وزارة البيئة والمياه والزراعة
Ministry of Environment Water & Agriculture

Innovation in the Water sector in Saudi Arabia

Technology Adoption Roadmap

His Royal Highness Prince Mohammed bin Salman

Crown Prince، Prime Minister، Chairman of the Council of Ministers، and Chairman of the Supreme Committee for Research، Development، and Innovation

"Our ambition for Saudi Arabia is to become a global leader in research، development، and innovation with an annual investment equivalent to 2.5% of GDP in 2040. This will diversify and add 60 billion Saudi Riyals (US$ 16 billion) to the economy in 2040 while creating high-value jobs in science and technology."

Statement by His Excellency the Minister of Environment, Water, and Agriculture

The Kingdom's leadership believes in the importance of research and innovation to build a knowledge economy and achieve true diversification of the state's resources، especially in the vital، priority sectors of environment، water، and agriculture. The Ministry of Environment، Water، and Agriculture aims to enable partners across the innovation ecosystem to stimulate and localize technologies to provide effective sustainability solutions within the Ministry's sectors.

His Excellency Eng. Abdulrahman Abdulmohsen AlFadley

Statement by His Excellency the Vice Minister of Environment, Water, and Agriculture

The innovation ecosystem enjoys unlimited support and keen interest from our wise leadership، may God support them. The Ministry of Environment، Water، and Agriculture has taken several steps to enable innovation، including establishing a deputyship for research and innovation to help find innovative solutions for issues related to sustainability of natural resources، environmental protection، meeting basic water and food needs، and achieving economic and developmental outcomes.

His Excellency Eng. Mansour bin Hilal Al Mushaiti

Dr. Abdulaziz bin Muharib AlShaibani

Deputy Minister for Water Affairs

Statement by the Deputy Minister for Water

The Kingdom of Saudi Arabia is among the countries with the lowest availability of water resources, which necessitates the activation of effective and integrated management of its water resources. This will ensure their sustainability as an essential factor for societal and economic development, and help achieve the goals and ambitions of the Kingdom's Vision 2030.

The National Water Strategy 2030 serves as a comprehensive plan and approach for the water system in the Kingdom, to activate integrated management of water resources, and to find solutions to water challenges. This will enable the Kingdom to reduce pressure on its natural water resources, in addition to achieving security of supply, quality, and excellence in water services, and achieving environmental, economic, and cost management sustainability.

Perhaps the most prominent solutions addressed in the strategy in this regard are seawater desalination, in which the Kingdom is a pioneer in the world, and raising the efficiency of recycling treated wastewater, which has witnessed remarkable growth in recent years. However, the Kingdom still needs more solutions in the water sector. For example, reducing the cost of water desalination will save billions of riyals for the Kingdom by reducing energy use and reducing losses in water networks. Managing agricultural and industrial requirements in a sustainable manner also involves increasing water consumption through reuse. This helps reduce reliance on natural sources without compromising productivity and quality.

The National Water Strategy 2030 has set a number of goals in this regard, such as enhancing water supply through desalination, reusing wastewater, increasing efficiency in the value chain of the water sector, and improving the coverage of water services to consumers. The strategy also aims to reduce losses from networks to 15%, reaching 100% distribution network coverage by 2030.

The National Water Strategy consists of 10 programs, with the fourth program focused on developing solutions through research, innovation, and technology localization. These tools are crucial for the strategy's success, and activating these solutions will pioneer advancements in various areas of the water sector. This includes desalination of water using advanced technologies, smart management of waste, innovative treatment and reuse of wastewater, and development of water sources through innovative methods of harvesting rainwater and floods. Therefore, widespread adoption of technologies is necessary to reduce the cost of water production and improve the digitization of water services along the value chain to ensure enhanced water security.

The Ministry of Environment, Water, and Agriculture affirms its commitment to harnessing innovation to serve the water sector. It has developed a roadmap for adopting technologies that are compatible with the National Water Strategy, to ensure improving the performance of the water system in the Kingdom, and to raise the standards of water, environmental, and financial sustainability. The ministry encourages those in the water sector to be guided by this report to direct their efforts in the field of technology and innovation.

Dr. Abdulaziz bin Malik Al-Malik

Deputy Minister for Research and Innovation

Statement by His Excellency the Deputy Minister for Research and Innovation

Many countries have focused on developing their technical and innovative capabilities, as it is a key enabler for sustainable economic growth. It helps increase the competitiveness and productivity of various economic sectors and provides effective solutions to many pressing challenges. The Kingdom of Saudi Arabia has given remarkable attention to technology and innovation in various fields. HRH Prince Mohammed bin Salman bin Abdulaziz Al Saud, Crown Prince, Prime Minister, Chairman of the Council of Ministers and Chairman of the Supreme Committee for Research, Development, and Innovation, announced the aspirations and national priorities for research, development, and innovation in Saudi Arabia for the next two decades. These are based on four main priorities, including environmental sustainability and basic needs. This reflects Saudi Arabia's commitment to sustainably provide for basic human needs for water and food by developing environmentally friendly technologies for water supply and desalination, and modern and sustainable techniques for food production and increasing green spaces.

The urgent need to adopt technology and innovation in the water sector in the Kingdom stems from the necessity of balancing the Kingdom's water needs for agricultural, industrial and residential uses, and the reality of the scarcity of water resources in the Kingdom, which affects the Kingdom's water security and the sustainability of its water resources.

Recognizing the importance of adopting technology and innovation, the Ministry of Environment, Water, and Agriculture established a Deputyship for Research and Innovation within its organizational structure to activate the Ministry's role within the institutional framework and the national governance model for the research, development, and innovation sector. It has developed an executive institutional plan for research and innovation to make the environment, water, and agriculture system the most ready and capable to embrace and develop innovative technologies and practices. One of the most important components of this plan, which is the focus of our report, is the strategic focus on adopting priority innovative technical solutions to meet the needs in the water sector. This will serve as a guide for institutional interventions and initiatives to ensure optimal direction of efforts and resources.

The Ministry of Environment, Water, and Agriculture has followed a carefully designed methodology to analyze demand and identify available supplies of the most important innovative solutions for the water sector that should be focused on in the short and medium term. It detailed the waves of their adoption and widespread dissemination in a technology adoption roadmap for the water sector in the Kingdom. This methodology relied on a several criteria, including expected impact of technology deployment, its ability to address the challenges facing the water sector, and ease of adoption, with a focus on the most mature, deployment-ready technologies. After piloting and adaptation to suit local conditions, these technologies can be broadly disseminated in the sector. This roadmap was developed through integration, cooperation, and support from various stakeholders and in alignment with relevant national strategies for the environment, water, and agriculture, and research, development, and innovation sectors. The process involved dozens of policymakers and experts specialized in water innovation.

The purpose of publishing this report is to inform all actors in the water system, including leading and emerging companies, research and development centers, and non-profit organizations, of the Ministry's strategic direction in this sector. To help them make their decisions and develop their own plans and policies, informed by the promising opportunities contained in this report; To include technology and innovation in their operations and systems, which will have the greatest impact, God willing, in improving the national water system.

About the Report

This report is one of three reports issued by the Ministry of Environment, Water, and Agriculture on technology adoption in its sectors in the Kingdom. It aims to identify ready technologies contributing to solving sectoral challenges in the Kingdom and outlining the Ministry's executive plan in this regard.

Agricultural Innovation in the Kingdom of Saudi Arabia

Environmental Innovation in the Kingdom of Saudi Arabia

Water Innovation in the Kingdom of Saudi Arabia

About the Ministry of Environment, Water, and Agriculture

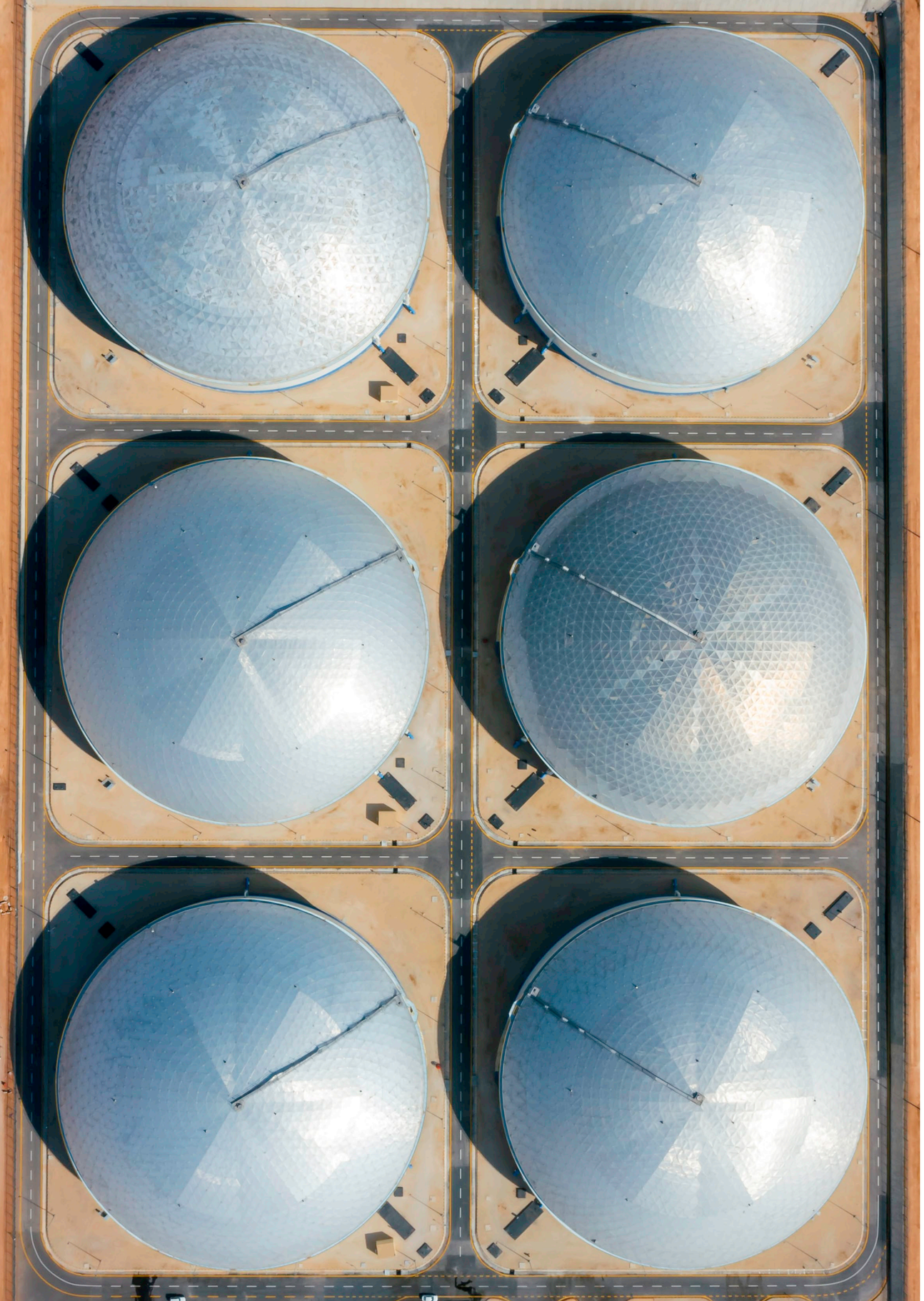
The Ministry of Environment, Water, and Agriculture in the Kingdom of Saudi Arabia is responsible for regulating and implementing all aspects of the Kingdom's policies in the environment, water, and agriculture sectors. The Ministry implements environmental, water, and agricultural plans and programs at the national level, with a focus on sustainability and value creation. Its contribution to the national economy has increased through various programs, especially in food security, water provision, and environmental protection.

