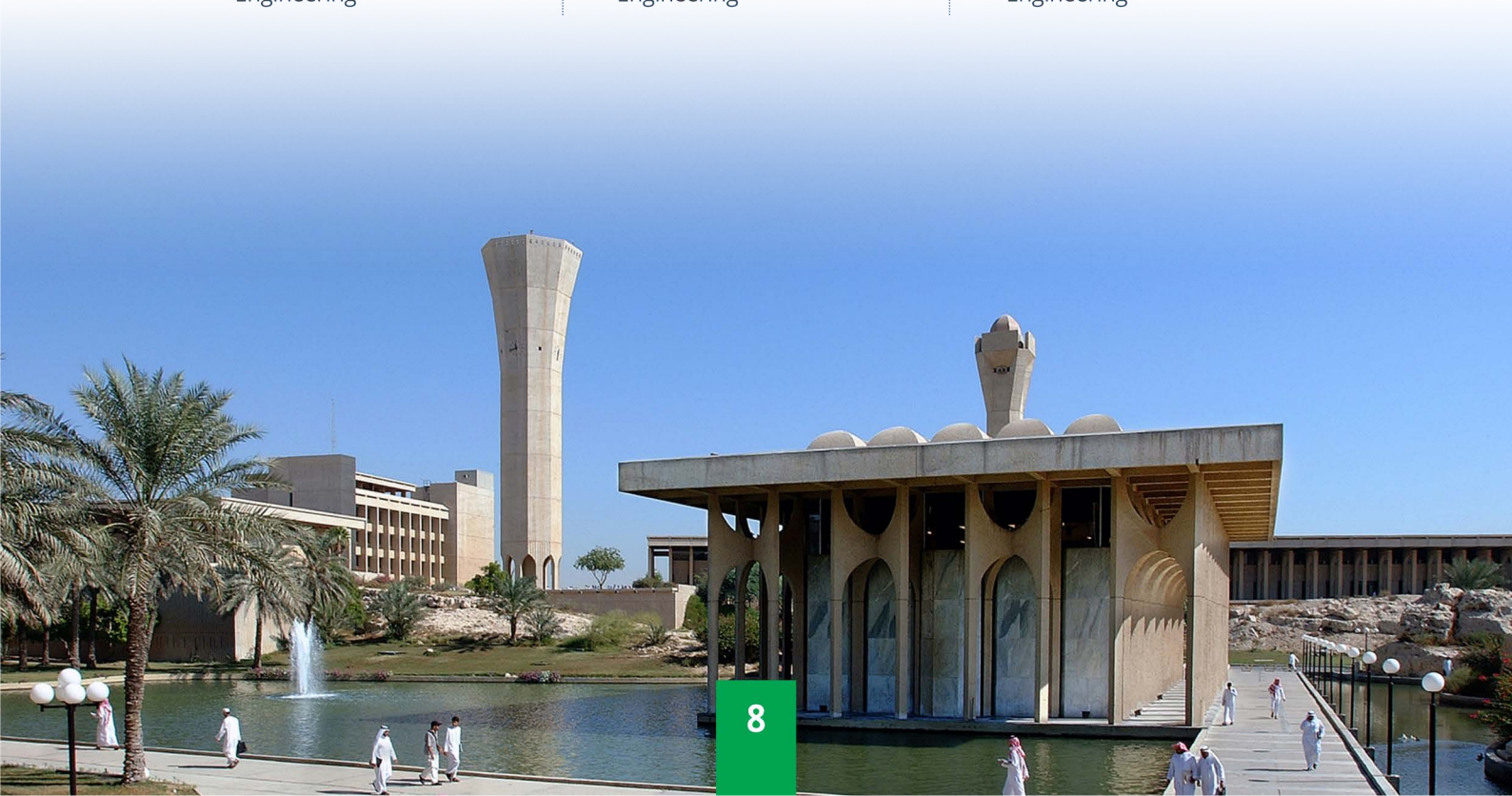
TOP 10
- Petroleum Engineering **7th** IN THE WORLD

TOP 20
- Mineral Engineering **16th** IN THE WORLD

TOP 100
- Chemical Engineering **60th** IN THE WORLD

TOP 100
- Electrical Engineering **86th** IN THE WORLD

TOP 100
- Civil Engineering **98th** IN THE WORLD



RESEARCH PROFILE

Life Time

26K+
ISI Publications

404K+
Citations

132
Number of Books

19.5K
Number of Journal Articles

In 2021, KFUPM's scholars published 2,337 journal papers.

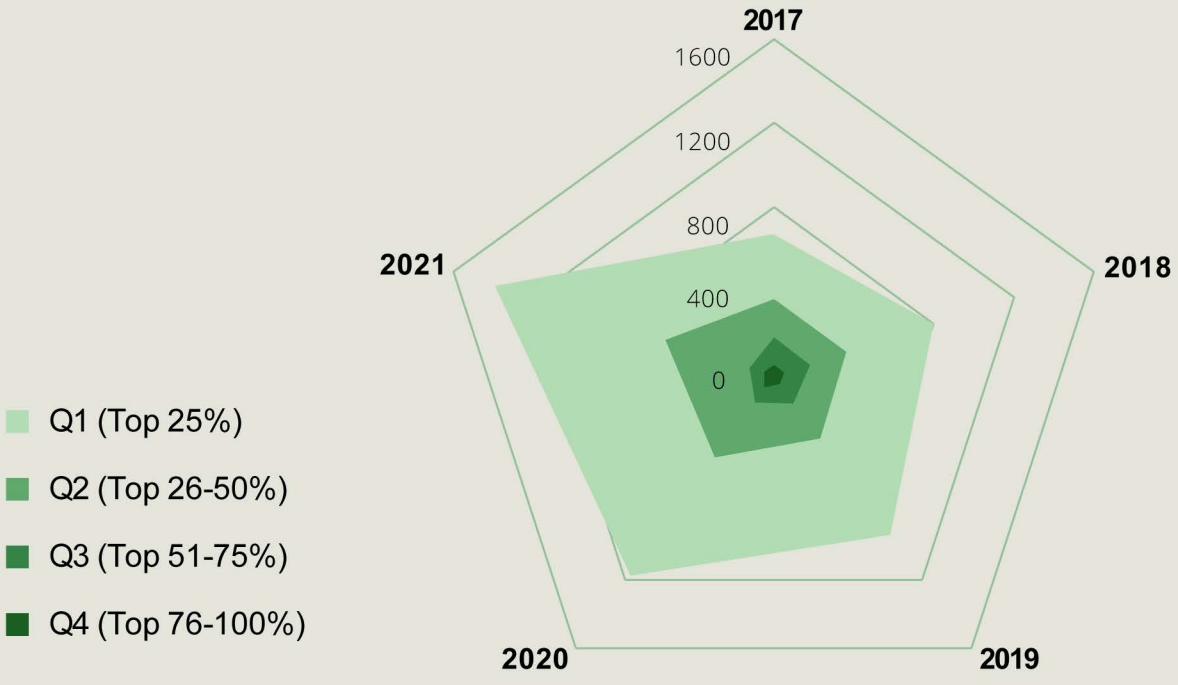
79%
1,850
Papers have been published as article types

20%
467
Papers have been published in the top 10% most cited publications worldwide

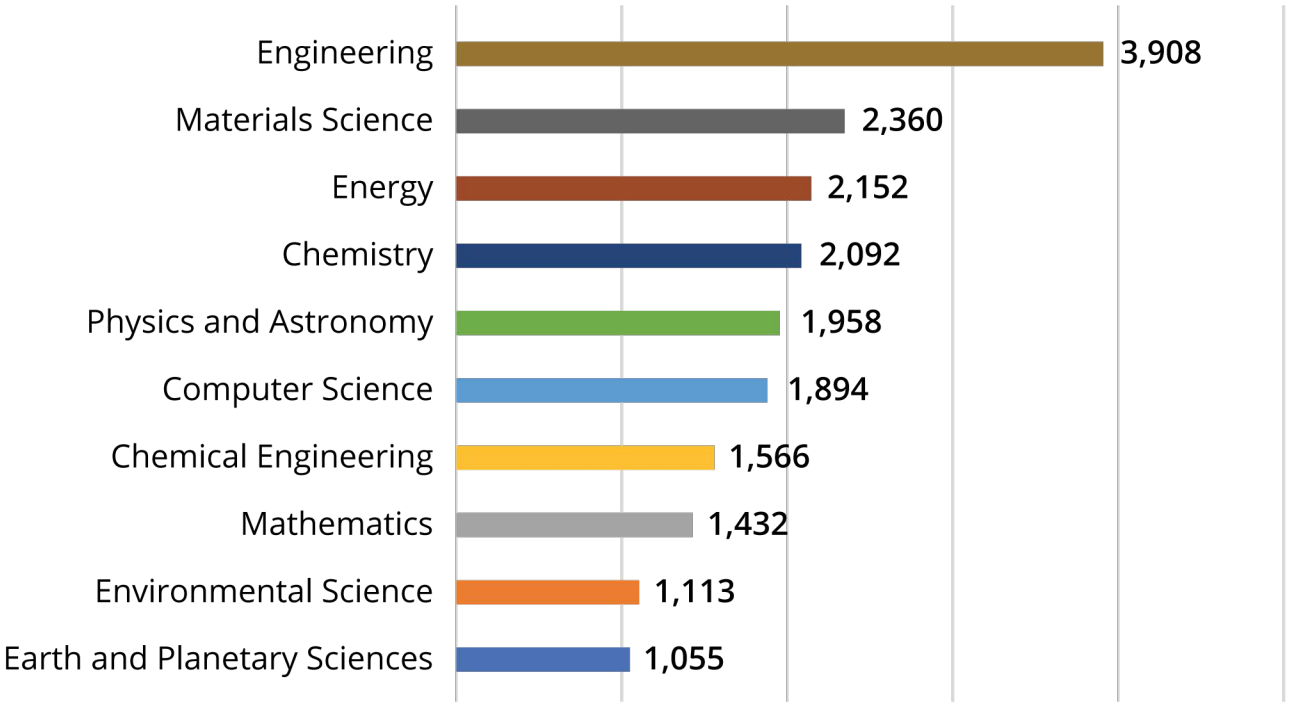
59%
1,382
Papers have been published in the first quartile (Q1)

