

# From Oil to Sun: Mechanical Engineering Solutions for Renewable Desalination in the Kingdom of Saudi Arabia

Faris Sami Alshammari<sup>1</sup>, Harfan Saeed Alahmary<sup>2</sup>, Ali Jaber Suhluli<sup>3</sup>

<sup>1,2,3</sup>Mechanical Engineering Trainers, Technical and Vocational Training Corporation, Riyadh, Saudi Arabia (TVTC) (KSA)

---

## INTRODUCTION

Water scarcity is among the most pressing challenges of the 21st century, and in few places is this challenge as acute as in the Kingdom of Saudi Arabia. With extremely limited freshwater resources, high population growth, and rapid industrialization, the Kingdom has historically relied heavily on desalination to secure water supplies. Saudi Arabia today produces more than 20% of the world's desalinated water, making it the global leader in this field.

However, desalination traditionally depends on fossil fuels, with multi-stage flash (MSF) and reverse osmosis (RO) plants consuming vast amounts of oil and gas. This reliance creates two major challenges: (1) economic strain due to high energy consumption and opportunity costs of burning valuable hydrocarbons for water, and (2) environmental impact through greenhouse gas emissions and marine brine disposal. These factors make the integration of renewable energy sources into desalination not merely an option, but a strategic necessity.

Solar-powered desalination stands out as the most promising solution for Saudi Arabia, which benefits from one of the highest solar irradiance levels in the world, exceeding 2,200 kWh/m<sup>2</sup>/year in many regions. Yet, harnessing this potential is not straightforward. It requires sophisticated thermal system design, advanced materials, careful fluid flow control, and complex energy integration — all domains squarely within the expertise of mechanical engineering. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia's water future.



Mechanical engineering contributes at every stage of the desalination process: the design of solar collectors to maximize thermal capture, the optimization of pumps and turbines for fluid transport, the modeling of heat exchangers and evaporators to achieve efficient phase change, and the application of computational simulations to test designs before costly deployment. The profession provides both the theoretical foundation and the practical innovation needed to realize large-

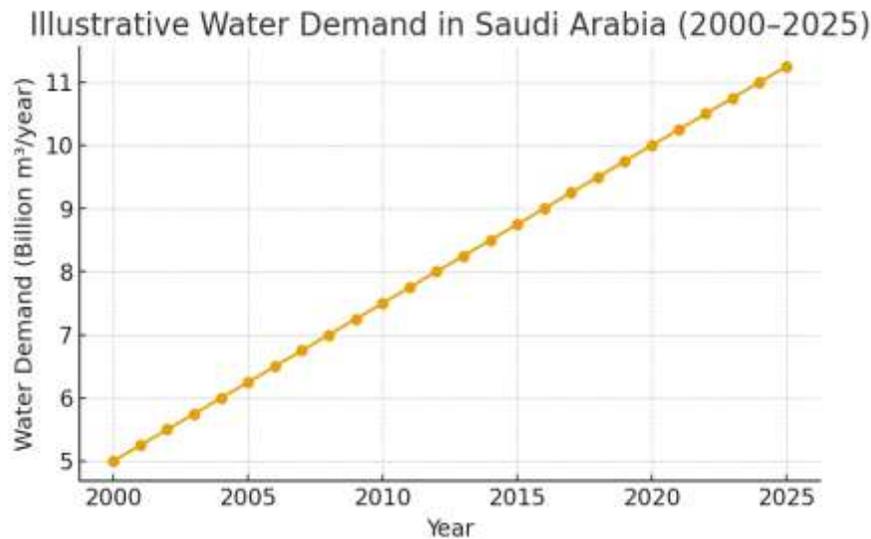
scale, cost-effective solar desalination aligned with Saudi Vision 2030. Beyond setting sustainability as a strategic objective, Vision 2030 explicitly recognizes renewable-powered desalination as a key enabler of national water security.