Vision

Sustainable environment and natural resources that achieve water security, contribute to food security, and improve quality of life.

Mission

The Ministry strives for excellence in developing and implementing comprehensive policies, effective strategies, and improved services. It aims to achieve prosperity and sustainability in the fields of environment, water, and agriculture by actively involving the private sector and other relevant entities.



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Executive Summary

Technology and innovation is playing an increasing role in achieving national targets in the environment, water and agriculture sectors, such as achieving food and water security and environmental sustainability, increasing significantly. Adopting technology and innovation in the water sector has never been more paramount, given the ambitious national goals for this sector. To accomplish these objectives, it is crucial to widely implement innovative technologies and practices to transform sectoral challenges into opportunities.

This report sheds light on the Ministry's executive plan to promote adoption of innovative technologies and practices in the water sector, and the strategic focus towards adopting priority innovative products and solutions to meet the most pressing needs in the water sector. This will serve as a guide for institutional measures and initiatives to ensure the optimal steering of efforts and resources.

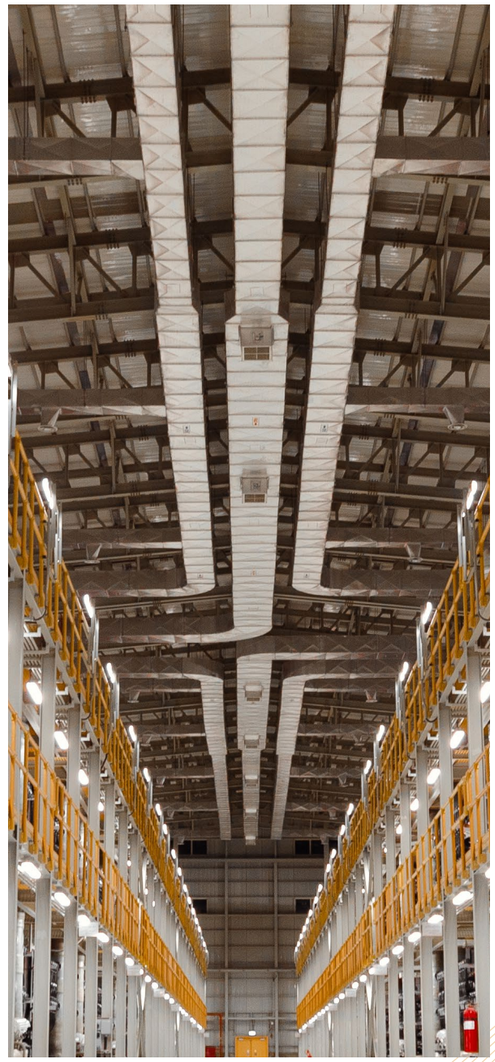
The Ministry followed a detailed methodology to select priority technologies in the water sector. This process began by analyzing the demand side for technology and innovation by examining the challenges faced by the water sector across the value chain and within subsectors. Additionally, the Ministry considered the expected impact of technology and innovation adoption on addressing these challenges. On the supply side, the Ministry surveyed an extensive list of available technology and innovation solutions and refined them based on several criteria. From this, the Ministry generated a list of technologies and innovations that are ready for adoption and scaling up. These selected technologies have the potential to make the greatest impact and offer quick and effective solutions to the most pressing challenges in the water sector in the short and medium term

This effort involved more than a hundred policymakers and technology and innovation experts, identified more than 45 challenges and opportunities, and selected over 100 individual technologies, categorized into 20 technology families. Based on this, 10 technology families were chosen for the environment sector, half of which will be adopted in a first "high priority" activation wave until 2025, and the other half in a second, subsequent wave. A third, future wave will involve the adoption of broader technologies beyond the initial 10 identified ones. The first-wave are advanced reverse osmosis systems, smart leakage management, wastewater treatment and reuse, irrigation Innovative, For innovative water consumption in homes. This report covers these four families in detail by introducing them and explaining the demand and supply drivers and current barriers to their widespread adoption. The report further touches on the technologies of the subsequent second and third waves, which the Ministry intends to adopt between 2025 and 2030.

TheMinistryaimstoimplementseveralinstitutional initiatives to adopt and disseminate priority technologies in the water sector in partnership with relevant stakeholders. These initiatives were developed after a comprehensive survey and analysis of existing efforts in the water sector. The goal is to achieve the ambitious future aspirations for this sector within Vision 2030. This includes aligning with the national research, development, and innovation agenda and understanding the Ministry's role within the institutional framework governing it. Additionally, the initiatives consider the current state of technology adoption and innovation activities in the water sector, and the state of technology adoption enablers such as available infrastructure, human resources working in the water innovation ecosystem, and policies and regulations supporting technology adoption and innovation in the sector. It also utilized best practices of sectoral and national innovation policymaking recommended by several international organizations.

The priority measures to promote technology and innovation were identified, with the aim of achieving four main objectives:

- Directing and coordinating efforts: This involves overseeing and managing the plans, efforts, and resources allocated to adopting technology and innovation in the water sector. The focus is on addressing sectoral challenges in line with national research, development, and innovation priorities and the relevant national strategies.
- Enhancing collaboration and partnerships: The goal is to improve connections and cooperation between stakeholders engaged in technology and innovation adoption within the water sector. This collaborative approach aims to foster partnerships, leverage synergies, exchange expertise, and share knowledge. It also seeks to raise awareness of the water ecosystem's achievements in integrating technology and innovation into their plans and operations to create positive momentum and ensure the sustainability of these efforts.
- Stimulating technology demand: This involves increasing the interest and demand for technology products and innovative solutions within the water sector. It includes measures and incentives designed to boost the sector's willingness to adopt available technology solutions, ensuring that the supply of technology aligns with the demand.
- Building research and innovation capacities: This objective focuses on strengthening the research, development, and innovation capabilities within the water sector. The aim is to ensure a sufficient and continuous local supply of technology products and innovative solutions.



Saline Water Desalination Plant, Saline Water Conversion Corporation

Introduction

Technology and innovation are among the most important drivers of economic growth, primarily by enhancing the productivity of various sectors. This significance is particularly relevant to the water sector, given the challenges of ensuring adequate water supply for a growing population, and preserving non-renewable water resources. The call for innovation in the water sector in the Kingdom is even more pressing due to its harsh weather conditions placing the Kingdom eighth in the world for water scarcity.

Technology and innovation play a vital role in various aspects of the water sector. They help improve water demand management across all sectors, promote efficient and responsible water usage, and address challenges encountered in different stages of the value chain. For instance, in transmission and distribution, innovative leak detection techniques help minimize water loss. Additionally, advanced wastewater treatment methods enable its safe reuse for non-domestic purposes, reducing reliance on fresh water. Purification techniques, essential for urban water supply in the Kingdom, enhance service quality while conserving desalinated water and preserving non-renewable groundwater levels. Furthermore, technology facilitates innovative irrigation solutions, boosting productivity and reducing water consumption in agriculture.

In recent decades, the global water sector has undergone several transformations. Technology and innovation have attracted increasing attention and gained accelerating momentum for their integration into practices followed in the water sector, for two main reasons:

A rising demand for innovative technologies and practices to address the escalating challenges in the water sector, such as the decrease in global water levels, which has led to water scarcity in many regions of the world. Achieving water security is crucial for various sectors like agriculture, industry, health and quality of life. This heightened demand creates an environment more conducive to adopting technologies in the water sector. The second reason is increased supply. Rapid technical advancements have led to the emergence of innovative solutions. For instance, digital technologies offer effective solutions to issues like leakage and water conservation, while advances in materials science have led to innovative solutions for water desalination.

The water sector in the Kingdom has achieved significant milestones through regulatory and innovative approaches. For instance, there has been a notable reduction in the use of non-renewable groundwater, decreasing from 19 billion cubic meters in 2015 to 8.5 billion cubic meters in 2020,[1] thanks to proactive measures towards fodder and wheat production and improved irrigation. In addition, desalination production efficiency has improved significantly over the past two decades, with the gradual replacement of older cogeneration plants (electricity and water production) with modern, advanced desalination technologies. Finally, the sector is undergoing a major transformation characterized by increased private sector involvement and commercialization of water entities along the value chain.

Despite these achievements, ongoing challenges persist in the water sector. The threat of non-renewable groundwater scarcity and depletion, along with increasing global and macroeconomic pressures on the value chain, underscore the need for continued attention and focus on competitiveness, performance, and efficiency in the sector. Addressing these challenges is integral to Saudi Arabia's Vision 2030. To tackle these issues, the Kingdom has allocated a significant investment of 92 billion riyals to strengthen the environment, water, and agricultural sectors, in line with the National Transformation Plan. This investment includes more than **3,000 planned projects aimed at enhancing water sector infrastructure, with cumulative investments expected to exceed 300 billion riyals by 2030**.[2] These investments highlight the critical role of water in achieving sustainable development goals.