60%
1,409
Papers have been published with international collaboration

Productivity and distribution of KFUPM publications over the quartiles



TOP TEN RESEARCH AREAS AT KFUPM



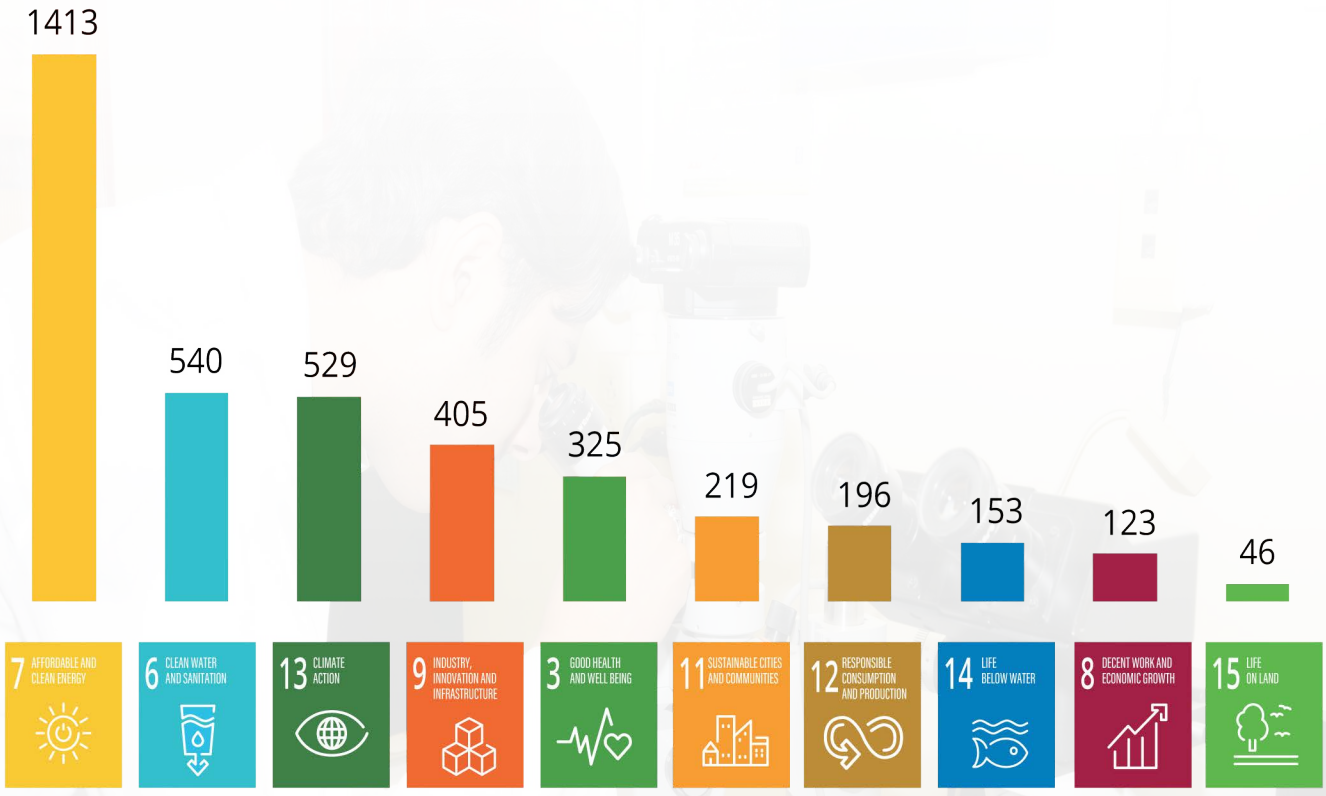
Distribution of publications over the research areas (2016-2021) - Source: Scopus database

RESEARCH
GUIDED BY SUSTAINABLE DEVELOPMENT GOALS

KFUPM is committed to finding solutions to complex problems to help build a sustainable global future. Consequently, a great deal of our research is closely aligned with the **United Nations Sustainable Development Goals** (SDGs).

Furthermore, we continue to make a significant impact towards achieving these goals.
KFUPM believes it is critical that all research centers advance these goals. In this report, we classify project highlights using the SDG icons shown below.

KFUPM publications (between 2016-2021) contributing to the SDGs



Source: Scopus database

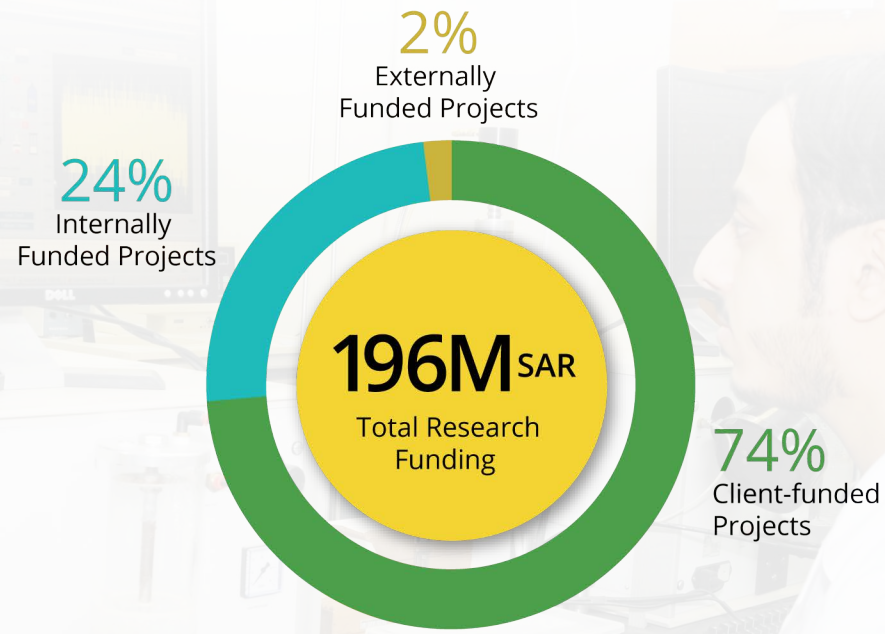
2021 RESEARCH FUNDING

SAR 100 Million - Annual Average of Sponsored Research Funds

10
Funding Program

265
Active Projects

21
Industry Partners (Clients)



In 2021, KFUPM generated over **196** Million in research funding. External research funding comes from a variety of sources, including the government, industry partners, and non-profit organizations. The endowment funds supporting research and innovation at the University amounted to more than **25** Million.

KFUPM INNOVATION

14th
AMONG GLOBAL UNIVERSITIES FOR NUMBER OF U.S. PATENTS (**2020**)

1,653
TOTAL PATENTS GRANTED

1,400
TOTAL U.S. PATENTS GRANTED

2,434
TOTAL INVENTION DISCLOSURES

2,773
TOTAL PATENT APPLICATIONS FILED

521
TOTAL PATENTS PENDING

11
TOTAL NUMBER OF PROOF OF CONCEPT PROJECTS

154
TOTAL NUMBER OF IPs IN COMMERCIALIZATION

4
TOTAL NUMBER OF LICENSES TO STARTUPS

102 TOTAL U.S. PATENTS GRANTED IN **2021**

KFUPM is listed in the **TOP 100 Global Innovator 2021** and **TOP 28 Innovators to Watch 2021**

LICENSES AND OPTIONS

The KFUPM Innovation & Technology Transfer Office (ITT) negotiated and signed several license/option agreements during academic year 2020-21.

YOKOGAWA

A collaboration agreement was finalized for a project to design and implement a reliable robotic and Internet of Things (IoT) network to monitor and inspect in an open environment and also build a small-scale test bed for testing the developed methods. Commercialization is based on KFUPM's background IP and is intended to bring the technology closer to commercialization.