It prioritizes projects that integrate advanced engineering solutions, highlighting the role of local innovation and technology transfer. By supporting mechanical engineering education, research, and industrial practice with Vision 2030 objectives, Saudi Arabia is positioning itself not only as a consumer of technology but also as a global leader in solar-powered water systems. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

**Water Scarcity and Energy Demands in Saudi Arabia**

Saudi Arabia receives less than 100 mm of rainfall annually in most regions and has no permanent rivers. Groundwater aquifers, once heavily relied upon, are being depleted at unsustainable rates. Consequently, desalination is not a supplementary water source but the primary solution to ensure water security. Municipal, industrial, and agricultural demand continues to rise with population growth, projected to exceed 40 million by 2030.

The reliance on desalination is energy-intensive. Current desalination plants in Saudi Arabia consume more than 25% of the country’s total oil production for domestic use. This creates an unsustainable cycle where precious hydrocarbons are diverted away from export and domestic industrial use, solely to provide water. Thus, the shift toward renewable-powered desalination is not only environmentally critical but also economically strategic.



**Figure 1. Illustrative growth of water demand in Saudi Arabia, highlighting the increasing reliance on desalination. Values are indicative.**

**Principles of Solar-Powered Desalination Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience.**

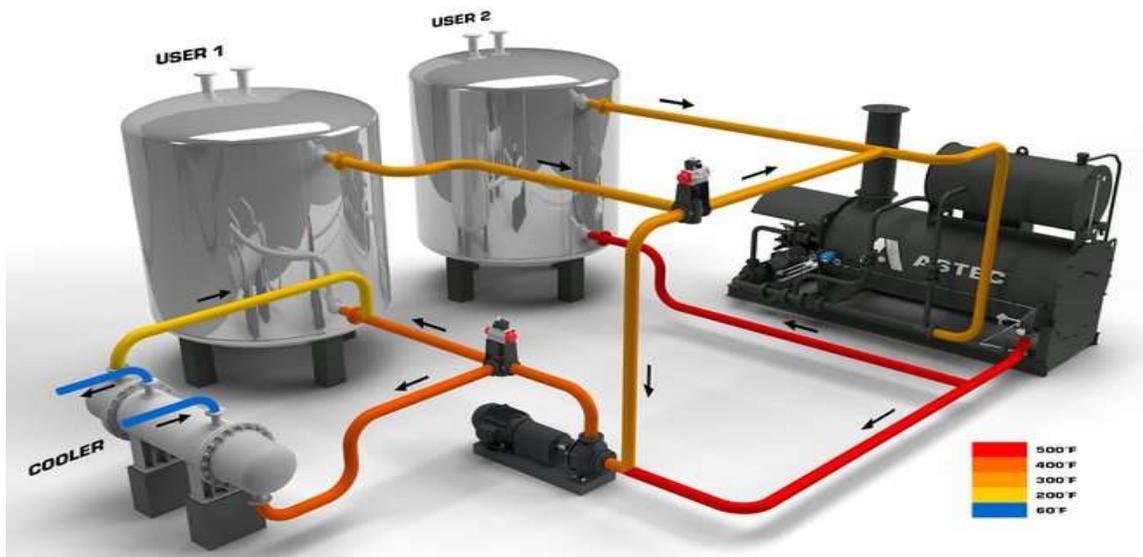
Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

Solar-powered desalination is broadly divided into two categories: solar-thermal systems and photovoltaic-driven systems. Solar-thermal systems capture heat energy from the sun and apply it to phase-change desalination technologies such as multi-effect distillation (MED), multi-stage flash (MSF), or membrane distillation (MD). These systems exploit the principle that salts do not evaporate with water vapor, enabling the production of freshwater through condensation. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

In contrast, photovoltaic-driven desalination converts solar radiation into electricity via PV panels, which then power reverse osmosis (RO) systems. RO relies on applying pressure greater than the osmotic pressure of seawater (typically 55–80 bar) to force freshwater through semi-permeable membranes while leaving salts behind. Mechanical engineering expertise ensures the durability and efficiency of pumps, membranes, and pressure vessels under such demanding conditions. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

Hybrid systems are increasingly relevant, combining solar thermal with PV-driven units to optimize performance and reliability. For instance, solar-thermal can provide low-grade heat for distillation, while PV electricity can power high-pressure RO pumps. This dual approach maximizes the use of available solar energy and minimizes system downtime.