Figure No. (1) shows an overview of the Kingdom's water sector along the value chain.

Figure 1: An overview of the water sector in the Kingdom of Saudi Arabia

1 Ministry of Environment, Water and Agriculture, «Statistical Book», 2021

2 Ministry of Environment, Water and Agriculture, ""The achievements of the environment, water and agriculture ecosystem during 2018 confirm the collaboration of the sector in achieving Vision 2030", 2018

Figure No. (2) below shows the current outlook for the water sector and their classification according to the value chain. These aspirations were developed based on the results of national strategy analyses and intensive meetings with stakeholders. Through these aspirations you will address the diverse challenges facing the water sector and will contribute overall to improving sustainability and costliness.

Investments in research and development in the water sector are crucial, given the global challenges faced in this area, not limited to just the Kingdom. What further underscores the importance of enhancing local innovative capabilities is the diverse goals and issues each country faces regarding water. Therefore, directing efforts towards technologies that address local challenges is vital. This approach contributes to achieving national goals by continuously monitoring the current national context, integrating it with the latest technical and innovative developments in the water sector, and aligning national efforts towards unified goals that add value to this sector. It is also essential to empower current and future efforts by providing necessary support through ongoing updates to supporting systems and policies. Creating an environment conducive to innovation, addressing challenges encountered by the water innovation system, and offering continuous support and guidance are equally important steps in this direction.

Figure 2: Overview of challenges and opportunities for the water sector

Supply	Transmission & storage	Distribution	Wastewater treatment & reuse	Demand
Optimize circular economy of water / net positive water				
Reduce production energy and major costs	Reduce transmission cost	Improve network coverage	Improve wastewater network	Reduce urban water consumption levels (LCD)
Optimize environmental impact of desalination	Increase number of storage available days	Reduce distribution losses	Improve wastewater treatment	Reduce industrial water consumption levels
Increase non-renewable water sources		Ensure uninterrupted and reliable water supply	Increase use of treated wastewater	Reduce use of non-renewable water sources (agri. water consumption)
Improve preservation of groundwater quality				

Saline Water Conversion Floating Plant, Saline Water Conversion Corporation

Recognizing the pivotal role of technology and innovation in driving growth across vital sectors, including the water sector, the government of the Kingdom of Saudi Arabia has prioritized innovation within its strategic agenda. Environmental sustainability and essential needs are emphasized among the four national innovation priorities outlined by HRH Crown Prince Mohammed bin Salman. Acknowledging the transformative potential of technology and innovation, the Ministry of Environment, Water, and Agriculture has established a dedicated deputyship for research and innovation. This deputyship aims to enhance the Ministry's role within national frameworks governing research, development, and innovation.

The Ministry has embarked on a comprehensive plan, extending until 2030, to integrate technology and innovation into its systems and operational processes across the environmental, water, and agriculture sectors. The objective is to position these sectors as leading adopters and developers of innovative technologies and practices.

The Ministry of Environment, Water, and Agriculture has initiated structural reforms, regulatory policies, and established new entities to drive progress. The next pivotal factor for advancing the Ministry's sectors is innovation. Innovation holds the potential to enhance efficiency, increase productivity, and raise the sector's economic contribution. The case studies in the following pages point to one global and two local examples where innovation was decisive in providing effective solutions.

Global Success Story

Intelligent precision irrigation system

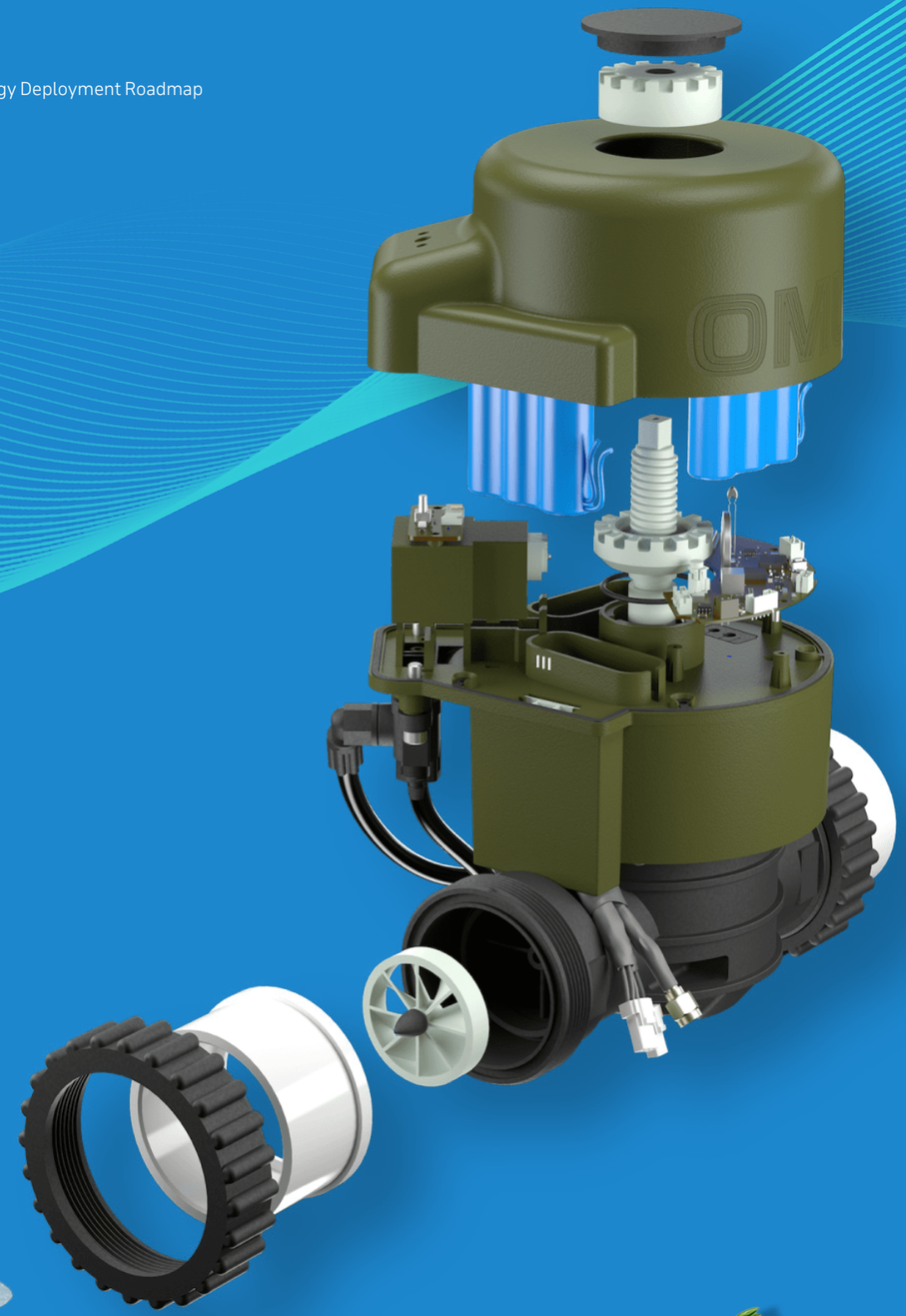
This smart irrigation system project was implemented by Lumo, a company dedicated to developing water management technologies and addressing the global challenge of water scarcity. This innovation offers a practical and sustainable approach to irrigation management by addressing the shortcomings of traditional irrigation methods. By developing an advanced smart valve, the project ensures precise water usage, reducing cost and enhancing efficiency.

Equipped with built-in controllers, water flow and pressure sensors, and internet connectivity, the smart irrigation system enables accurate water distribution based on real-time needs. This automation replaces fixed schedules, ensuring optimal water delivery.

Additionally, the system facilitates compliance with water use regulations through advanced reporting features. Smart valves also receive data that can be used to generate instant reports, making it easier to comply with increasingly stringent regulatory environments.

Achievements:

This smart irrigation system achieves significant savings, cutting irrigation labor costs by up to 90% and reducing excess water use by at least 20%. This innovation plays a vital role in conserving water resources, promoting effective water management, and bolstering environmental sustainability.



Local Success Stories

A groundbreaking desalination plant

"The Saline Water Conversion Corporation (SWCC) in the Kingdom of Saudi Arabia is committed to making a meaningful impact in the global fight against water scarcity and ensuring access to safe drinking water for all. With a strong belief in its capabilities, SWCC strives to develop and implement innovative water solutions that not only meet the needs of humanity but also preserve ecosystems in a fair and sustainable manner. Through its efforts, SWCC aims to make a positive difference in the lives of millions worldwide."

His Excellency the Governor of the General Saline Water Conversion Corporation Eng. Abdullah bin Ibrahim Al-Abdulkarim

The Saline Water Conversion Corporation in collaboration with the Institute for Water Technology Innovation and Advanced Research has developed an innovative pilot plant for zero salt reflux technologies in seawater desalination. This pilot plant focuses on economically extracting valuable products from seawater including sodium chloride bromine and magnesium metal.

The pilot plant employs nanotechnology for water purification, specifically nanofiltration (NF), which selectively separates ions like magnesium, calcium, and sulfate, allowing sodium and chloride ions to pass through. This process divides the streams into a concentrated magnesium-rich stream and a sodium chloride-rich stream, which can be efficiently concentrated further using brine concentration technology.

Approximately 25% of the solids are concentrated by the membrane, leading to the production of high-purity sodium chloride crystals suitable for use in the chemical industry. Additionally, the crystallizer produces a concentrated solution rich in potassium and bromine, which can be processed to extract bromine, an essential chemical used in oil field development.

The magnesium-rich stream is treated to produce magnesium hydroxide, which is then dried to magnesium oxide and converted into magnesium metal. A newly developed thermal process reduces energy consumption and carbon footprint compared to traditional methods.

Overall, this project aims to demonstrate the technical feasibility for the Kingdom to transition from a net importer to a significant net exporter of sodium chloride, bromine, and magnesium metal. This would make the Kingdom self-sufficient in these essential materials without relying on large-scale onshore mining operations.