Schneider Electric

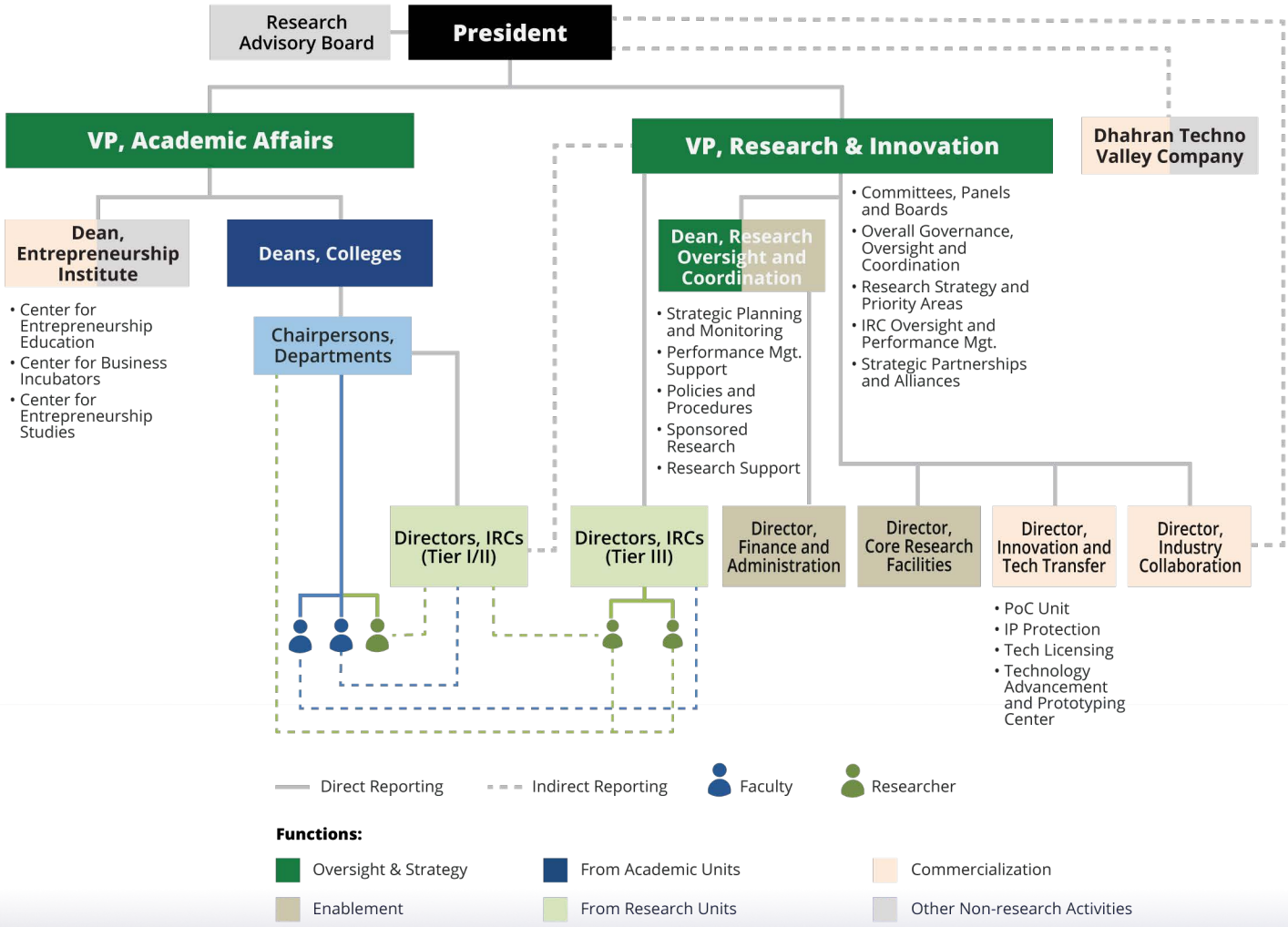
The Innovation & Technology Transfer office negotiated a collaborative research agreement with Schneider Electric, which includes an upfront license for KFUPM's rights in any foreground IP resulting from the collaboration.

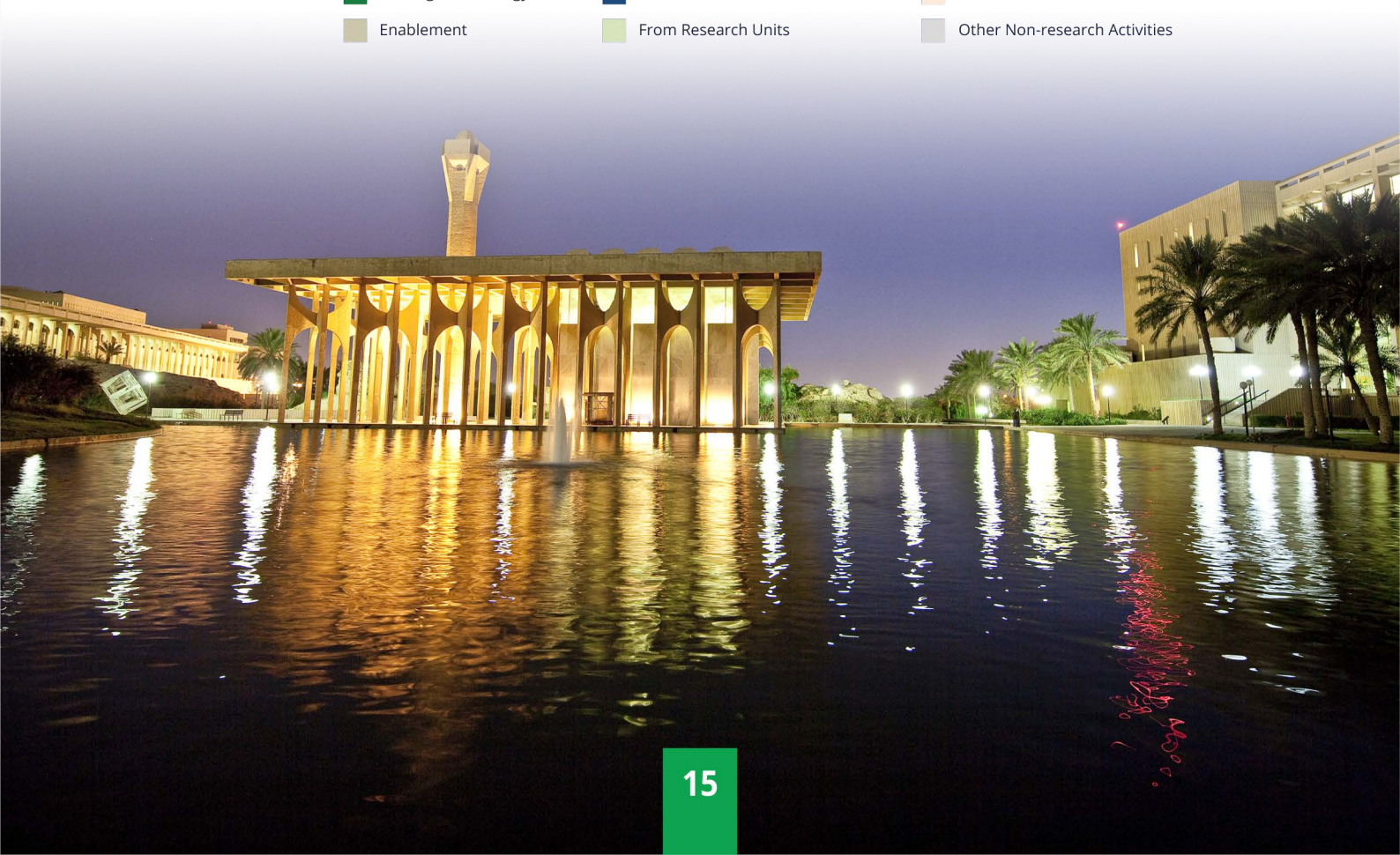
Axens
Powering integrated solutions

Axens, the licensee, and S-Oil, the end-user, of the HSFCC technology completed performance guarantee tests in their plant in Ulsan, South Korea, and thus KFUPM received its share of the license fee.

Research **Transformation Journey**

The new organization structure with a strong emphasis on interdisciplinary research streamlines KFUPM's research





KFUPM has completely overhauled its research program. KFUPM now emphasizes interdisciplinary research, signifying that the true objective of research is to improve the wellbeing of humans and make an impact on the nation and the world.

2021 Transformation of KFUPM's Research Model

KFUPM has embarked on a journey to transform its research model with six key objectives.

Objectives

01 Align research areas with the Kingdom's strategic priorities, **Vision 2030** and ambitions.

02 Enhance the research delivery model and boost **interdisciplinary collaboration.**

03 Attract and nurture top research **talent.**

04 Streamline the **research-to-commercialization** continuum and strengthen linkages with the industry.

05 Support the Kingdom's transition to a **digital economy.**

06 Boost measurable scientific, community, and economic **impact** in the Kingdom and beyond.

An Exciting **Journey of Transformation**
Quality Research and Innovation

King Fahd University of Petroleum & Minerals has a long track record of high-quality scientific research. With that background, the University sought to adopt a new model in which many researchers from different disciplines can work together to overcome major challenges. The new KFUPM research model has restructured strategic research directions, awakening the spirit of innovation and promoting high-quality research.