### Mechanical Engineering and Thermal System Design



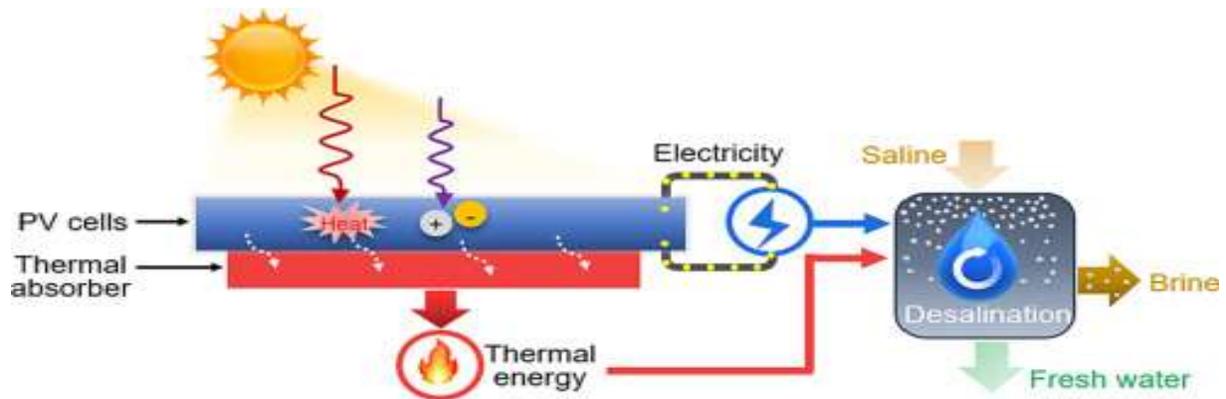
Thermal system design is where mechanical engineering makes its most direct contribution to solar desalination. Solar collectors must be designed to maximize absorption of direct normal irradiance while minimizing reflection and heat loss. Mechanical engineers analyze collector geometries such as flat-plate collectors, evacuated tube collectors, parabolic troughs, and solar towers, each suited for different temperature ranges and efficiencies. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

Heat exchangers are another critical component. Engineers must optimize surface area, flow configuration, and material selection to ensure efficient transfer of heat from solar collectors to the desalination brine. Common designs include shell-and-tube, plate, and spiral heat exchangers, each with advantages in maintenance, fouling resistance, and scalability. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

Evaporators and condensers, central to phase-change desalination, are designed to achieve maximum heat recovery. Multi-effect distillation (MED) units, for example, recycle latent heat across successive stages, reducing specific energy consumption. Mechanical engineers apply thermodynamic modeling to determine the optimal number of stages, pressure drops, and heat recovery factors.

Thermal energy storage systems, such as molten salts or phase-change materials, are increasingly integrated into solar-thermal desalination. These systems ensure continuous water production even after sunset. The design and sizing of storage systems require careful thermodynamic and mechanical analysis to balance cost, reliability, and efficiency. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

### Fluid Mechanics and Heat Transfer in Desalination



Fluid mechanics and heat transfer form the theoretical backbone of desalination engineering. In thermal desalination, seawater undergoes heating, phase change, and condensation processes. Mechanical engineers apply the Navier–Stokes equations, continuity equations, and Fourier’s law of heat conduction to model these processes with precision. In multi-effect distillation (MED) systems, thin films of seawater are sprayed over heated surfaces, creating evaporation under reduced pressure. Engineers analyze Reynolds numbers to determine whether flow regimes are laminar or turbulent, which directly affects heat transfer coefficients. Similarly, Nusselt numbers are calculated to evaluate convective heat transfer efficiency, while Prandtl numbers indicate the relative significance of thermal and momentum diffusion.