Reverse osmosis equipment inside a saline water desalination plant, Saline Water Conversion Corporation

Local Success Stories

Membrane crystallization system

ENOWA, a leader in NEOM's sustainable energy and water initiatives, is spearheading the Membrane Crystallization System project to revolutionize mineral extraction from desalination brine. This innovative project aims to significantly enhance the economics of mineral extraction from concentrated brine solutions, typically discharged into the sea as a by-product of desalination.

By utilizing a new crystallization process, this project transforms concentrated brine into valuable resources, including salt, lithium, bromine, and others, generating new revenue streams for desalination plants. The patented technology reduces energy consumption dramatically, making mineral extraction economically viable.

The technology employs a specialized membrane crystallizer operating on forward osmosis principles. This allows a wide range of minerals to be extracted from seawater, with selected minerals crystallizing on the membrane's surface due to osmotic pressure differences. The membrane's smooth surface prevents peeling and promotes the formation of easily collectible small crystals. Additionally, an osmotically assisted reverse osmosis system reconcentrates the diluted drawing solution internally, facilitating its reuse for crystallization.

This innovative membrane-based approach leads to significant energy savings compared to conventional thermal evaporation and crystallization processes. ENOWA has achieved remarkable success, reducing energy consumption from 75 kW/m3 to just 7 kW/m3, highlighting the potential of membrane crystallization technologies for mineral extraction. This project underscores broader opportunities for the water sector to contribute to sustainability and the circular economy.

NEOM's Specialized Membrane Crystallization Device [ENOWA]

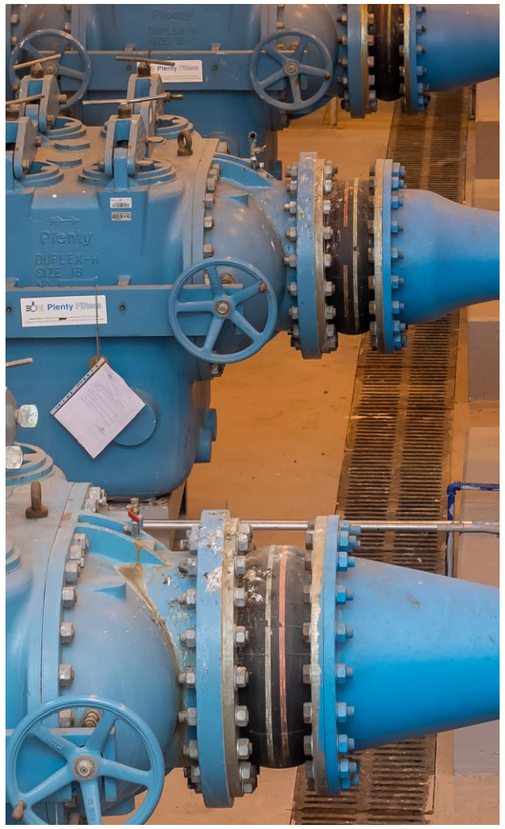
Localization of membrane production at NEOM Energy and Water Company [ENOWA] and development of a selective membrane for brine extraction

Purpose of the Report

The Ministry aims through this work to develop a strategic scope built on the water sector's needs and oriented towards adopting readily available technical solutions to meet those needs. The Ministry seeks for this scope to guide institutional interventions and initiatives to ensure optimal steering of efforts and resources.

The report thereby presents a roadmap for deployment-ready technologies that the Ministry of Environment, Water, and Agriculture plans to adopt, starting from identifying the problems facing the Kingdom in the water sector, moving to the technologies addressing them, and ending with executive programs enabling adoption of these solutions.

The roadmap illustrates the path the Ministry aims to take in adopting technologies, with objectives including confirming the availability of solutions for many of the challenges facing the water sector, and clarifying the Ministry's strategic direction for stakeholders playing vital roles in realizing Saudi Arabia's ambition towards a sustainable water sector. The next section links stakeholders with this report.



Pumps for water distribution, National Water Company

Relevant Parties

The innovative technologies deployment roadmap is the culmination of intensive efforts led by the Ministry of Environment, Water, and Agriculture with support and contributions from all water system stakeholders, including government institutions, the private sector, startups, research centers and universities, and investors.

More than 120 experts and specialists from relevant entities, representing about 30 organizations, contributed to this report. The project team analyzed over 50 survey responses on sectoral technologies, aligned these technologies with more than 10 national strategies, and organized several workshops and meetings to gain a deeper understanding of stakeholders' perspectives.

Various entities can benefit from this report, including:

1. **Government institutions:** These are responsible for providing regulatory and strategic support, enabling an environment for innovation, and ensuring policy and standard alignment with sustainable water growth objectives. While this report provides an overview of technologies expected to be adopted in the Kingdom over the next few years, several governmental entities play a role in facilitating the adoption of these technologies in various aspects, such as enabling technology providers to enter the Kingdom, and ensuring regulatory tools enable implementation of these advanced technologies.

2. **Private sector:** The private sector is a key partner in this endeavor, playing various roles in adopting advanced technologies, including importing mature technologies into the Kingdom, localizing and developing them, and propagating them locally. Additionally, the water private sector is targeted to implement these technologies in its systems and operations. As a major representative of the demand side targeted in this report, it is the driver towards water sector sustainability and increased effectiveness.

3. **Innovative startups**: These small emerging enterprises have sufficient knowledge to comprehend advanced technologies and implement them on the ground. They have the agility to absorb medium-term technology investments with economic impact. They can also access specialized innovation financing tools like venture capital funds. Such enterprises play an essential role in introducing technologies into markets, since innovation is at the core of their sectoral activity, and their intermediary position between scientific and sectoral systems.

4. **Research centers and universities:** They contributing to creating and developing technologies in the water sector. They play various roles, including consulting on applied advanced technologies, adapting these technologies to suit the local environment, and developing them to increase their effectiveness in the future.

5. **Investors:** These include national and private investment funds, angel investors, financial institutions, and more. They play pivotal roles in technology adoption, such as financing and monetary support. They mitigate risks for innovators by enabling them to introduce new products despite high uncertainty. They provide expertise and guidance for innovators using their market experience, facilitate market access through commercial and industrial networks, and lend credibility to innovators with markets by adopting their innovations. They also enable innovators to scale locally and internationally.

Sedimentation tank in wastewater treatment plant, National Water Company

Methodology for Technology Adoption Roadmap

Designing an accurate and adaptable technology deployment roadmap is a complex task for several reasons, including the accelerating pace of technological advancement and market demands. Developing a roadmap for adopting innovative technologies requires anticipating future technology trends and aligning them with long-term national ambitions, which poses a challenge in the fast-changing technology landscape.

Several factors contribute to this complexity. These include the necessity to anticipate emerging technologies and seamlessly integrate them with existing systems. Effective resource allocation, along with the capacity to remain flexible in response to new information or market shifts, adds another layer of complexity. Additionally, ensuring alignment among stakeholders introduces further organizational complexities. Consequently, the technology deployment roadmap must balance future visions and adaptability with the sector's current state, making its design a delicate process.

Overview

The comprehensive approach to developing a technology deployment roadmap consists of three core components: First, assessing the scale and nature of demand for technology solutions through close communication with sectors to understand their challenges and demands. Second, identifying technologies suitably matched to sectors at large, resulting in more than 100 technologies across 20 families for the water sector. Third, agreeing on technology priorities based on two key criteria: impact on challenges, for instance the technology's ability to address sectoral challenges, and ease of adoption of these technologies in the Kingdom. Adoptability is critical, since a key goal of the technologies is to address the most pressing challenges. Therefore, how quickly a technology could be deployed was an important factor in prioritizing technology adoption, resulting in waves for adoption. The following subsections focus on these three components.

Demand Side for Technologies

Demand for technology solutions in the water sector is driven by several factors, including the challenges for this sector, most notably water scarcity, the need to preserve non-renewable groundwater, and ensuring water security. Additionally, opportunities like wastewater recycling for non-domestic use and providing fresh water drive this demand. Despite these opportunities, challenges like water network leakage persist. The sector has witnessed the introduction of several regulations in recent years aimed at organizing it, and it needs innovative solutions in the coming years to align it with national ambitions.

Therefore, it was necessary for the technology adoption roadmap to be based on these national challenges and urgent needs (demand side) as well as the opportunities available at the same time (supply side). To that end, extensive efforts were undertaken, in close cooperation with the sectors, to identify and characterize the most important challenges. Existing aligned national strategies tailored to local requirements as well as sectors' ongoing efforts greatly facilitated the work.

To reach the scale and nature of demand for technical solutions, the report began by characterizing the sectors and dividing them into several lists according to their value chain. In the water sector, these value chain steps were: Production, transportation, distribution, water treatment and reuse, and water consumption. The report then precisely determined the challenges for each list, assessing the potential of technical solutions for each. Finally, the report connected the challenges with the corresponding technologies, concluding in the creation of maps that represent the demand for technical solutions.

Wastewater Treatment Plant, Ministry of Environment, Water and Agriculture

Supply Side for Technologies

Efforts to find technical solutions for the water sector have been ongoing for decades, and these solutions vary according to regional needs and national orientations. Many attempts have been made to align available water technologies with these needs. Since there are a large number of available water technologies and some may not be suitable in all cases for national needs, it was necessary to develop an approach that enables classifying readily available technologies and matching them with sectoral needs in the Kingdom, to identify priority technologies, and then design strategic initiatives to enable their adoption.

To facilitate classifying these technologies, the approach used identified an extensive list of water technologies, then categorized them into families of technology families, with each family addressing similar problems. For example, all technologies that provide solutions in distribution and transportation are clustered in one group, even if they differ in their technical fields, such as advanced materials, digital applications, biotechnology, or others. More than 100

technologies in the water sector were reviewed by specialized experts, who contributed to classifying them into 20 technology families, before these technologies were evaluated according to the urgency and priorities of the challenges they address and the ease of their adoption.

When determining technology priorities and waves — which is necessary to ensure that the most relevant technologies are adopted for the most pressing challenges — demand and supply for each technology were considered. During this process, technologies that are easier to adopt were prioritized, particularly those with the potential for growth and expansion within the Kingdom. Thus, this report assessed the enablers associated with these technologies based on available facts and information, with the results reviewed by experts and stakeholders.