PHASE 1
Leveraging Historical KFUPM Excellence

PHASE 2
Defining Research Strategy and Direction

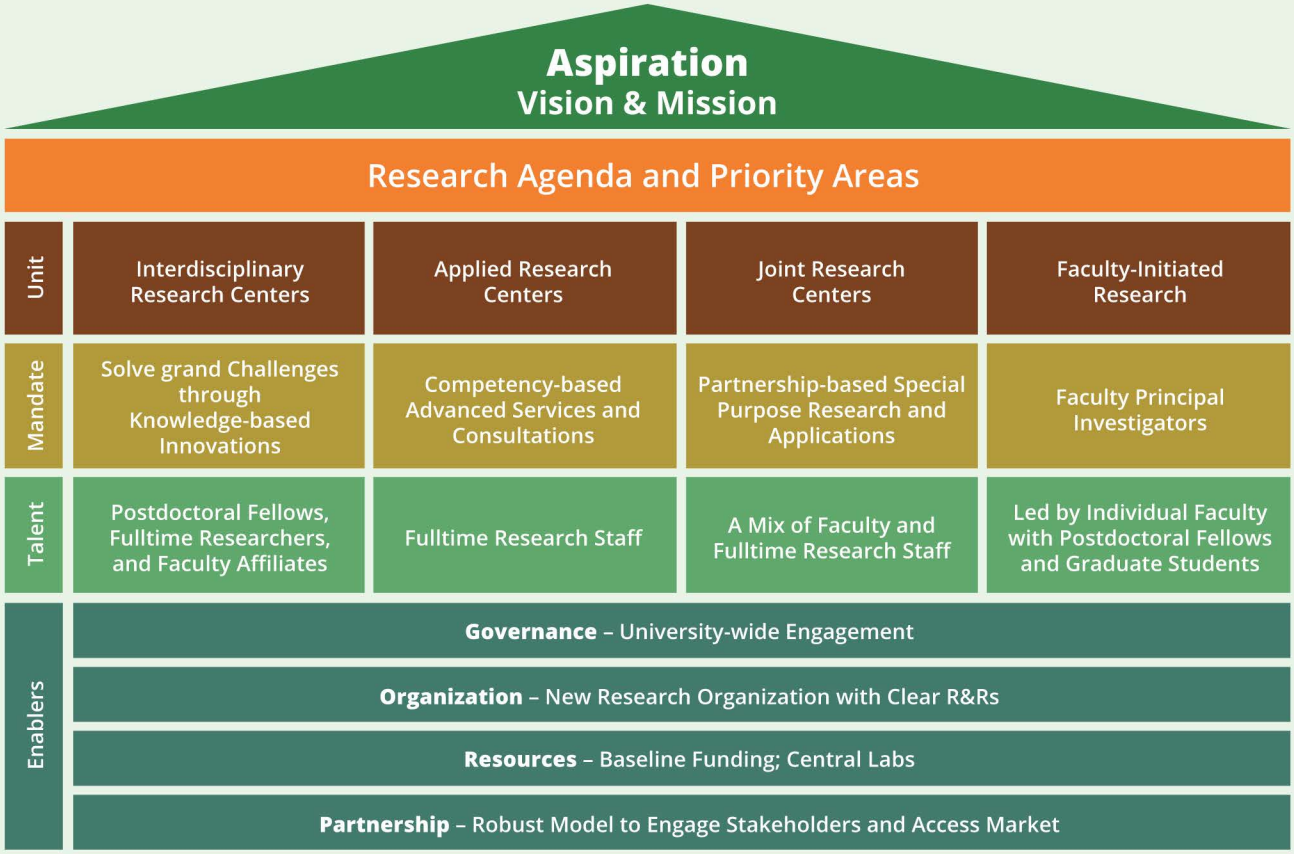
PHASE 3
Creating a Research Engine

PHASE 4
Joining Global Research Networks

PHASE 5
Igniting Innovation Spirit

PHASE 6
Improving Research Outcomes

The New Research Engine at KFUPM



Four Main Objectives

Drive impact-oriented research addressing national and global challenges

Drive research efforts in line with University research strategy and priority areas

Foster interdisciplinary collaboration across University research ecosystem

Leverage existing University resources and build new capabilities in research areas of strategic importance

Interdisciplinary Research Centers

With 300+ researchers, a bold start for research full of opportunities

Established 12 new mission-oriented Interdisciplinary Research Centers, creating a powerful research engine to overcome grand challenges through the conversion of knowledge across disciplines into useful practical applications.

Twelve Interdisciplinary Research Centers (IRCs)

- Advanced Materials (IRC-AM)
- Membranes & Water Security (IRC-MWS)
- Intelligent Manufacturing & Robotics (IRC-IMR)
- Smart Mobility & Logistics (IRC-SML)
- Intelligent Secure Systems (IRC-ISS)
- Construction & Building Materials (IRC-CBM)
- Hydrogen & Energy Storage (IRC-HES)
- Renewable Energy & Power Systems (IRC-REPS)
- Refining & Advanced Chemicals (IRC-RAC)
- Communication Systems & Sensors (IRC-CSS)
- Finance & Digital Economy (IRC-FDE)
- Integrative Petroleum Research (CIPR-CPG)

Three Applied Research Centers (ARCs)

- Environment & Marine Studies (ARC-EMS)
- Strategic Studies & Planning (ARC-SSP)
- Metrology, Standards & Testing (ARC-MST)

Three Joint Research Centers (JRCs)

- SDAIA Center for Artificial Intelligence (JRC-AI)
- KACST Center of Excellence in Energy Efficiency (JRC-EEE)
- KACARE Center for Energy Research (JRC-ER)

New IRCs/JRCs | Existing Center | Reconfigured Existing Centers

For more information: https://ri.kfupm.edu.sa/Research-Centers.html

KFUPM's Ecosystem for Research Innovation

KFUPM's ecosystem for research and innovation is progressively growing to become a comprehensive technological- economic cycle. The major constituents of known technological innovation, viz., learn, work, live, and play, is coming together in and around KFUPM's campus.

Local and international large industrial R&D is present in the Dhahran Techno-Valley (DTV) Science Park. This includes the world's largest cluster of R&D centers of upstream petroleum engineering service providers (within a single geographic location), industrial automation/control/automation technology providers, and downstream petroleum corporations. The Business Park (AMMAD), construction of which is nearing completion, includes flexible housing options, areas for hospitality, shopping, conventions, office space, and multi-purpose buildings.

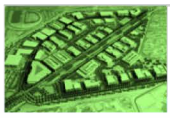
Within this environment, DTV represents the venue where collaborative R&D takes place with the starting point of the pipeline for technology commercialization and where new enterprises and startups are planned and incubated, whereas the business park is the place where businesses are grown, ventured, and capitalized.

KFUPM aspires to be a leading research-intensive University achieving distinction not only nationally, but also regionally and internationally and providing creative and impactful knowledge and innovation. As such, the University research transformation has been founded with the establishment of Interdisciplinary Research Centers (IRCs) that are specialized in priorities of strategic importance to Saudi Arabia. The University research agenda is focused on addressing - through the IRCs - national "grand challenges", and major socioeconomic problems. The "partnerships" are a major aspect of the ecosystem. The partnerships include the DTV tenants as well as stakeholders representing important national economic sectors that contribute significantly to aligning the University research programs with goals that are of highest significance to the country.

Moreover, the ecosystem includes enablers that support the commercialization of innovative technological push emanating from the IRCs. These enablers include access to funding (internal KFUPM funds and venture investments through DTVC) for supporting the progression of innovation, business incubation (KFUPM Entrepreneurship Institute - EI), and prototyping and product development (Technology Advancement and Prototyping Center - TAPC).

The Business Park (AMMAD)

- Business development and growth
- Venturing and capitalization



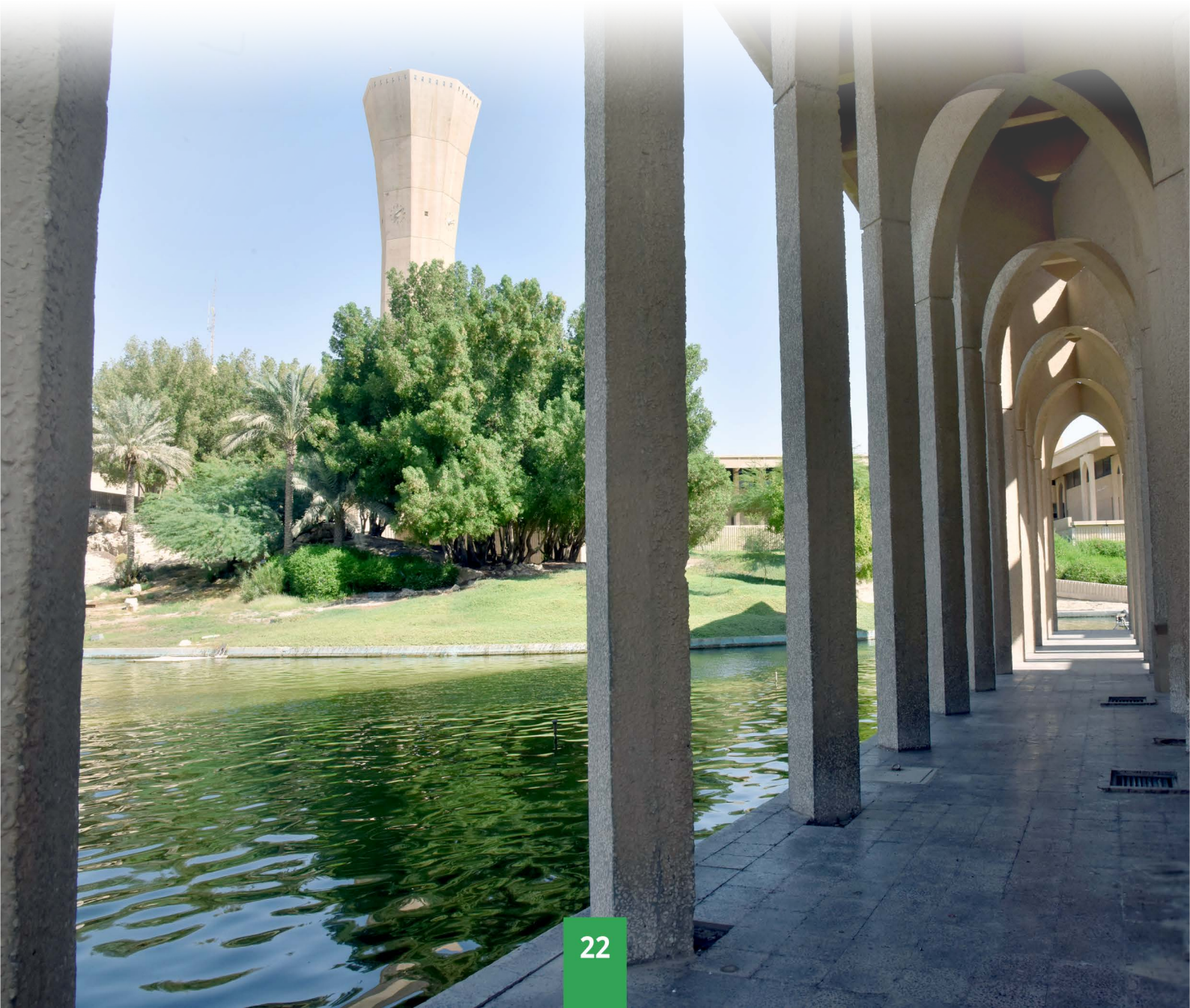
The Science Park (DTV)