In reverse osmosis (RO), the focus shifts to high-pressure fluid transport across semi-permeable membranes. Mechanical engineers must account for concentration polarization, which occurs when salt accumulates at the membrane surface, reducing efficiency. This requires careful hydrodynamic modeling of crossflow velocities, pressure gradients, and turbulence promoters. Computational Fluid Dynamics (CFD) simulations are frequently employed to visualize flow patterns, predict scaling hotspots, and optimize module design.

Illustrative Specific Energy Consumption vs. Feed Pressure in R

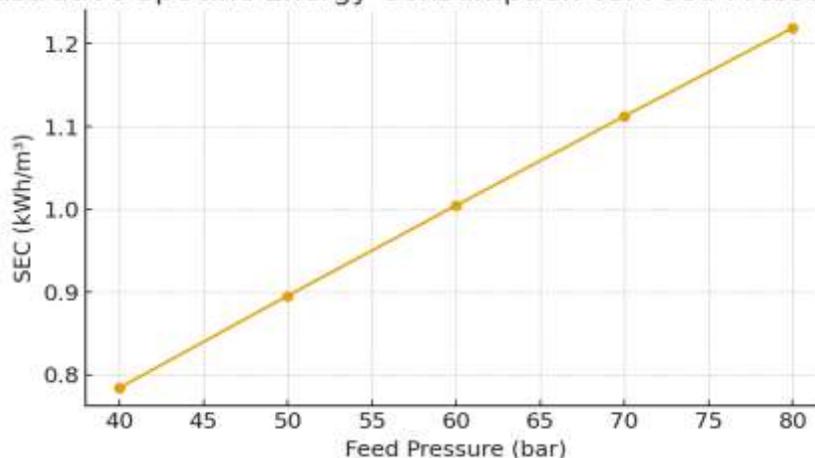


Figure 2. Illustrative relationship between RO feed pressure and specific energy consumption (SEC). Values shown are conceptual.

### Energy Systems Integration and Optimization

One of the greatest challenges in solar desalination is matching intermittent solar energy with steady water demand. Mechanical engineers play a critical role in designing hybrid and storage systems that achieve this balance. For PV-RO systems, engineers integrate photovoltaic panels with battery storage or grid backup. For solar-thermal MED/MSF plants, thermal energy storage solutions such as molten salts or phase-change materials are incorporated to extend operation into the night. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

Optimization involves techno-economic modeling to determine the optimal collector area, storage size, and desalination capacity. Engineers employ methods such as exergy analysis, pinch analysis, and parametric simulations to balance cost and performance. Key performance indicators include Levelized Cost of Water (LCOW), capacity factor, and system reliability.

**Table 2. Illustrative Components of Levelized Cost of Water (LCOW)**

Component	Description	Typical Share (%)
Capital Expenditure (CAPEX)	Collectors, pumps, membranes, civil works	45–60
Operational Expenditure (OPEX)	Labor, chemicals, spare parts	20–35
Energy Costs	Electricity/thermal energy supply, storage	15–25

### Materials and Reliability in Harsh Desert Conditions

Saudi Arabia’s harsh desert climate presents unique challenges for solar desalination systems. High ambient temperatures, saline feedwater, and frequent dust storms accelerate material degradation. Mechanical engineers must therefore select materials that can withstand corrosion, scaling, fouling, and erosion. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

Corrosion resistance is critical for heat exchangers, evaporators, and piping. Duplex stainless steels, titanium alloys, and specialized polymer coatings are often employed. Anti-fouling coatings and cathodic protection methods are also used to prolong component lifespans. For PV modules and solar collectors, engineers integrate anti-soiling coatings and robotic cleaning systems to maintain efficiency under dusty conditions.