Figure No. [3] below shows the technological framework, categorized in 20 families — arranged horizontally by elements of the value chain in the water sector. The framework provides a comprehensive picture of the uses of water technologies in the value chain, and ensures comprehensive coverage of all innovative technologies in the water sector.

Figure 3: Technological framework for the water sector

Supply		Transmission & distribution	Wastewater treatment & reuse	Demand
Desalination & alternative supply technologies	Groundwater & freshwater technologies			
1. Advanced RO	6. Surface water preservation technology	10. Smart sensors	13. Wastewater treatment and reuse	17. Innovative water consumption in homes
2. New desal methods (excl. RO)	7. Groundwater technology	11. Smart materials	14. Recovery technology	18. Innovative water consumption in industry
3. Brine mining	8. Watershed management, monitoring and forecasting	12. Smart leakage management	15. Innovative treatment	19. Innovative irrigation
4. Renewable desalination	9. Water purification		16. Innovative water testing	
5. Alternative supply				
20. Smart water control systems				

Source: Technological Foresight Center at King Abdulaziz City for Science and Technology

Technology Assessment

In the technology assessment stage, it was important to first determine the criteria for evaluation. After studying several technology evaluation methods and applying them to current national requirements, it was clear that the two most important criteria to achieve the desired purpose were expected impact of technology deployment, and ease of adoption in the Kingdom. The impact of technologies is measured through indicators like contribution to achieving sector strategy targets, potential to address local and global challenges, and potential role in the Saudi market (for instance, increasing productivity or competitiveness). Ease of implementation is measured through indicators like the ability to adopt these technologies in the Kingdom based on current infrastructure, availability of supply chains, presence of supporting regulations, potential for localization through human capabilities, awareness of the technologies' functions and benefits, and capacity to absorb the technology.

A comprehensive assessment of the identified techniques was carried out and focused on the expected impact and ease of implementation of those techniques. The impact criteria measure the role that the identified technology will play in the sector strategy, addressing challenges and meeting market demands, while the ease of implementation criteria examine the time required for the technology to enter the market, barriers to its entry and localization possibilities as shown in Figure No. (4) below.

Figure 4: Evaluation of technology families

Impact potential		Ease of implementation	
Assessment at technology family level		Assessment at technology level, aggregation at technology family level	
Strategic fit to KSA	• Alignment with sector strategies (objectives.programs. initiatives) and priorities • Contribution to solve sector challenges	**Time to market**	Assessment of total time to market for technologies
Global challenges	Contribution to solve global pressing challenges	**Entry barriers**	Assessment of technology -related entry barriers: • Existing Infrastructure and Supply Chain • Regulatory • Deployment complexity
KSA market demand	Potential contribution to KSA market: • Revenue increase • Cost reduction • Productivity improvement	**KSA localization potential**	Assessment of localization potential: • Adaptability • Existing capabilities • Awareness

Based on these two criteria, all technology families were evaluated by experts across the aforementioned metrics, and these assessments underwent several analyzes, subsequently categorizing the technologies into four families according to impact level (high or medium) and ease of adoption (easy to implement or implementable) — starting with the high impact, easy to implement group, while the other families would follow after addressing factors affecting their evaluation.

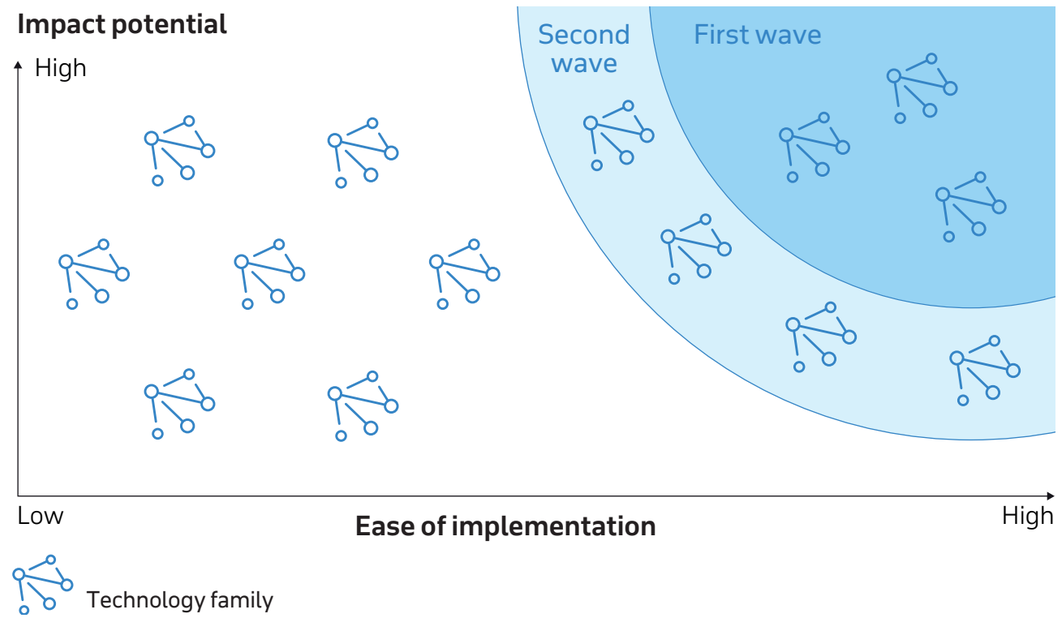
After developing a preliminary list of high priority technologies for adoption, this list was extensively reviewed and validated by specialists and stakeholders to ensure evaluation accuracy and alignment with sector expectations — scientific experts evaluated the technical considerations, and stakeholders looked at regulatory and industry perspectives.

This stage utilized several review methods according to the metrics and reviewers, including individual meetings, specialized surveys, and workshops where multiple parties could come together for discussion.

It is worth mentioning that all these methods compiled reports from workshops, minutes of meetings, and survey data for the purpose of utilizing them in future projects or when re-evaluating technologies in the future if necessary.

Figure No. (5) shows the positioning of technology families and their deployment based on impact potential and ease of implementation criteria. The focus will be on the adoption of the technology families included in the first wave, and then on the second wave of adoption.

Figure 5: Evaluation of technology families



Priority Technologies

The technology waves were defined based on the methodology mentioned in the previous section, with the first wave comprising five technologies targeted for adoption in 2024 and 2025. The second wave also consisted of five technologies targeted for adoption starting 2025. The broader third wave between 2026 and 2030 will be considered based on readiness for adoption.

This report provides details on the first wave of technologies planned for adoption in 2024 and 2025, discussing the demand side (the challenges these technologies help address), the supply side (the capabilities the Kingdom has in these technologies), major challenges they may face during adoption, and finally the means to adopting them. The first wave included the following technology groups:

Advanced reverse osmosis systems

Smart leakage management

Wastewater treatment and reuse

Innovative irrigation

Innovative water consumption in homes

Advanced reverse osmosis systems

Overview

Advanced reverse osmosis (RO) systems enhance the performance of desalination plants by utilizing thin, semi-permeable membranes with narrow pores to filter pure water while capturing larger particles like dissolved salts and impurities such as bacteria. This technology is considered cutting-edge in water desalination. Reducing the cost of seawater desalination is crucial because it serves as a vital source for meeting residential, industrial, and potentially agricultural water needs. These advanced technologies fall into two categories:

Desalination system technologies: These include membrane materials, energy recovery devices, and broader equipment improvements such as pumps and valves. They focus on optimizing reverse osmosis system settings, enhancing efficiency, and reducing pollution.

Plant balance technologies: This category encompasses pre-treatment, post-processing, inputs, and outputs, aiming to optimize overall plant performance and output quality.

Demand drivers

Reverse osmosis (RO) is the primary technology utilized in the Kingdom due to its superior performance compared to alternatives like cogeneration plants. The Kingdom has significantly contributed to reducing RO costs over the past two decades and aims to further reduce production stage costs.

The global demand for advanced reverse osmosis technology is expected to rise, with the market value projected to increase from $2.5 billion in 2019 to $9.2 billion by 2032.[3]

This growth is driven by the increasing adoption of energy-efficient RO plants over thermal methods.

Supply drivers

The use of advanced reverse osmosis technologies is widespread in the Kingdom, with high levels of adoption. The Institute for Water Technology Innovation and Advanced Research (WTIIRA) is a leading research institute in the Kingdom, and works to enhance RO performance,[4] achieving a record-low energy consumption of 2.27 kWh/m3. Saudi Aramco has introduced rapid charging technology and post-treatment for RO membranes, while institutions like King Abdullah University of Science and Technology (KAUST) and King Abdulaziz City for Science and Technology (KACST) are actively involved in RO technology research programs. A number of international companies excel in this regard, including ACCIONA Water, Veolia Water Technologies, ABB, and Siemens.

Barriers to adoption

Policies mandate a minimum 5-year testing period for advanced RO technologies before implementation, necessitating advanced infrastructure and specialized experimental environments. The Ministry has initiated specialized programs, such as demonstrating priority technologies in real environments, and launched initiatives to review, develop, and amend legislative frameworks to address challenges in coordination with regulatory authorities.

3 The Brainy Insights, Reverse Osmosis Membrane Market, 2023

4 United Nations, "Saline Water Conversion Corporation: Decarbonatization in desalination sector in KSA", 2022

Reverse osmosis equipment inside a saline water desalination plant, Saline Water Conversion Corporation

Smart leakage management

Overview

Smart Leakage Management focuses on utilizing advanced technologies and strategies to detect, locate, and mitigate leakages within the transportation and distribution stages of the water value chain. It includes the following components:

Direct leak detection: Techniques involve manual inspection of on-site distribution systems using methods like robotic leak detection, gas trace sensing, and laser technology.

Remote leak detection: Utilizes advanced technologies and data analysis processes, such as sensor networks, water flow sensors, pressure sensors, and SCADA, to identify leaks without direct physical access to the water distribution system.

Leak mitigation techniques: Involves technologies, devices, and systems to detect leaks early, mitigate their impact, and prevent further damage. This includes methods like remote welding, sealing leaks with viscous curing materials, and optical emission spectroscopy (OES).