- R&D
- Business planning and incubation

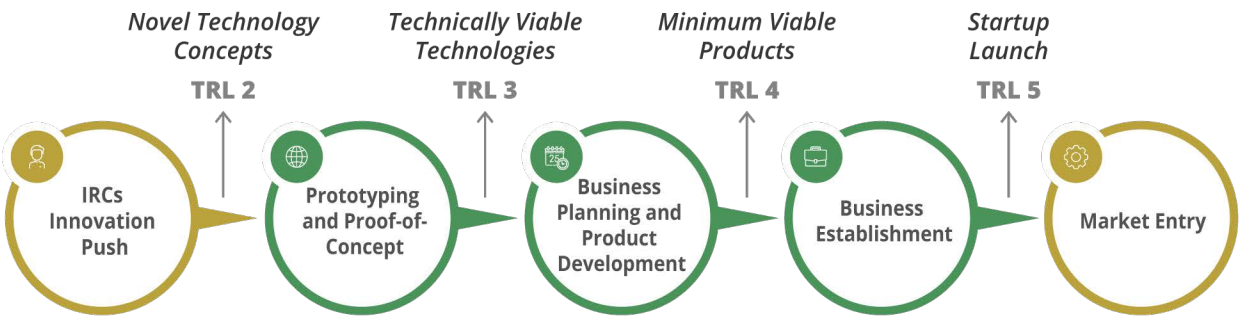
KFUPM Innovation Support System

KFUPM's support for innovation has been structured to advance early-stage technologies developed by the IRCs towards commercialization and startup establishment systematically. The University has an effective invention disclosure system that captures innovative outcomes of the IRCs and provides them with the necessary intellectual property protection for converting them into potential socioeconomic assets.

Inventors of the technologies that have low technical readiness for commercialization can apply for Proof-of-Concept (PoC) funds for prototyping their inventions and validating the technical viability. The successfully completed PoC projects or the technologies that have a higher technical readiness can be supported to develop the technologies suitable for the next commercialization phases: i.e., developing the minimum viable products MVPs, business planning, and raising seed capital for startup establishment.



KFUPM Innovation Support System



IRCs Innovation

TAPC Prototyping and Product Development

Business Incubation

DTVC Venture Investments

- Technology assessment/market research
- IP protection/management
- Functional prototype development
- Assessing development requirements

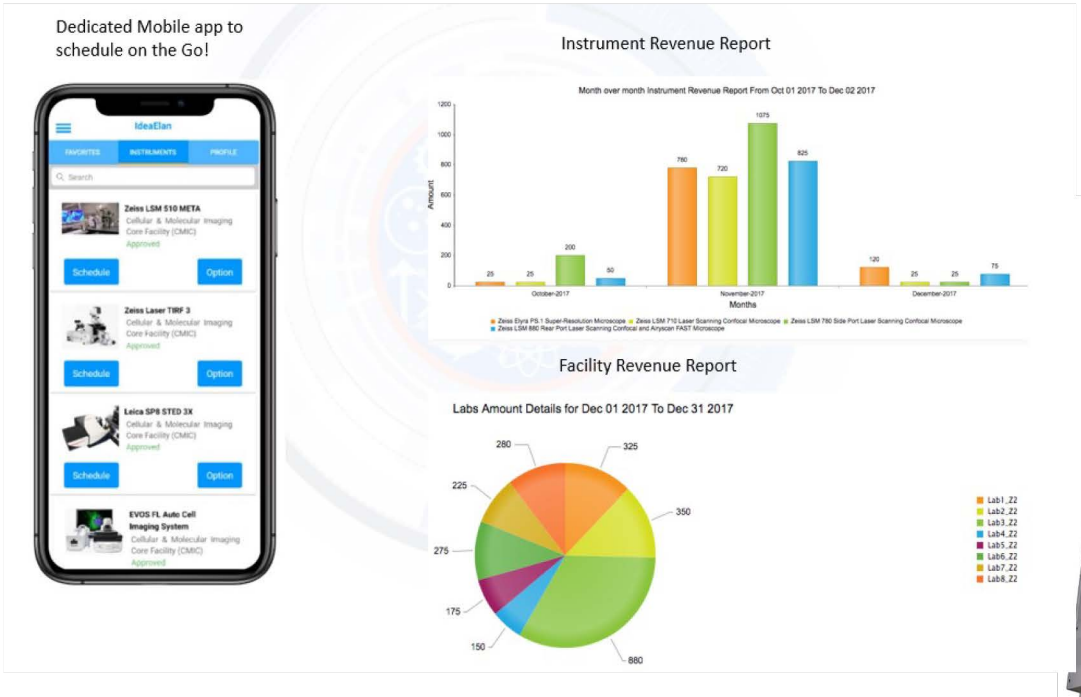
- Define product, and develop engineering prototype/MVP and align with technology market and industrial requirements
- Develop funding strategy and start-up financials
- Prepare a business plan

CORE Research Facilities

Core Research Facilities provide research support to academic departments and research centers at the University.

Facilities	Capability
• Field Emission Transmission Electron Microscope • Field Emission Scanning Electron Microscope • Optical Microscopes • Atomic Force Optical Microscope • Nanoindenter • Tribometer • X-ray Diffractometer • Energy Dispersive X-ray Fluorescence Spectrometer • X-ray Photoelectron Spectrometer • Nuclear Magnetic Resonance Spectrometer	• Microstructure property relationship • Surface morphology • Microchemical analysis • Structural analysis • Phase identification • Nano-hardness • Nanoindentation creep • Nano indentation modulus • Adhesion of coatings • Coefficient of friction • Wear resistance • Micro-scratch testing • High-temperature oxidation

One-lab Model



Integrated Safety Platform

An integrated centralized software platform for environment, health, and safety (EHS) functions of the research sector.

Partnerships and Industrial Relationships

Engaging the industry by higher education institutions is crucial for improving and developing the educational process. Students and faculty must be involved beyond the university educational system, and for this engagement with industry and government partners must be enhanced. We, therefore, aim to completely transform the system to enhance the effectiveness of such engagements. The first action was establishing the **Industry Collaboration (IC)** office responsible for regulating and building new bridges. Following are the activities of the IC office in 2021:

- Designing a matching tool for sharing our research competencies with companies and vice versa, thereby enabling the identification of common areas of interest.
- Finalizing KPIs for evaluating collaboration performance and developing a dashboard (under preparation). KPIs will include the following elements: (i) Hours of part-time teaching; (ii) Number of completed/initiated senior design projects and initiated MS and PhD thesis topics; (iii) Number of KFUPM students who completed training as COOP/Summer Interns; (iv) Number of CX/MS/MX/PhD student sponsorships; (v) Number of collaborative research projects (active/completed) and co-authored publications; (vi) Total amount of research funding; (vii) Number of technology transfer outcomes, including products launched or processes implemented by partner facilities; (viii) Number of patents (filed and issued), etc.
- Visits/meetings were conducted to engage companies at their premises to widen and establish our network. Visited partners in DTV (Halliburton, Baker Hughes, Yokogawa, Emerson, Weatherford, Schneider Electric, Sipchem, etc.). All showed interest in reconnecting and enhancing engagement.
- Assigning a high-level champion from within KFUPM to be responsible for the entire relationship and to drive the collaboration with a specific organization or set of organizations. This champion will unify our engagement and forge a substantially more meaningful relationship.

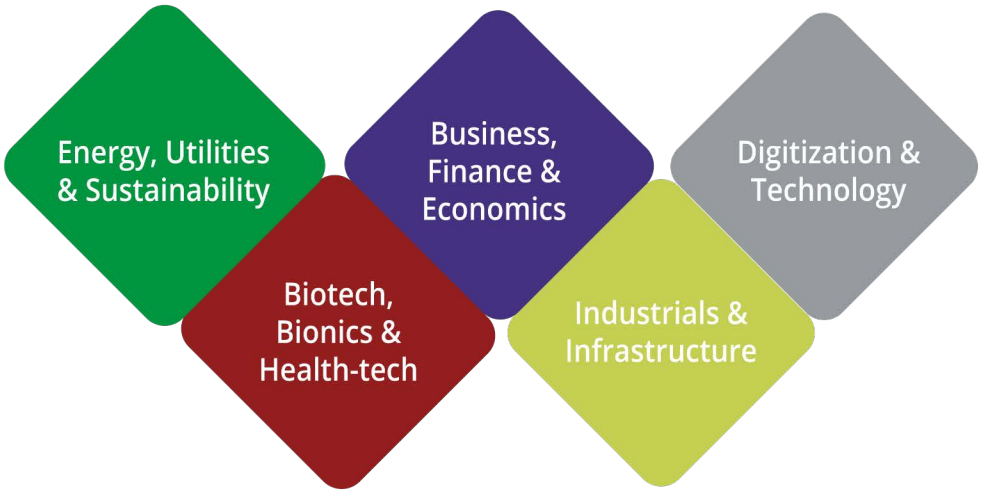
Following are the activities scheduled for 2022:

- Introducing a summer training program for faculty to join an industry and engage in their research projects for one month.
- Getting students undertaking senior design projects to work with the industry on solutions for real-life challenges and problems.
- Engaging more companies and government organizations and building new relationships.

Finally, our objective is to increase the level of education, so that students and faculty can benefit from the activities of industry partners. Students will graduate with at least more knowledge and experience on industrial jobs. In addition, our faculty will be part of finding solutions to challenging and real-world problems.

Research **Project Highlights**

2021 Five Main Research Themes



KFUPM expanded the five themes into 12 sub-fields

Energy of the Future
Conducting research on oil and gas, power generation, renewables, decentralized generation, biofuels, transmission, storage, petrochemicals, and energy digitization/robotics.

Industry 4.0/5.0
Automating conventional manufacturing and industrial practices, using modern devices, smart technologies, and robotics.