Reliability engineering ensures that systems remain operational over decades of service. Engineers apply techniques such as Reliability-Centered Maintenance (RCM) and Failure Modes and Effects Analysis (FMEA) to anticipate breakdowns and schedule proactive interventions. Predictive maintenance using IoT sensors and AI-driven analytics is increasingly applied in Saudi pilot projects.

### Modeling, Simulation, and Control Tools

Simulation tools are indispensable in modern mechanical engineering practice. ANSYS Fluent and COMSOL Multiphysics enable detailed CFD simulations of heat and mass transfer in evaporators, condensers, and membrane modules. Finite element analysis (FEA) is used to test the mechanical integrity of pressure vessels and piping under high stress. MATLAB and Simulink are applied for process modeling, optimization, and control system design.

Digital twin technology is emerging as a frontier application, where a virtual replica of the desalination plant is maintained in real time. This enables predictive control, fault detection, and scenario testing without interrupting operations. In Saudi Arabia, research institutions such as KAUST are pioneering the use of such advanced modeling techniques for solar desalination. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

### Economic Analysis of Solar-Powered Desalination Solar energy

Economic Analysis with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future. The economic feasibility of solar desalination is measured primarily through the Levelized Cost of Water (LCOW). Mechanical engineering influences LCOW by enhancing energy efficiency, extending equipment lifespan, and reducing maintenance costs. Comparative studies show that solar desalination can achieve costs as low as 0.5–0.8 USD/m<sup>3</sup>, which is competitive with conventional fossil-fuel-based desalination once externalities like carbon emissions are considered. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

Economic analysis also includes sensitivity studies to evaluate how fluctuations in solar irradiance, component costs, and water tariffs affect project viability. Saudi Arabia’s abundant solar resource and policy support under Vision 2030 create favorable conditions for investment in this sector. Beyond setting sustainability as a strategic objective, Vision 2030 explicitly recognizes renewable-powered desalination as a key enabler of national water security. It prioritizes projects that integrate advanced engineering solutions, highlighting the role of local innovation and technology transfer. By arrange in a line mechanical engineering education, research, and industrial practice with Vision 2030 objectives, Saudi Arabia is positioning itself not only as a consumer of technology but also as a global leader in solar-powered water systems. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

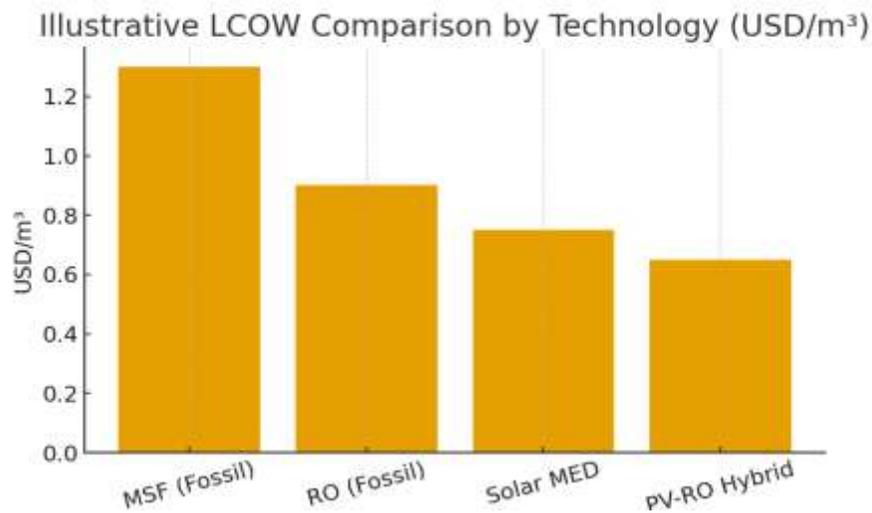


Figure 3. Illustrative comparison of LCOW across conventional and solar desalination technologies. Values are conceptual. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

### Case Studies in the Kingdom and International Benchmarks

To demonstrate the practical application of mechanical engineering principles in solar-powered desalination, it is important to review both Saudi Arabian initiatives and international benchmarks. These case studies highlight real-world integration of thermal system design, fluid mechanics, materials, and optimization techniques. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

In Saudi Arabia, the NEOM project represents one of the world’s most ambitious sustainability experiments. NEOM aims to produce 100% renewable-powered desalinated water, integrating PV-RO systems with thermal energy storage and advanced digital twin technology for predictive optimization. Mechanical engineers are central in designing modular systems capable of adapting to fluctuating demand and solar variability.