Demand drivers

Smart leak management techniques maximize water efficiency by reducing wasted water during transportation and distribution. This is crucial for achieving the goals of the National Water Strategy, which aims to reduce wasted water by 15% and ensure 100% continuity of water supply. Additionally, these techniques can increase the potential amount of water consumed and billed.

The global smart leak management technologies market is expected to grow from $10.1 billion in 2023 to $14.4 billion in 2026.[5]

This growth is driven by increasing water scarcity, rising levels of water pollution, and technological advances in the Internet of Things and data analysis sectors.

Supply drivers

There is a significant research and development effort in the field of smart leak management technologies, with KAUST working to develop a system that uses sound, pressure sensors, ERP system analysis, and 3D GIS mapping to detect leaks. Researchers from the Massachusetts Institute of Technology (MIT) also collaborated with King Fahd University of Petroleum and Minerals (KFUPM) to develop an automated system for detecting leaks in pipes. In addition, the Saline Water Conversion Corporation is implementing pilot projects for pipe leak detection systems and distributed fiber optic sensing technologies.

A number of international companies excel in these technologies, such as Echologics, Grundfos, Aqualeak, Xylem, and Sensus.

Barriers to adoption

Implementing smart leak management techniques faces challenges due to the Kingdom's geographical expansion and the complexity of transportation network designs. To address this, the Ministry has launched a program to demonstrate technologies in real environments, working closely with agencies like the National Water Company to facilitate widespread adoption.

5 Global Water Intelligence, "Digital Water", 2022

Command and Control Center, National Water Company

Wastewater treatment and reuse

Overview

Wastewater treatment and reuse comprise two technology families aimed at treating and recycling wastewater for additional purposes. Given water scarcity, wastewater reuse is vital for the Kingdom, necessitating the use of appropriate technologies. These include:

Innovative processing: Utilizes advanced processes and technologies for wastewater treatment, including suspended solids removal, biological treatment, disinfection, and absorption and adsorption.

Adaptive technologies for wastewater reuse: Encompasses technologies that repurpose wastewater for beneficial purposes rather than discharging it into the environment. Examples include water recycling systems, filtration systems, and gray water recycling systems.

Demand drivers

Saudi Arabia aims to treat 100%[6] of collected wastewater, with expected advancements in wastewater treatment and reuse technologies poised to facilitate this goal. By 2030, these technologies aim to increase the reuse rate of treated wastewater from 17% to 70% by 2030[7] and expand sanitation service coverage from 60% to 75%.

The global market for wastewater treatment and reuse technologies is expected to grow from $178.7 billion in 2023 to $236.2 billion by 2028. The Middle East and Africa regions are growing at the highest rates,[8] at 9.3% and 8.3% compound annual growth rate respectively. This is due to increased investment in sanitation infrastructure.

Supply drivers

Wastewater treatment is a key priority in the Kingdom, with a notable trend towards increased application of tertiary treatment methods. Significant efforts are underway to research and develop wastewater treatment and reuse technologies. KAUST conducts research in wastewater reuse and sustainable water technologies in industry, agriculture, and aquaculture, and has established a globally recognized research and development facility for wastewater treatment. KACST also has important research programs on water treatment technologies. Finally, the private sector, including entities such as Water Solutions and Saudi Binladin Group, is already developing commercial solutions.

A few international companies are distinguished in this field, such as Netafim, Hydrosol Inc., Veolia, SUEZ, and Watergen.

Barriers to adoption

The utilization of treated wastewater falls short of achieving strategic objectives due to regulatory challenges, particularly concerning the use of gray water. The Ministry has initiated efforts to review and amend legislative frameworks to address these challenges and stimulate demand. Awareness programs have also been launched to highlight the importance and effectiveness of wastewater treatment technologies, aiming to promote the feasibility of utilizing treated water for non-domestic purposes alongside current freshwater sources.

6 Ministry of Environment, Water and Agriculture, "National Water Strategy", 2018

7 Ministry of Environment, Water and Agriculture, "National Water Strategy", 2018

8 Global Water Intelligence, "Market Insight" 2022

The wastewater treatment and reuse unit is a decentralized unit installed in Rabigh, invented at KAUST

Innovative irrigation

Overview

Innovative irrigation techniques encompass a range of systems designed to optimizing water usage and increase efficiency in managing water resources. These techniques allow for the efficient allocation of irrigation water tailored to specific plant needs and land characteristics, without compromising plant growth. These technologies include:

Linear irrigation: A mechanical irrigation system that distributes water to crops in a straight-line using sprinkler mechanisms.

Center pivot irrigation: A mechanical irrigation system for watering large fields or crops in a circular pattern using a sprinkler system. Particularly suitable for flat lands.

Micro/drip irrigation: Delivers water directly to the roots of plants in small quantities that can be controlled using a network of pipes, releasing water in the form of drops or a slow, steady flow.

Smart irrigation: Systems that include sensors, weather data, and internet connectivity to monitor and adjust irrigation schedules based on prevailing conditions at the time of actual irrigation.

Demand drivers

Saudi Arabia ranks eighth in the world on the water scarcity index, with 80% of agricultural water sourced from non-renewable groundwater. adopting modern irrigation techniques becomes imperative to achieve long-term sustainability. Innovative irrigation methods lead to increased vegetation growth with a significant reduction in water use, compared to a traditional open irrigation system. For example, partial irrigation techniques can reduce water consumption by 10% to 15%.[9]

Globally, the demand for micro-irrigation/ drip irrigation systems is surging, with market projections indicating a fourfold increase from $15 billion in 2022 to $64 billion by 2032.[10]

Supply drivers

Institutions such as KAUST and Taibah University, along with private companies such as Almarai, are involved in significant research and development activities in the field of innovative irrigation technologies. The Kingdom also benefits from advanced technologies, with increased adoption of systems like partial irrigation/drip irrigation.[11]

Barriers to adoption

The challenges in adopting innovative irrigation technologies can be narrowed down to several points: Limited farmer awareness: Farmers may lack awareness of the effectiveness of these technologies in enhancing productivity and reducing groundwater consumption. To address this, the General Organization for Irrigation has initiated a specialized awareness campaign. Additionally, the Ministry plans to launch an initiative aimed at improving cooperation and enhancing awareness in technology fields. Cost considerations: The cost of these techniques is estimated to be around $1,000 per hectare.[12] This expense can be a barrier for some farmers, especially when compared to accessing cheaper non-renewable groundwater. Competition with traditional methods: There is competition for these technologies, which may be perceived as expensive by some farmers compared to utilizing less expensive non-renewable groundwater. Weakness in local industry: The local industry for irrigation lines and pipes may not adequately meet national needs. To address this, an initiative will be launched to build research, development, and innovation capabilities in the water sector. This aims to ensure a sufficient and continuous local supply of innovative solutions.

Using drip irrigation technology to grow lettuce

9 EPA Water Sense, "Saving Water with Micro irrigation", 2023

10 Morgan Stanley, "Sustainability Report", 2022

11 Ghanim, Abdulnoor, "Water Resources Crisis in Saudi Arabia Challenges and Possible Management Options an Analytic Review", 2019

12 Feed the Future, "Drip Irrigation in Smallholder Markets: A cross-partnership study", 2016

Innovative water consumption in homes

Overview

Innovative water consumption in homes focuses on adopting advanced practices and technologies to rationalize water use. This is necessary within a context in which per capita urban consumption in the Kingdom remains high, and results in an increased need for water infrastructure along the value chain (including desalination, transportation, strategic storage and distribution). Innovative water consumption technologies can generally be classified into two main technologies: Automated control and management systems, and efficient gardening techniques. Automated control and management systems provide processes and technologies to enhance the effectiveness and efficiency of water use in homes (such as faucet accessories that include a screen to display the amount of water flowing, smart toilet accessories that rely on low water flow, smart control of water used outdoors, smart toilets, and detection systems Leakage and monitoring, and high-water efficiency home appliances). Efficient gardening techniques enable water-efficient landscaping practices in home environments (such as water-retaining soils, dry gardens, rainwater harvesting, micro-irrigation, drip systems, and greywater recycling systems).

Demand drivers

Currently, per capita water consumption in urban areas exceeds liters per day 275.[13] The National Water Strategy aims to reduce this to 150 liters per day per capita by 2030, necessitating increased awareness of water-saving technologies and local water conservation efforts, alongside initiatives to improve irrigation efficiency.

The global market value for residential water consumption technologies is expected to grow from $2.5 billion in 2024 to $3.8 billion by 2028.[14] This growth is driven by the adoption of sustainable water usage practices worldwide.

Supply drivers

While innovative technologies for household water consumption are gradually gaining traction in the Kingdom, there are many research, development, and innovation initiatives in this field. Activities include gray water reuse research at King Saud University, research on dry gardens by King Faisal University, and research by KAUST on water sensing for irrigation purposes. In addition, KAUST has successfully implemented dry garden technology on both campuses and residential communities, which has contributed to reducing its irrigation water consumption by 50%. There is also active participation from private companies such as Elm, which provides homes with water leak detection services through the Kashf application. A number of international companies excel in the field of innovative technologies for water consumption in homes, including Greenwater, Moen Smart Home, and Netafim.

Barriers to adoption

The main barriers to the use of innovative water consumption technologies in homes are infrastructure and awareness. Although initiatives like Qatra have helped in raising awareness, additional efforts are still required to educate the populace about current techniques for managing water consumption at home. The Ministry, in collaboration with its partners in the water system, is actively working to enhance the demand for these technologies. This includes initiatives such as reviewing and amending regulatory frameworks to address barriers that impede demand and proposing mechanisms and policies to stimulate interest in innovative technologies.

13 Ministry of Environment, Water and Agriculture, 2021

14 Fortune Business Insights, "Smart water meter", 2020

Xeriscaping at KAUST, KAUST Campus

Wider technologies

In addition to the five priority technology families in the first implementation wave, there are 15 other technology families that have the potential to address sector challenges in Saudi Arabia. These technologies are supported by a combination of targeted initiatives designed specifically for their adoption and more comprehensive systemic approaches.

The next section provides an overview of the implementation plan, covering all technologies suitable for the water sector, in addition to the specific initiatives described above for the five technology families in the first wave.