Environment and Circular Economy
Conducting research on the impact of environmental and climate change, including impact on the effects of rising temperature and the development of decarbonization and carbon-efficient technology.

Future of Defense
Development of innovative, smart and secure technologies for ground, air, and maritime defense.

Future of Mobility
Conducting research on methods and technologies leading to more sustainable, automated and efficient travel and mobility.

Infrastructure/Cities of the Future
Making construction more affordable, efficient, sustainable, safe, and healthier through smart infrastructure and sustainable materials.

Water Systems Evolution
Development of water management, water supply, desalination, and wastewater treatment technologies.

Developing Advanced Materials
Development of new materials and improving existing materials and composites with multiple applications across industries and products.

Development of Biotechnology, Bionics, and Health-tech Digital Services
Development of novel solutions for healthcare, including biotechnology, bionics and health-tech digital services.

AI and Data Economy
Leveraging combined power of data and technologies through areas such as Augmented Reality/Virtual Fragment Reassembly, AI, Machine Learning, Quantum technologies, Cybersecurity, Blockchain etc.

Future of Business and Financial Systems
Conducting research on economics and financial policies/regulations with a focus on the financial and banking systems and tapping into trends of business analytics.

Future of IoT and Connectivity
Development of innovative network technologies, network security systems, communication, and routing protocols to improve efficiency and cybersecurity.

01

Development of High-Temperature Membranes for Hydrogen Separation from a Reactive Environment

The main aim of this project is to establish in-house competency for the fabrication of a range of palladium (Pd) and Pd-alloy membranes as per the requirements and future needs of Saudi Aramco. During the project, which commenced in April 2018, technology was successfully transferred from a laboratory in the Netherlands to KFUPM, satisfying the needs of Saudi Aramco. In addition to establishing in-house competency for the fabrication of the required membranes, the IRC-HES team developed a facility of H_2 separation, starting from scratch. The team also developed a sophisticated gas permeation system in-house to test the fabricated Pd-based membranes at elevated temperatures. Pd-membranes were successfully fabricated using an electroless process and they were evaluated for H_2 and N_2 permeation at temperatures in the range of 350 - 600 °C and pressures from 1 to 5 bar. The effects of these conditions on the flux, selectivity, and thermal and mechanical stability of the membranes were systematically investigated. This study allowed the team to understand the development of defects and their impact on the H_2 permeation and separation performance of the membranes.

02

Development of Carbon-Supported Ordered Mesoporous Transition Metal Phosphides as High-performance Pt-free Cathodes for Hydrogen Evolution Reactions

The objective of this study, funded by the Ministry of Education and conducted by IRC-HES, is to develop cost-effective and high-performance electrode materials to be used in electrolysis to produce hydrogen from water and to demonstrate their efficacy in a larger-scale water electrolyzer. Carbon-supported low-cost transition-metal-based electrode materials are the target. More specifically, the surfaces of the target materials are engineered by introducing porosity. The suitability of the electrode materials with the highest potential for larger-scale electrolysis are evaluated in a water electrolyzer. The research in this field has the potential to enhance the IP portfolio and contribute to both the national and international scientific communities.

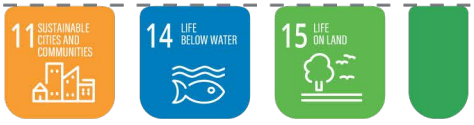
03 Direction of Arrival Estimation for **Drone/UAV Localization plus ML-Based Detection** of Multi-Rotor and Fixed-Wing UAVs Over Restricted Areas in Cluttered Environments

Drones and unmanned aerial vehicles (UAVs) are becoming ubiquitous with many potential civilian and environmental applications. They have been deployed in battlefields for surveillance and/or attacks, among other military purposes. Under the circumstances, the threat of UAVs carrying payloads containing explosives and are controlled/programmed to breach into highly restricted areas such as critical oil and gas facilities exists. The existing methods of countering threats from unmanned aerial systems rely mainly on radar, electro-optical/infrared (EO/IR), RF directional finding (RFDF), and acoustic sensors. The challenge is that drones and UAVs are different in size, endurance/flight time, the weight of the payload, and flying aerodynamics, e.g., multi-rotor or fixed-wing UAVs, which generate various Doppler signatures in the received radar signals/echoes. The signals are contaminated by background clutter, which has non-Gaussian and slowly varying signatures. Due to the size of UAVs and their construction material, they have a low radar cross-section (RCS). This project conducted by IRC-CSS aims to develop novel detection algorithms to identify unauthorized aerial vehicle(s) under heavily congested environments using Machine Learning. This requires an accurate statistical characterization to model both the target(s) and channel (urban/rural), and optimization of the radar parameters to enhance the probability of detection and its accuracy. The results will have a direct impact on the development and enhancement of anti-drone systems and national security.

04 Sustaining Research Project (SRP)

The sixth phase of the Sustaining Research Project (SRP-VI) is one of the strategic projects conducted by ARC-EMS that has improved the transfer of knowledge between KFUPM and Saudi Aramco. Continued for around 40 years, the SRP program has produced a wealth of information regarding marine ecology in the Arabian Gulf. An information gap on the occurrence, distribution, diversity, behavior, and resilience of endangered marine species such as seagrass, corals, sharks, marine turtles, and marine mammals of the western Arabian Gulf exists. The overall objective of SRP-VI was to conduct comprehensive biological, chemical, and physical assessments of the status of the Arabian Gulf ecosystem, including plankton, seagrass, corals, sharks, marine turtles, and marine mammals using modern techniques. The goal was to provide Saudi Aramco managers engaged in conservation the information necessary to facilitate appropriate management interventions. SRP-VI was unique because it integrated studies of microscopic marine organisms with megafauna such as marine mammals. Advanced knowledge and technologies were integrated to investigate historical trends and the fate of pollutants in the marine ecosystem. The diversified nature of the work in SRP-VI demanded a dedicated skilled workforce and sophisticated research equipment. In this study, KFUPM collaborated with well-known knowledge centers such as Woods Hole Oceanographic Institution, Chapman University, University Barcelona, and local universities such as KAUST.

05 Baseline Survey for the **NEOM Environment**



NEOM is born from the ambition of Saudi Arabia's Vision 2030 to see the country develop into a pioneering and thriving model of excellence in various and important areas of life. Large-scale developmental activities are planned in different parts of the NEOM development area. These development activities include both inland and marine areas and only a few studies have been conducted in the NEOM region. Hence, baseline data are required to develop the Environmental and Social Impact Assessments (ESIAs) for the development activities of NEOM. As part of the project titled, Development of Regional Baseline Standards and Performance of Surveys for the NEOM Environment (RFP–100775), conducted in partnership with Wood company, ARC-EMS developed standards for various surveys and conducted studies on landform features, terrestrial flora and fauna, seawater and sediment quality, benthic primary producer habitats, fishes, coral reefs, sea turtle nesting, and marine mammals. KFUPM conducted extensive field surveys encompassing a land area of 350 km^2 and a marine area of 150 km^2. As the Red Sea is generally deep, a large vessel with an extended endurance at sea was also required to conduct the marine surveys. The baseline data developed by KFUPM are being used to establish ESIAs for the development activities of NEOM.

06

Assessment of the Possibility of using Non-Metallic Fibers for Soil Stabilization

Sand is prone to liquefy, collapse, slide, and subjected to other related problems due to its loose structure without cohesion. Consequently, sand has to be stabilized for use in civil infrastructure, such as embankments for highways, dams, etc. This is achieved by using mechanical and chemical methods or both. Cement, limestone powder, and other low-cost and readily available cementitious materials are used along with mechanical means to compact sand. However, there is a recent trend to use fibers and polymers for this purpose. In this study conducted by ARC-MST, the application of existing methods (use of cement, lime, and indigenous industrial waste materials) and emerging technologies (use of fibers and polymers) for soil stabilization (sand, sabkha, and marl) were studied. The results of the experimental work would be useful for Saudi Aramco in the selection of the appropriate soil stabilization technique.

07

Development of a Down-hole Flow Metering Mechanism for an Electrical Submersible Pump to Measure Mutiphase Flow (Water and Oil)

The existing multiphase flow meters, which are in use in oilfields, do not measure the multiphase flow rate of water and oil accurately. Highly accurate multiphase flow meters are expensive and need frequent maintenance. In this project funded by Saudi Aramco, the multiphase flow loop at ARC-MST was used to develop a down-hole flow metering mechanism for an electrical submersible pump (ESP) to monitor multiphase flow (water and oil). The objectives of the project were to develop a down-hole flow metering mechanism for an ESP to monitor multi-phase flow and a mathematical model and related multiphase flow rate software. Specifically, the experiments were conducted using the KFUPM multiphase flow loop for flow rates ranging from 2000 to 13000 bpd, water-cuts varying from 0 to 100 %, inclination angles ranging from 40 to 90 degrees, and two oil viscosities in the range of about 2 to 5 cps.

08 Renewable Energy **Technical Incubator**

Renewable Energy Technical Incubator program is a 4-year SR 23 Million program funded by the National Industrial Development and Logistics Program (NIDLP). The main objective of the program is to establish a leading national technical incubator in the Kingdom of Saudi Arabia that serves the researchers, students, and local content developers to boost their RDI capabilities in renewable energy, energy efficiency, and Industry 4.0 in the energy sector. A state-of-the-art renewable energy incubator at KFUPM will facilitate research and implementation of proof-of-concept ideas in the renewable energy sector, which will serve in accomplishing the goals of Vision 2030.