The Red Sea Project is another example, focused on luxury tourism developments powered entirely by renewable energy. Here, solar desalination plants are designed to minimize environmental impact, with engineers optimizing brine disposal methods and integrating hybrid RO-MD systems for resilience. KAUST (King Abdullah University of Science and Technology) has also pioneered membrane distillation powered by solar collectors, demonstrating proof-of-concept systems that combine academic research with applied engineering. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

Internationally, Spain has piloted solar RO plants along its Mediterranean coast, while the United Arab Emirates has invested heavily in solar-powered MED at Masdar City. Australia has experimented with off-grid PV-RO units for remote communities. These international cases provide valuable lessons for Saudi Arabia, especially in scaling and integrating renewable desalination with national grids. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

Table 3. Illustrative Case Studies in Solar-Powered Desalination Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

<b>Project</b>	<b>Location</b>	<b>Technology</b>	<b>Capacity (m<sup>3</sup>/day)</b>	<b>Key Engineering Features</b>
NEOM	Saudi Arabia	PV-RO Hybrid	50,000+	Digital twin, modularity, storage integration
Red Sea Project	Saudi Arabia	Hybrid RO + MD	5,000–10,000	Brine minimization, eco-design
KAUST Pilots	Saudi Arabia	Solar MD	50–200	Research-scale, membrane innovation
Masdar City	UAE	Solar MED	1,000–2,000	Parabolic troughs + thermal storage
Canary Islands	Spain	PV-RO	500–1,000	Grid-tied, demonstration scale

**Alignment with Saudi Vision 2030 Beyond setting sustainability as a strategic objective, Vision 2030 explicitly recognizes renewable-powered desalination as a key enabler of national water security.**

Clearly, it prioritizes projects that integrate advanced engineering solutions, highlighting the role of local innovation and technology transfer. By aligning mechanical engineering education, research, and industrial practice with Vision 2030 objectives, Saudi Arabia is positioning itself not only as a consumer of technology but also as a global leader in solar-powered water systems. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future. Saudi Vision 2030 articulates a future where economic diversification, environmental sustainability, and technological innovation converge. Renewable desalination is a pillar of this strategy. The Vision emphasizes reducing dependence on fossil fuels, lowering carbon emissions, and ensuring water security. Solar-powered desalination satisfies all three. Beyond setting sustainability as a strategic objective, Vision 2030 explicitly recognizes renewable-powered desalination as a key enabler of national water security. It prioritizes projects that integrate advanced engineering solutions,

highlighting the role of local innovation and technology transfer. By aligning mechanical engineering education, research, and industrial practice with Vision 2030 objectives, Saudi Arabia is positioning itself not only as a consumer of technology but also as a global leader in solar-powered water systems. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

More importantly, mechanical engineers enable this transition by developing scalable, efficient, and reliable systems. Their expertise in thermodynamics, materials, and systems optimization aligns directly with Vision 2030’s objectives of local capacity-building and global leadership in clean technology. Investments in research hubs, such as KAUST and KACST, reflect this commitment by advancing solar desalination from pilot to commercial scale. Beyond setting sustainability as a strategic objective, Vision 2030 explicitly recognizes renewable-powered desalination as a key enabler of national water security. It prioritizes projects that integrate advanced engineering solutions, highlighting the role of local innovation and technology transfer. By aligning mechanical engineering education, research, and industrial practice with Vision 2030 objectives, Saudi Arabia is positioning itself not only as a consumer of technology but also as a global leader in solar-powered water systems. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