Ministry's Executive Plan for Adopting and Disseminating Technologies

The Ministry of Environment, Water, and Agriculture conducted a review and analysis of existing efforts in the water sector to achieve the sector's ambitious future aspirations under Saudi Vision 2030. The analysis covered: Priorities, aspirations, and the National Water Strategy, in addition to the National Research, Development, and Innovation Agenda, the current state of technology adoption and innovation activities in the water sector, and the state of technology adoption and innovation enablers such as available infrastructure, human capabilities working in the water innovation ecosystem, and policies and regulations supporting technology adoption and innovation in the sector.

Based on this, current challenges and gaps were identified. Drawing on best practices in sectoral and national innovation policymaking, the scope of priority institutional measures to promote technology adoption and innovation in the sector was defined to achieve four main goals:

Directing and coordinating plans, efforts and resources allocated to adopting technology and innovation in the water sector. The focus is on addressing pressing sectoral challenges, in line with national research, development, and innovation priorities and relevant national strategies.

Improving connection and cooperation between stakeholders active in adopting technology and innovation in the water sector to enhance partnerships and synergies within the sector and share knowledge. The goal is also to raise awareness of the water ecosystem's efforts and successes in embedding technology and innovation in their plans and operations to create positive momentum and ensure the sustainability of these efforts.

Stimulating demand for technology products and innovative solutions adoption in the water sector and improving demand responsiveness to available technology supply through deliberate measures and targeted incentives.

Building research, development, and innovation capacities in the water sector to ensure sufficient and continuous local supply of technology products and innovative solutions.

Therefore, the Ministry will implement four institutional initiatives encompassing several carefully designed sub-programs:

Initiative to Technology Adoption and Innovation Steering and Coordination Initiative in the Water Sector, which aims to

- Establish a transparent and effective governance framework defining the roles and mechanisms required to identify priority innovative solutions aligned with national and sectoral priorities, and engage stakeholders in the ecosystem through aligning objectives and enabling effective information exchange and collaboration to sustain technology adoption and innovation activities in the sectors.
- Develop a mechanism to direct funding from various entities towards technology adoption and innovation activities in the environment, water and agriculture sectors undertaken by public and private entities in the ecosystem, in a performance-based manner considering alignment with priority innovative solutions for the environment, water, and agriculture sectors, and balancing institutional and project financing.
- Develop and activate tools to measure and monitor the performance of the environment ecosystem in technology adoption and innovation, and provide evidence-based visions and recommendations on the current state of technology adoption and innovation activities in the sector to support decision-making processes.
- Develop an institutional technology foresight program to provide regular insights on potential technologies and innovative solutions that might be suitable to address challenges and leverage opportunities in the water sector, and support planning processes and institutional policy proposals.
- Collaborate with the Research, Development, and Innovation Authority to prepare detailed implementation plans for national research, development and innovation tasks relevant to the water sector.

Initiative to Improve Collaboration and Raise Awareness on Technology, Innovation, and Entrepreneurship in the Water Sector, which aims to

- Develop a framework for initiating and managing technology adoption and innovation partnerships in the water sector with various potential partners including government, private, research and innovation entities locally and internationally, enhancing the efficiency of such partnerships and achieving their intended goals.
- Develop a digital platform containing information on available support programs, ongoing research projects, advisory services, Research, Development and Innovation (RDI) outputs and technology adoption, learning opportunities, news, events, and success stories, to support communication and connection in the ecosystem.
- Plan and launch competitions and awards for technology adoption and innovation, in collaboration with relevant entities, to promote a culture of research, development, innovation, and technology adoption, and disseminate success stories in the sector for inspiration.
- Raise awareness on the efforts of the environment, water, and agriculture ecosystem in technology adoption and innovation by publishing periodic reports on prominent platforms about the water innovation ecosystem's key achievements and aspirations.
- Organize events and exhibitions to provide a platform for local and international R&D entities and technology providers to showcase their products to potential investors and buyers, facilitating partnerships and encouraging innovation and uptake of the latest technologies in the water sector.

Initiative to Stimulate Demand for Innovative Products and Solutions in the Water Sector, which aims to

- Review and develop legislative environments to address existing barriers constraining demand for water RDI technologies and solutions, through coordination with regulators.
- Validate priority water technologies and innovations by testing them in real environments for adaptation and deployment suitable for widescale local rollout.
- Propose mechanisms and policies to incentivize demand for priority water RDI technologies and solutions.
- Increase technology absorptive capacity of end-users in the water sector to improve adoption of innovative products and solutions and boost market demand.

Initiative to Build Environment Research, Development, and Innovation Capabilities to Ensure Sufficient Local Supply of Innovative Solutions, which aims to

- Strengthen the entrepreneurship ecosystem in the water sector, including developing mechanisms to attract financing and investment towards emerging sector companies, establishing entrepreneur communities, addressing information barriers and regulatory challenges faced by entrepreneurs, and tracking emerging company and market performance in the sector.
- Facilitate the establishment of dedicated water entrepreneurship spaces and entrepreneurship support programs encompassing incubators, accelerators, startup studios, co-working spaces and technical assistance clinics, in collaboration with relevant stakeholders at national and sector levels.
- Establish intermediary innovation organizations to bridge the gap between the water sector and research/academia, such as technology development centers, technology valleys, technology transfer offices, etc.
- Develop institutional policies and frameworks for technology management and intellectual property protection in the water sector, and collaborate with the Saudi Authority for Intellectual Property to develop relevant national IP policies pertaining to the sector.
- Collaborate with relevant stakeholders in the education and skills development ecosystem to launch tailored programs focused on developing capabilities that contribute to technology adoption and innovation in the water sector, and develop institutional programs to build specialized skills of Ministry of Environment, Water, and Agriculture employees through tailored training programs.

Conclusion

Technologies play a critical role in addressing challenges faced by the water sector, including the pressing need to increase productivity, preserve natural resources, adapt to harsh environmental conditions and water scarcity, and transform the challenges represented by wastewater into opportunities by recycling and using it. Innovative technologies enable finding sustainable solutions to these problems, as well as create numerous opportunities to increase the water sector's contribution to economic output, achieve environmental sustainability, and reach national goals.

This report sought to demonstrate the role of technology adoption and innovation in solving challenges in the Kingdom's water sector, citing international and local examples of water innovation where technologies played a decisive role in providing solutions. Its key objective was to map the challenges faced by the Kingdom in the environment, water, and agriculture sectors to readily available technology solutions, and outline the Ministry's implementation plan to adopt and deploy these technologies in the short and medium term.

The report followed an objective methodology to produce a list of technologies with high readiness that provide solutions for the water sector, starting by identifying the challenges faced by this sector in the Kingdom, dividing the sector into four families: production, distribution and transportation, recycling and use of wastewater, and water use. It then looked at available technologies and categorized them into technology families according to these sector families before prioritizing them based on the impact of these technologies and the ease of their adoption and deployment. This resulted in three technology waves that the Ministry intends to adopt in the coming years.

Given the complexity of the environment, water, and agriculture ecosystem, and the multitude of stakeholders in the water sector, the report considered the national and sectoral strategies of the environment and national innovation ecosystems. It also incorporated the perspectives of the Ministry's sector representatives, through a series of meetings and workshops with more than 30 entities, taking into account the views of over 120 experts and specialists at all preparation stages.

In publishing this report, the Ministry of Environment, Water, and Agriculture has several objectives. Firstly, it aims to demonstrate its strategic direction towards adopting technologies that address sectoral challenges. It also seeks to explain its implementation plan to deploy these technologies. The report defines its four key objectives in this regard: Steering and coordinating plans, efforts, and resources allocated to technology adoption and innovation in the water sector within a focused strategic scope. This scope targets the resolution of sectoral challenges. The next goal is improving connectivity and cooperation between players in the water research, development, and innovation ecosystem. This cooperation aims to build positive momentum in the sector, ensuring the sustainability of efforts. The third objective is stimulating demand for adopting innovative products and solutions in the water sector. This includes improving the sector's responsiveness to available supply through targeted interventions and incentives. The final aim is building water research and innovation capabilities to ensure sufficient and continuous supply of innovative products and solutions.

The Ministry firmly believes in the importance of collaborative work and its necessity to achieve national targets and invites all its partners across water sector stakeholders to contribute to the implementation of this plan. The Ministry aspires for this report to be an enabler in adopting innovative solutions that help overcome challenges faced by ecosystem players and make possible the realization of ambitions and national targets for the environment, water, and agriculture sectors.

Finally, the Ministry of Environment, Water, and Agriculture expresses its sincere gratitude to all who contributed to this report, including its ecosystem partners, the team of experts who offered their invaluable expertise, and the dedicated efforts of the Research and Innovation Deputyship team in developing and editing this report.

Appendix

Localization and definition of technologies

	English Technology Group	English Description	English Technology Examples
1	Advanced RO	Technologies involved in the membrane-based desalination process, including advanced pre-treatment and energy recovery	Desalination systems Balance of plant
2	New desalination methods (excluding RO)	Innovative methods to convert saline water to freshwater, including solvent extraction, electrodialysis, forward osmosis, membrane distillation, hybrid methods and osmotically assisted reverse osmosis	Solvent extraction Electrodialysis Forward osmosis Membrane distillation Hybrid methods Osmotically assisted reverse osmosis Bioengineering
3	Brine mining	Processes involved in the valorization of brine, including brine evaporation, advanced zero-liquid discharge, and valuable products extraction	Evaporation of brine Advanced ZLD Valuable products extraction
4	Renewable desalination	Technologies involved in renewable desalination, including salinity gradients, wind energy, solar collector techniques, direct solar and PV-powered desalination, and energy storage	Salinity gradients Wind energy Solar collector techniques Direct solar desalination PV powered desalination Energy storage and CO2 capturing
5	Alternative supply	Unconventional methods of obtaining water resources beyond traditional sources, including cloud seeding, air to water technologies and rain/ stormwater harvesting	Cloud seeding Air to water technologies Rain/stormwater harvesting
6	Surface water preservation technology	Technologies to improve preservation of surface water, including dam and infrastructure engineering	Dams and Infrastructure Engineering
7	Groundwater technology	Technologies used to manage and utilize groundwater resources effectively. Including artificial groundwater recharge technologies	Artificial Groundwater Recharge Technologies Point Source Pollution Control Flooding and Drought Modelling