09 Digitalization, Workplace Organization, and Job Transformation: **A Multi-Level Analysis**

Digital technologies have created new opportunities to enhance business processes and improve the performance of organizations. At the same time, digital technologies pose challenges for organizations as they are required to prepare for significant transformation of work associated with digital technologies. More specifically for entrepreneurship, digitalization is creating new opportunities that affect organizational economic activities. Digitization promotes decoupling between form and function, promotes disintermediation— reducing the power of middlemen in value chains, and drives generativity—enabling the coordination of geographically dispersed parties and opening new ways to build organizational capabilities. However, it is currently unknown how digitalization shifts or couples with different elements of entrepreneurial ecosystems — namely skilled workers, work environment, and the existing systems within an organization to create new business values. This project conducted by IRC-FDE uses a mixed-method approach and tackles three critical questions: (i) What are the elements of digitalization that facilitate or hinder innovation within an organization?; (ii) How does digitalization change the entrepreneurial ecosystems (i.e., job characteristics, information sharing capability, work environment, etc.)?; and (iii) Under what conditions will digitalization complement already established organizational capabilities to advance innovation and organizational outcomes?

10 Facile Synthesis of an **Advanced Visible-Light-Driven Organic-Inorganic Nanocomposite Photocatalyst** for Efficient Removal of Hazardous Organic Pollutants and Bacteria from Water

Wide-ranging studies been conducted on the removal of hazardous organic pollutants and water-borne bacteria from water. Many methods for water purification systems involving complicated instrumentation and complex methodologies, which can also be a source of secondary contamination, exist. Photo-catalysis is a simple and cost-effective method, in which the light-induced charge carriers generated in the semiconducting material are used to degrade and demineralize the organic, inorganic, and microbial pollutants in water through redox reactions. Synthesis of advanced organic-inorganic nanocomposite photocatalysts with nano-engineered semiconducting materials remains a method of choice for visible-light-induced degradation of hazardous organic pollutants and disinfection of water-borne bacteria owing to its effectiveness, simplicity, and low cost. In this project, funded by the Ministry of Education, the IRC-MWS team synthesized advanced organic-inorganic photo-catalytic materials using advanced pulsed laser ablation in a liquid capable of operating under visible light, particularly using abundant solar radiation. This system was successfully used for photocatalytic degradation of hazardous organic pollutants and disinfection of water-borne bacteria. This material can be applied for decontamination and disinfection of water and in bio-films using solar light as the source of radiation, which is an application involving solar energy harvesting.

11 The Role of Facial Features, and Voice Recognition in Personal Identification

Voice and facial features are considered as important cues in social communications. Several recent studies have shown that both facial and voice features may contribute effectively to establishing an individual's identity. Furthermore, it has been shown that voice features are closely related to biological factors, providing scientific evidence that individuals from the same biological family have similar voice frequency, pitch range, intonation, loudness, and tempo. Hence, establishing individual identity based on voice recognition alone may not be effective and may need confirmation from other measures, such as facial features (e.g., eyes). Facial features are considered one of the most important aspects that help establish individual identity while maintaining privacy. Previous studies have shown that eyes carry important information that facilitates social communication between individuals. In this project conducted by IRC-ISS, the effect of combining different voices and facial features and their impact on accurately identifying an individual were investigated. To achieve this objective, experiments to understand the contribution of voice and facial features to establishing individual identity, based on a factorial design, were conducted. In the next phase, both effects of facial features and voice recognition will be investigated to focus on establishing individual identity based on different individual traits.

12 Readiness of Organizations to Counter Insider Attacks

An insider threat is a malicious activity against an organization from users with legitimate access to the network, applications, or databases. According to a recent Ponemon Institute study, insider threats are a growing challenge for organizations. The number of incidents attributed to insiders has increased by 47% in the last couple of years, each insider-related incident costing $755,000. Typically, insider attacks are difficult to detect as the offenders have legitimate access to the relevant infrastructure and data. As such, the development of frameworks that can help organizations to evaluate their readiness to protect against such insider attacks is vital. Evaluating the readiness to manage insider attacks will help organizations to identify their weaknesses and hence establish necessary mitigation steps against such threats. The objective of this project conducted by IRC-ISS is to propose a readiness model for insider attacks to assist an organization to evaluate its readiness to counter insider attacks. For this purpose, a multivocal literature review will be conducted to identify the main knowledge areas and best practices of insider attacks. Furthermore, necessary steps for the implementation of the readiness model will be identified to help organizations quickly adapt the readiness model. A case study approach will be used to assess the readiness model in a real-world environment.

13 Development of Structural Electrolytes using Local Saudi Resources for Energy Storage

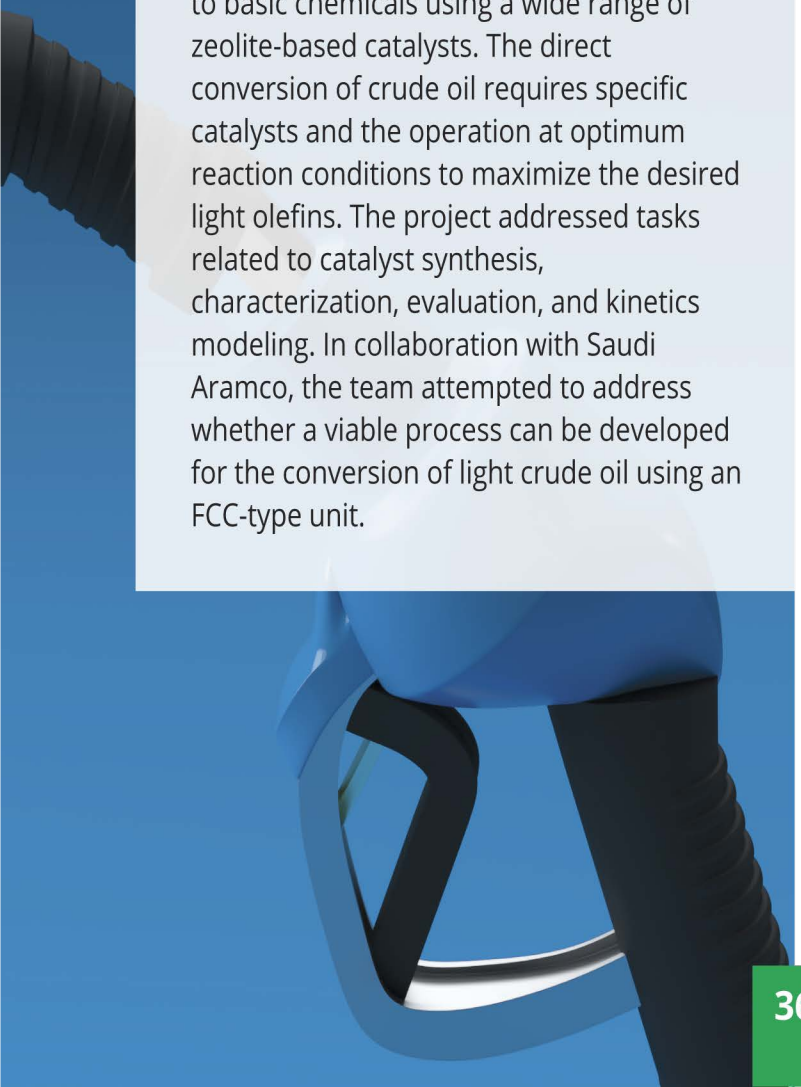
Electrode materials are essential for the production of conventional supercapacitors. Electrolytes are also important components required for structural supercapacitors (SSCs). In fact, structural electrolytes are required to combine load-bearing mechanical properties and ionic conductivities to integrate the electro- chemical-mechanical properties to enhance the performance of SSCs. The common structural electrolytes are ionic liquid-based electrolytes acting as ionic conductive phases and polymer materials acting as structural components. However, they are not very suitable for civil engineering applications. For civil engineering applications, SSCs in the form of cement-matrix composites are required. However, one of the most significant challenges in the application of such SSCs is the development of structural electrolytes in the form of electrolytes based on inorganic cementitious materials, which should possess excellent mechanical properties, ionic conductivity, and good compatibility with electrodes. Therefore, a new structural electrolyte based on locally available resources with high strength and a better ionic conductivity for building applications will be developed in this project conducted by IRC-CBM.

14 Development of a Novel Coating for GFRP bars for Enhancing the Bond Strength and Fire Resistance

Glass fiber reinforced polymer (GFRP) is a non-metallic composite fabricated using a matrix of polymer material (polyester, vinyl ester, or epoxy) reinforced with high-strength glass fibers. The corrosion resistance of GFRP bars makes them an attractive option in regions which a harsh environment. However, concrete structures reinforced with GFRP bars are commonly known to have a lower fire resistance than equivalent conventional steel-reinforced concrete structures, which is one of the major obstacles against using GFRP bars, particularly in industrial facilities. The main focus of this project conducted by IRC-CBM is to develop a novel coating technology that could accomplish the dual purpose of increasing the fire resistance of GFRP bars as well as enhancing their bond strength with concrete. Coatings prepared with ammonium polyphosphate, acrylic/vinyl/polyvinyl acetate polyphenylene sulfide, or tannic acid-functionalized graphene and polysilicon will be evaluated. Also, hybrids of these materials will possibly be investigated. This interdisciplinary study will promote and expand the application of GFRP bars in concrete structural elements and components as part of key infrastructure and industrial facilities. The developed coating technology can overcome the high cost of repair and rehabilitation of steel-reinforced concrete structures. The outcome of the proposed study will have socio, economic, and environmental benefits.

15 Adding Value to Crude Oil

Along with the decarbonization efforts worldwide due to environmental protection regulations, the refining industry is transforming from “fuel-based” into “chemical-based”. Accordingly, the demand for transportation fuels will remain flat, while the demand for basic chemicals, including the value chain comprising light olefins and aromatics, will increase. Within this context, the direct conversion of crude oil into basic chemicals has become one of the important processes in refinery energy transformation. The IRC-RAC team has completed a project funded by Saudi Aramco for the conversion of light crude oil to basic chemicals using a wide range of zeolite-based catalysts. The direct conversion of crude oil requires specific catalysts and the operation at optimum reaction conditions to maximize the desired light olefins. The project addressed tasks related to catalyst synthesis, characterization, evaluation, and kinetics modeling. In collaboration with Saudi Aramco, the team attempted to address whether a viable process can be developed for the conversion of light crude oil using an FCC-type unit.



