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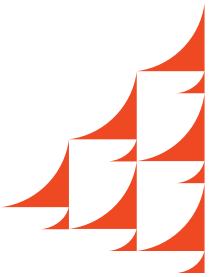
Water Worries: The Future of Desalination in the UAE

Robert Mogielnicki



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The Arab Gulf States Institute in Washington (AGSIW), launched in 2015, is an independent, nonprofit institution dedicated to providing expert research and analysis of the social, economic, and political dimensions of the Gulf Arab states and key neighboring countries and how they affect domestic and foreign policy. AGSIW focuses on issues ranging from politics and security to economics, trade, and business; from social dynamics to civil society and culture. Through programs, publications, and scholarly exchanges the institute seeks to encourage thoughtful debate and inform the U.S. foreign-policy, business, and academic communities regarding this critical geostrategic region.

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The AGSIW *Next Gen Gulf* Series

This paper was developed as part of AGSIW's *Next Gen Gulf* series, which explores how the latest trends in technology are shaping the economies and governments of Gulf Arab states. *Next Gen Gulf* analyzes the implications of digital agendas, artificial intelligence, blockchain, and other tech services and applications for the region, by country and sector, and identifies the associated opportunities and risks of the Gulf's digital transformation.

About the Author

Robert Mogielnicki is a resident scholar at the Arab Gulf States Institute in Washington. An expert in the political economy of the Middle East and North Africa, he previously served as a senior analyst with the Siwa Group and head of public relations and marketing for Oxford Strategic Consulting, a United Kingdom/Gulf Cooperation Council-focused research consultancy. Prior to his consulting career, he worked as a journalist covering political and economic developments in post-revolutionary Egypt and Tunisia. His work and commentary on the region have appeared in Axios, Forbes Middle East, Al Jazeera's Inside Story, MEED, Al Bawaba, The National (UAE), Gulf Daily News, Tunisia Live, Egypt Oil and Gas Magazine, and Egypt Daily News.

Mogielnicki received his PhD from the University of Oxford's Magdalen College, where he conducted research in conjunction with the Oriental Institute and Middle East Centre. Drawing on extensive fieldwork in the United Arab Emirates, Oman, Qatar, Bahrain, and Kuwait, his dissertation examines the political economy of free zones in Gulf Arab countries. He earned his MA in modern Middle Eastern studies from St Antony's College, University of Oxford, and completed a master's thesis on labor policy formulation and implementation in the emirates of Abu Dhabi and Dubai. He received his BA from Georgetown University as a double major in Arabic and government, graduating magna cum laude and Phi Beta Kappa.

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Executive Summary

Desalination is a blessing and a curse for the United Arab Emirates. The water-scarce country's expansive desalination infrastructure provides the water resources needed to sustain life and support a broad range of commercial, agricultural, and industrial activities. Yet the UAE's dependence on desalination to meet the country's burgeoning water demand exacts a heavy economic and environmental toll. A continued reliance upon desalination as the primary source of the country's potable water likewise increases the population's vulnerability. The potential for disruptions to desalination operations and infrastructure poses a genuine risk to the country's residents and companies.

With few available alternatives for accessing water resources, the UAE is continuing to expand existing desalination facilities and construct new desalination plants. This development has been coupled with government-led efforts to reduce per capita water usage, adopt new desalination technologies, and streamline water and power production through the consolidation of government entities. As the UAE's desalination system evolves, it is becoming more complex. While the complexity of desalination processes in the UAE increases individual points of vulnerability across the system, the dispersed nature of the system simultaneously reduces the likelihood of a single or limited number of shocks to the system inflicting catastrophic harm on the region's residents or other consumers.