	Arabic Technology Group	Arabic Description	Arabic Technology Examples
1	أنظمة التناضح العكسي المتقدمة	التقنيات المستخدمة في عملية تحلية المياه بالأغشية، بما في ذلك المعالجة المسبقة المتقدمة واستعادة الطاقة	أنظمة تحلية المياه بقية محطة التحلية
2	تحلية المياه بطرق جديدة (باستثناء التناضح العكسي)	طرق مبتكرة لتحويل المياه المالحة إلى مياه عذبة، بما في ذلك استخراج المذيبات، والفصل الكهربائي للأيونات، والتناضح المباشر، والتقطير الغشائي، والطرق الهجينة، والتناضح العكسي المعزز بالتناضح.	الاستخلاص بالمذيبات الفصل الكهربائي للأيونات التناضح المباشر التقطير الغشائي الأساليب الهجينة التناضح العكسي المعزز بالتناضح الهندسة الحيوية
3	تعدين المياه المالحة	عمليات الاستفادة من المحلول الملحي، ومن بينها تبخير المحلول الملحي، و رجيع ملحي صفري، واستخلاص النواتج ذات القيمة	تبخير المحلول الملحي تصريف صفري متقدم للسوائل استخلاص النواتج ذات القيمة
4	تحلية مياه البحر باستخدام الطاقة المتجدّدة	التقنيات المستخدمة في تحلية المياه بالطاقة المتجددة، من بينها تدرجات الملوحة، وطاقة الرياح، وتقنيات تجميع الطاقة الشمسية الحرارية، وتحلية المياه المباشرة بالطاقة الشمسية والكهروضوئية، وتخزين الطاقة.	تدرجات الملوحة طاقة الرياح تقنيات الطاقة الشمسية تحلية المياه بالطاقة الشمسية الحرارية المباشرة تحلية المياه بالطاقة الكهروضوئية تخزين الطاقة واحتجاز ثاني أكسيد الكربون
5	الامدادات البديلة	طرق غير تقليدية للحصول على موارد مائية تتجاوز المصادر التقليدية، بما في ذلك تلقيح السحب وتقنيات الماء من الهواء وتجميع مياه الأمطار	استمطار السحب تقنيات الماء من الهواء تجميع مياه الأمطار/ مياه تصريف العواصف
6	تقنية الحفاظ على المياه السطحية	تقنيات لتحسين الحفاظ على المياه السطحية، بما في ذلك هندسة السدود والبنية التحتية	هندسة السدود والبنية التحتية
7	تقنية المياه الجوفية	التقنيات المستخدمة لإدارة واستخدام موارد المياه الجوفية بشكل فعال. بما في ذلك تقنيات إعادة تغذية المياه الجوفية الاصطناعية	تقنيات إعادة تغذية وتعبئة المياه الجوفية الاصطناعية التحكم في التلوث من المصدر نمذجة الفيضانات والجفاف

	English Technology Group	English Description	English Technology Examples
8	Watershed management, monitoring, and forecasting	Technologies to manage, monitor and forecast watershed, including sedimentation management	Sedimentation Management Real-time Watershed Monitoring Leak Mitigation Technology Watershed Modelling (simulation and analysis of water movement)
9	Water purification	Technologies to remove contaminants and impurities from water supply to make it safe for consumption and other uses	Organic Matter Removal Filtration Technology Renewable Energy Purification UV and Ozone Disinfection Aeration and Air Stripping Technologies
10	Smart sensors	Advanced sensing devices, and technologies used to monitor and collect real-time data on various parameters in water distribution systems	Network-Level Sensors Plant-Level Sensors
11	Smart materials	Specialized coatings and pipeline materials to enhance performance, durability, and safety of water distribution pipelines	Specialized Coatings Specialized Pipeline Materials
12	Smart leakage management	Advanced technologies and strategies to detect, locate, and mitigate leaks in water distribution systems	Direct Leak Detection Remote Leak Detection Leak Mitigation Technology
13	wastewater treatment and reuse	Technologies utilizing wastewater for beneficial purposes instead of discharging it into the environment	Agriculture and aquaculture/ animal husbandry reuse technologies Industrial reuse technologies Municipal reuse technologies (e.g. greywater or irrigation)
14	Recovery technology	Innovative processes and methods that extract valuable resources or generate energy from wastewater	Energy Generation Nutrient Recovery Precious Metal Recovery
15	Innovative treatment	Use of advanced processes and technologies to treat water and wastewater	Suspended Solid Removal Biological Treatment Disinfection Advanced Treatments

	Arabic Technology Group	Arabic Description	Arabic Technology Examples
8	إدارة تجمعات المياه ورصدها والتنبؤ بها	تقنيات إدارة ورصد وتوقع تجمعات المياه، بما في ذلك إدارة الترسيب	إدارة الترسيب مراقبة تجمعات المياه لحظياً تقنية السيطرة على التسرب نمذجة تجمعات المياه (محاكاة حركة المياه وتحليلها
9	تنقية المياه	تقنيات لإزالة الملوثات والشوائب من إمدادات المياه لجعلها آمنة للاستهلاك والاستخدامات الأخرى	إزالة المواد العضوية تقنية الترشيح التنقية بالطاقة المتجددة التطهير بالأشعة فوق البنفسجية والأوزون تقنيات التهوية والتنقية بالهواء
10	أجهزة الاستشعار الذكية	أجهزة الاستشعار المتقدمة والتقنيات المستخدمة لرصد وجمع البيانات لحظياً حول مختلف قياسات أنظمة توزيع المياه	أجهزة استشعار للمياه على مستوى شبكة الري أجهزة استشعار للمياه على مستوى النبات
11	المواد الذكية	الطلاءات المتخصصة ومواد خطوط الأنابيب لتعزيز الأداء والمتانة وسلامة خطوط أنابيب توزيع المياه	الطلاءات المتخصصة مواد خطوط الأنابيب المتخصصة
12	إدارة التسرب الذكية	التقنيات والاستراتيجيات المتقدمة للكشف عن التسربات في أنظمة توزيع المياه وتحديد موقعها والتخفيف من حدتها	كشف التسرب المباشر كشف التسرب عن بعد تقنيات الحد من التسرب
13	معالجة مياه الصرف الصحي وإعادة استخدامها	تقنيات تستفيد من مياه الصرف الصحي بدلاً من تصريفها في البيئة	تقنيات إعادة استخدام نفايات الزراعة وتربية الأحياء المائية وتربية الحيوانات تقنيات إعادة الاستخدام الصناعي تقنيات إعادة الاستخدام للصرف الصحي (مثل المياه الرمادية أو الري)
14	تقنية الاسترداد	العمليات والأساليب المبتكرة التي تستخرج موارد ذات قيمة أو تولد الطاقة من مياه الصرف الصحي	توليد الطاقة استعادة المغذيات استعادة المعادن الثمينة
15	المعالجة المبتكرة	استخدام العمليات والتقنيات المتقدمة لمعالجة المياه ومياه الصرف الصحي	إزالة العوالق الصلبة المعالجة البيولوجية التطهير المعالجة المتقدمة

	English Technology Group	English Description	English Technology Examples
16	Innovative water testing	Use of advanced technologies and methods for analyzing water quality	Portable Solutions Physical Chemical Testing
17	Innovative water consumption in homes	Adoption of advanced practices and technologies to optimize water usage in homes	Automated Control and Management Systems Efficient Landscaping Technology
18	Innovative water consumption in industry	Adoption of advanced practices and technologies to optimize water usage in industry	Efficient Cooling Technology Efficient Cleaning Technology
19	Innovative irrigation	Adoption of advanced practices and technologies to optimize water usage in agriculture	Water Retaining Tools Demand Reduction Technology Smart Irrigation
20	Smart water control systems	Optimizes water use through sensors, remote control, and automation for conservation, efficiency, and sustainability	Satellite Imagery for Regulation and Monitoring Water Treatment Sensor Network Water Demand Sensor Network Water Supply Sensor Network Data Analytics Modelling and Integrated Assessment

	Arabic Technology Group	Arabic Description	Arabic Technology Examples
16	الفحص المبتكر للمياه	استخدام التقنيات والأساليب المتقدمة لفحص جودة المياه	تقنيات الفحص المحمولة الاختبارات الفيزيائية الكيميائية
17	الاستهلاك المبتكر للمياه في المنازل	اعتماد ممارسات وتقنيات متقدمة لتحسين استخدام المياه في المنازل	أنظمة التحكم والإدارة الآلية تقنية فعالة لبستنة الحدائق
18	الاستهلاك المبتكر للمياه في الصناعة	تبني الممارسات والتقنيات المتقدمة لتحسين استخدام المياه في الصناعة	تقنية التبريد الفعالة تقنية التنظيف الفعالة
19	الري المبتكر	اعتماد ممارسات وتقنيات متقدمة لتحسين استخدام المياه في الزراعة	أدوات الاحتفاظ بالمياه تقنيات خفض الطلب الري الذكي
20	أنظمة التحكم الذكية في المياه	تحسين استخدام المياه من خلال أجهزة الاستشعار والتحكم عن بعد والأتمتة للحفاظ على البيئة والكفاءة والاستدامة	صور الأقمار الصناعية للتنظيم والرصد شبكة استشعار معالجة المياه شبكة استشعار الطلب على المياه شبكة استشعار إمدادات المياه تحليل البيانات النمذجة والتقييم المتكامل

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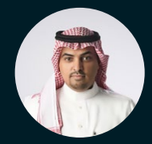

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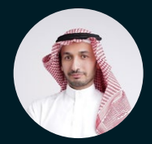

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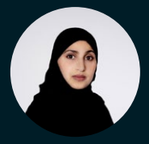

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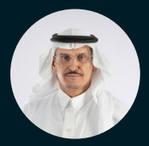

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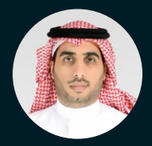

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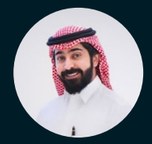

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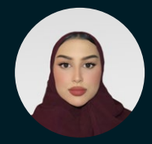

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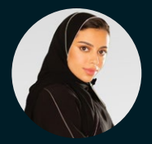

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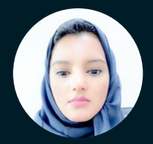

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