16 Novel Routes for the Production of Linear Alpha Olefins

Linear α-olefins (LAOs) are valuable commodity chemicals used as precursors in many areas of the industry, including detergents, synthetic lubricants, and plasticizer alcohols. LAOs are also used as co-monomers to produce linear low-density polyethylene to enhance the physical properties of polymers. Polyethylene resins based on 1-hexene and 1-octene are more attractive due to their superior properties, such as stress-crack and tear resistance. Traditionally, LAOs have been produced via non-selective ethylene oligomerization. Due to the high demand for pure fractions of specific LAOs (typically 1-hexene or 1-octene), selective ethylene oligomerization catalysts have been targeted for use on an industrial scale. The ongoing project focuses on developing novel catalysts for the ethylene tetramerization reaction that will permit the on-purpose production of 1-octene. The IRC-RAC team has developed several highly efficient novel catalytic systems with high productivity and selectivity and sent these catalysts to Saudi Aramco for further analysis in a scale-up reactor.

17 Evaluation of the **Behavior of FRCM Concrete** Improved with Self-healing Materials

Performance of fabric-reinforced cementitious matrix (FRCM) composites in concrete structures depends on their ability to withstand nucleation against localized damages. One of the factors affecting this is the initiation of micro-cracks in the matrix composite adhering the fabrics to the concrete. In this work, bio-self-healing mortars will be used to arrest the propagation of cracks and repair them to prevent their further degradation in typical settings. Comprehensive characterization of the material will be carried out, followed by studying the interaction between the cementitious matrix and concrete using molecular dynamic simulations.
Efficacy of the proposed material combination will be validated using a detailed experimental study of the FRCM-concrete by IRC-CBM using a recently patented Universal Test Apparatus that is capable of conducting single shear, double shear, beam bending, modified beam bending, and pull-off tests.

18 Assessment of Small PV Systems - **RE International Benchmarking Analysis**

A thorough assessment and benchmarking of environmental conditions, power sector reliability, infrastructure, nationwide RE policies, and initiatives for 10 developing countries were conducted by IRC-REPS. This project was funded by a UL-GCC LAB-Gulf Renewables Lab Joint Venture for King Abdullah City for Atomic and Renewable Energy (KACARE). The objectives of the project included assessing the techno-economic aspects of small-scale PV systems in the reference nations, assessing the policies and support mechanisms implemented, evaluating the social impact of small-scale PV systems, exploring and evaluating the best practices, and evaluating the code and regulations in the context of contributing to the deployment of renewables and determination of the impact of their implementation.

19 Development of **palm tree fiber reinforced polymer composites**

The objective of this study conducted by IRC-AM is to utilize the crop residues of local date palm trees as the fiber-phase of a polymer-based composite. About 26% of Saudi Arabia's annual budget (>800 billion USD) goes to construction projects, having to import many of the construction materials. Through modification of the techniques, palm-based composites will be fabricated with the same dimensions and properties as other common building materials, creating new business opportunities.
The first part of the project involves the identification and characterization of palm tree-based reinforcement materials obtained from the crop residues followed by pre-treatment. The conversion of date palm crop residues into fiber reinforcement raw materials is aligned with the goals of the Hydrocarbon Sustainability Program (HSP) of the Ministry of Energy. The novelty of this work is the use of microwave curing of date palm fiber composites, which is expected to significantly decrease energy consumption as it involves a more controlled volumetric heating over conventional curing methods.

20 Development of **Epoxy Nanocomposite Coatings** for Corrosion Protection of Steel Structures in Marine Environment

Recent progress made in the fabrication and characterization of nanomaterials will have a significant impact in the field of protective coatings for steel structures in the Kingdom. In particular, epoxy nanocomposites (NC) have become a promising area of research in the Kingdom in the past two decades, as nanomaterials have a significant beneficial effect on the mechanical, thermal, and especially anticorrosive and antifouling performance of the epoxy coatings on a steel surface. In the ongoing project conducted by IRC-AM, we are aiming to develop hybrid epoxy coatings with conducting-polymer-modified RGO possessing improved corrosion protection and tribological performance on mild steel structures in the marine environment.

Prospective **Initiatives**

Future Initiatives

KFUPM: An ultimate destination for **Impactful Research and Innovation in KSA**

KFUPM has a vision to make a difference within the Kingdom of Saudi Arabia and beyond in the fields of sciences, engineering, and business

KFUPM is launching research consortia as its primary external engagement and collaboration platform

Research consortia led by KFUPM can bring together the right mix of members to solve common problems using a win-win formula.

Consortia are a globally proven model for academia-industry, multi-party research engagement.

Multiple stakeholders can tackle grand challenges of common interest efficiently and collaboratively across the full value chain towards market adoption.

Consortium Collaboration Model
A new approach to sustainability

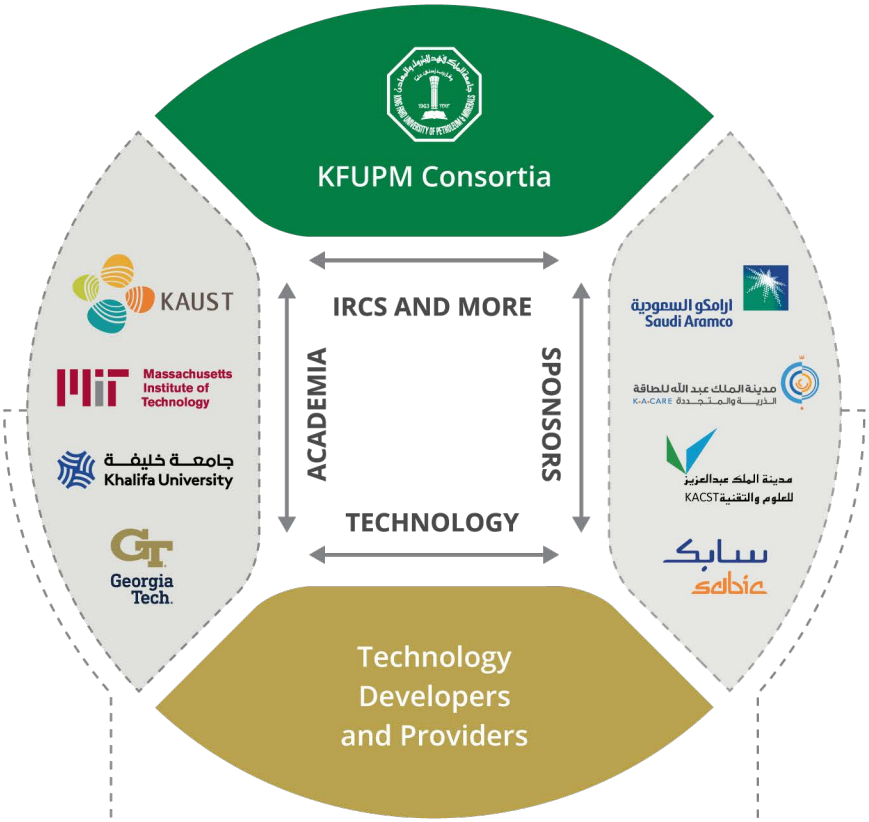
Consortia will be bringing together key complementary stakeholders around one **"collaboration table"**.

Government Entities - Realizing national research goals by catalyzing partnerships and investing in national R&D infrastructure and capabilities.

Academic and Research Organizations - Expanding own research relevance and capacity by accessing strategy, talent, capabilities, and key market players.

Technology Providers - Bringing prototyping, scale-up, commercialization, and marketing expertise, while training and accessing talent.

Industries End-Users - Defining key technological challenges, funding research projects, and deploying resulting technologies.



- Research capability
- People and ideas
- IRC labs and shared labs/centers
- Creation of knowledge and talent
- Training

- Complementary research capacity
- Ideas
- People and people exchange
- Labs and methods
- Training

- Scale-up and demonstration
- Commercialization and marketing
- Employment of graduates
- Training

- Challenges and problem definition
- Funding through membership
- Oversight of priorities, fund allocation and progress
- Adoption and deployment
- Entrepreneurship and VC
- Employment of graduates

01 KFUPM Consortium for a Sustainable Future

A growing, state-of-the-art research infrastructure for developing sustainable technologies.

Create innovation-based solutions and technologies that address a wide range of critical challenges:

1. Next generation materials and digital materials.
2. Development of new tools, operando and multimodal.
3. Basic research and its translation to solve challenges, e.g. in air, energy, and water.

The KFUPM Consortium for a Sustainable Future will focus on developing new generation materials and digital materials and utilization of artificial intelligence computations to develop new tools, operando and multimodal, that maximize the value of materials development.

02 KFUPM Consortium for a Hydrogen Future

A growing, state-of-the-art research infrastructure for developing hydrogen (H_2) technologies.

Create innovation-based solutions and technologies that address a wide range of critical challenges in the production, transport, and use of H_2, along with key associated carbon management topics.

1. Reducing H_2 production cost from all viable sources.
2. Improving H_2 transport, distribution, and storage.
3. Integrating H_2 into the circular carbon economy by managing carbon associated with H_2 value chain.

The Hydrogen Consortium will focus on design and development of hydrogen combustion systems, engineering materials for carbon capture, novel nano-colloidal formulations, and electrochemical energy storage devices.

For further information please contact:

RESEARCH & INNOVATION

King Fahd University of Petroleum & Minerals
University Box 5040
Tel. (013) 860 2200

https://ri.kfupm.edu.sa/Research-Centers.html