### Challenges and Future Research Directions

Despite progress, significant challenges remain. Intermittency of solar radiation requires cost-effective energy storage solutions. Brine disposal poses environmental risks, especially for projects near sensitive coral ecosystems on the Red Sea. Fouling, scaling, and corrosion continue to reduce system lifetimes, while dust accumulation reduces solar collector efficiency. Moreover, future research must focus on nanotechnology-enabled membranes with higher fouling resistance, AI-driven predictive maintenance, and circular approaches to brine management (e.g., mineral extraction for industrial use). Pilot projects must evolve into large-scale commercial operations, and economic models must be refined to attract private investment. The role of mechanical engineering will only grow as systems become more complex, requiring multi-disciplinary integration.

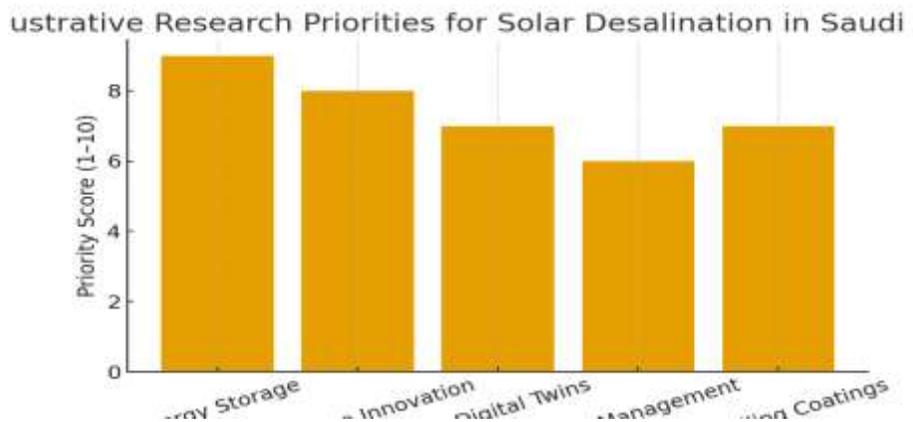


Figure 4. Illustrative research priorities for solar desalination in Saudi Arabia. Values represent conceptual rankings. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

### CONCLUSION

Mechanical engineering is indispensable to the success of solar-powered desalination in Saudi Arabia. By linking solar resource utilization with desalination processes, mechanical engineers ensure that water security is achieved without compromising environmental sustainability. From thermal system design and fluid mechanics to materials science and

economic optimization, mechanical engineering underpins every stage of development and deployment. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

As Saudi Arabia advances toward Vision 2030, solar desalination provides a pathway to achieve energy diversification and environmental stewardship. With continued research, innovation, and investment, the Kingdom is positioned to lead the world in renewable desalination technology. Beyond setting sustainability as a strategic objective, Vision 2030 explicitly recognizes renewable-powered desalination as a key enabler of national water security. It prioritizes projects that integrate advanced engineering solutions, highlighting the role of local innovation and technology transfer. By aligning mechanical engineering education, research, and industrial practice with Vision 2030 objectives, Saudi Arabia is positioning itself not only as a consumer of technology but also as a global leader in solar-powered water systems. Solar energy, with its unmatched availability across the Kingdom, is more than a resource—it is a foundation for energy independence and water resilience. Expanding solar-powered desalination reduces carbon emissions, supports global climate commitments, and creates opportunities for exporting sustainable water technologies to other arid regions. The synergy between solar abundance and mechanical innovation forms the cornerstone of Saudi Arabia’s water future.

## REFERENCES

- [1]. Al-Karaghoul, A., & Kazmerski, L. L. (2013). Energy consumption and water production cost of conventional and renewable-energy-powered desalination processes. *Renewable and Sustainable Energy Reviews*, 24, 343–356.
- [2]. Alkaisi, A., Mossad, R., & Shahin, M. A. (2017). A review of the water desalination systems integrated with renewable energy. *Energy Procedia*, 110, 268–274.
- [3]. El-Naas, M. H., Ghaffour, N., & others. (2015). Renewable energy-driven desalination technologies for sustainable water production: A review. *Renewable and Sustainable Energy Reviews*, 44, 757–768.
- [4]. Ghaffour, N., Missimer, T. M., & Amy, G. L. (2013). Technical review and evaluation of the economics of water desalination: Current and future challenges for better water supply sustainability. *Desalination*, 309, 197–207.
- [5]. International Energy Agency (IEA). (2022). *Renewables 2022: Analysis and forecast to 2027*. OECD/IEA.
- [6]. Intergovernmental Panel on Climate Change (IPCC). (2021). *Sixth Assessment Report (AR6)*. Cambridge University Press.
- [7]. Ministry of Environment, Water and Agriculture (MEWA), Saudi Arabia. (2020). *National Water Strategy 2030*.
- [8]. Our World in Data. (2023). *Water use and desalination statistics*. Retrieved from <https://ourworldindata.org>
- [9]. Shatat, M., Riffat, S. B., & Gan, G. (2013). Renewable energy powered membrane technology: A review of desalination systems for sustainable water production. *Applied Energy*, 123, 36–58.
- [10]. Zhou, Y., & Tol, R. S. J. (2005). Evaluating the costs of desalination and water transport. *Water Resources Research*, 41, W03003.
- [11]. Al-Karaghoul, A., & Kazmerski, L. L. (2013). Energy consumption and water production cost of conventional and renewable-energy-powered desalination processes. *Renewable and Sustainable Energy Reviews*, 24, 343–356. <https://doi.org/10.1016/j.rser.2013.03.059>
- [12]. Alkaisi, A., Mossad, R., & Shahin, M. A. (2017). A review of the water desalination systems integrated with renewable energy. *Energy Procedia*, 110, 268–274. <https://doi.org/10.1016/j.egypro.2017.03.139>
- [13]. Calise, F., Cipollina, A., d’Accadia, M. D., Piacentino, A., & Vanoli, L. (2016). A review on solar desalination technologies and plants. *Renewable and Sustainable Energy Reviews*, 41, 535–564. <https://doi.org/10.1016/j.rser.2014.08.058>
- [14]. El-Naas, M. H., Ghaffour, N., & others. (2015). Renewable energy-driven desalination technologies for sustainable water production: A review. *Renewable and Sustainable Energy Reviews*, 44, 757–768. <https://doi.org/10.1016/j.rser.2015.01.051>
- [15]. Ghaffour, N., Missimer, T. M., & Amy, G. L. (2013). Technical review and evaluation of the economics of water desalination: Current and future challenges for better water supply sustainability. *Desalination*, 309, 197–207. <https://doi.org/10.1016/j.desal.2012.10.015>
- [16]. Intergovernmental Panel on Climate Change. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. <https://www.ipcc.ch/report/ar6/wg1/>
- [17]. International Energy Agency. (2022). *Renewables 2022: Analysis and Forecast to 2027*. OECD/IEA.
- [18]. King Abdullah University of Science and Technology (KAUST). (2019–2023). *Research outputs on solar desalination and membrane distillation*. KAUST Publications.



- [19]. Ministry of Environment, Water and Agriculture (MEWA). (2020). National Water Strategy 2030. Riyadh: Government of Saudi Arabia.
- [20]. Our World in Data. (2023). Water use and desalination statistics. Retrieved from <https://ourworldindata.org>
- [21]. Shatat, M., Riffat, S. B., & Gan, G. (2013). Renewable energy powered membrane technology: A review of desalination systems for sustainable water production. *Applied Energy*, 123, 36–58. <https://doi.org/10.1016/j.apenergy.2014.02.012>
- [22]. Zhou, Y., & Tol, R. S. J. (2005). Evaluating the costs of desalination and water transport. *Water Resources Research*, 41(3). <https://doi.org/10.1029/2004WR003749>