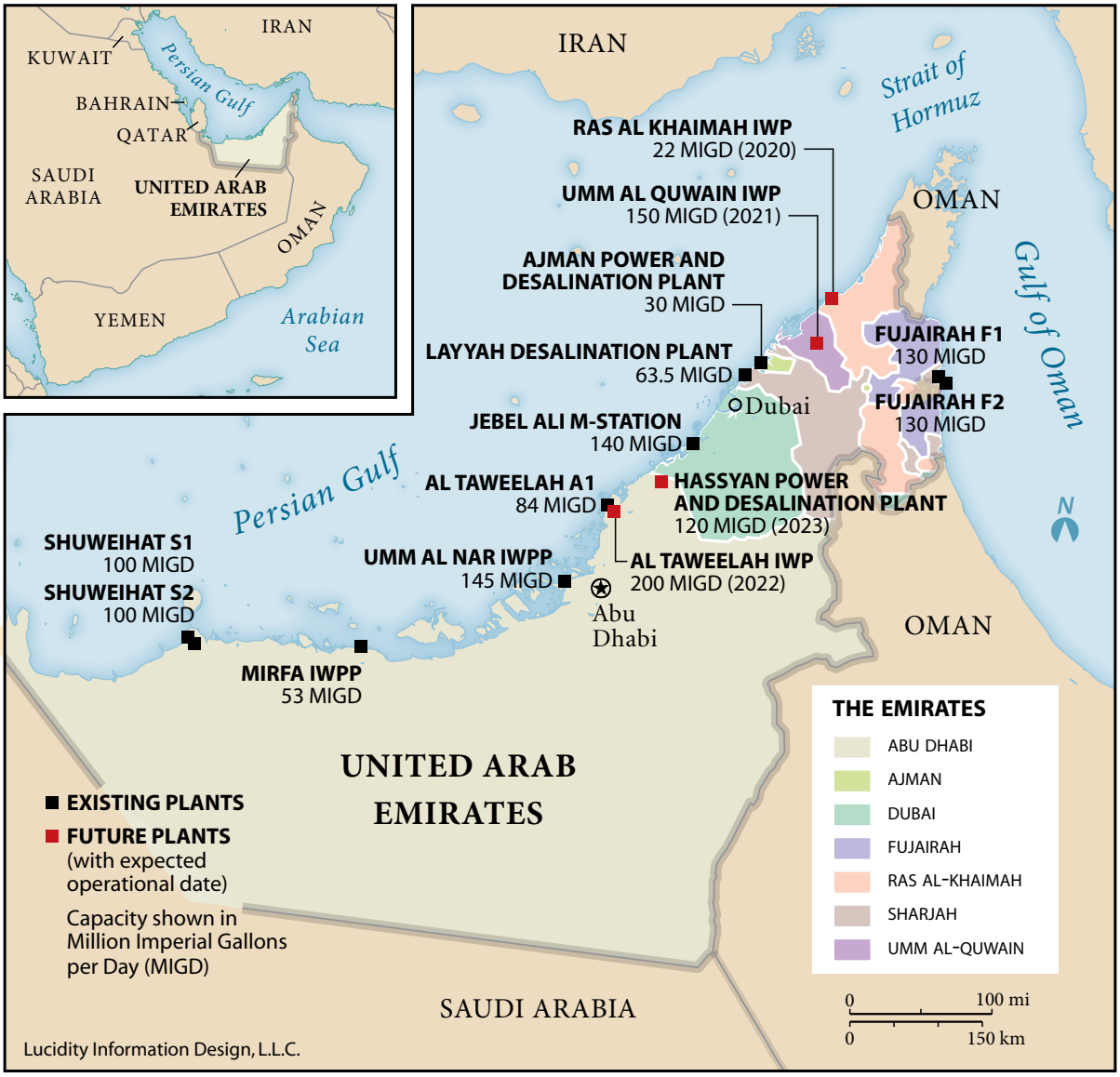
Major UAE Desalination Plants

Emirate	Plant	Method	Capacity (in millions of imperial gallons per day)	Date Operational
Abu Dhabi	Shuweihat S1	Multi-Stage Flash	100	2004
	Shuweihat S2	Multi-Stage Flash	100	2012
	Jebel Dhanna	Multiple Effect Distillation	4	1996
	Umm Al Nar IWPP	Multiple Effect Distillation/ Multi-Stage Flash	145	2007
	Mirfa IWPP	Reverse Osmosis	53	2017
	Al Taweelah A1	Multiple Effect Distillation/ Multi-Stage Flash	84	2003
	Al Taweelah A2	Multi-Stage Flash	50	2001
	Al Taweelah B	Multi-Stage Flash	75	1995
	Al Taweelah B Extension	Multi-Stage Flash	98	2008
	Al Taweelah IWP	Reverse Osmosis	200	2022
Dubai	Hassyan Power and Desalination Plant	Reverse Osmosis	120	2023
	Jebel Ali RO Plant	Reverse Osmosis	40	*
	Jebel Ali	Multi-Stage Flash	27	*
	Jebel Ali D-Station	Multi-Stage Flash	35	*
	Jebel Ali E-Station	Multi-Stage Flash	25	*
	Jebel Ali G-Station	Multi-Stage Flash	60	*
	Jebel Ali K-Station, Phase 1	Multi-Stage Flash	60	*
	Jebel Ali K-Station, Phase 2	Multi-Stage Flash	40	*
	Jebel Ali L-Station, Phase 1	Multi-Stage Flash	70	2005
	Jebel Ali K-Station, Phase 2	Multi-Stage Flash	55	*
	Jebel Ali M-Station	Multi-Stage Flash	140	2013
Fujairah	Fujairah F1 IWPPF	Multi-Stage Flash/ Reverse Osmosis	130	2015
	Fujairah F2 Plant	Multiple Effect Distillation/ Reverse Osmosis	130	2011
Sharjah	Layyah Desalination Plant	Multi-Stage Flash/Multiple Effect Distillation/Reverse Osmosis	63.5	2007
	Kalba Desalination Plant	Reverse Osmosis	6	Ongoing Expansion Project
	Khor Fakkan Desalination Plant	Reverse Osmosis	3	2008
	Al Rahmaniya (Sajaa)	Reverse Osmosis	5	2009
	Hamriyah	Reverse Osmosis	20	2014
Umm Al Quwain	Umm Al Quwain IWP	Reverse Osmosis	150	2021
Ajman	Ajman Power and Desalination Plant Phase 1	*	30	2011
	Ajman Desalination Plant	Reverse Osmosis	10	2011
	Al Zawra IWP	Reverse Osmosis	30	On Hold
Ras Al Khaimah	Ras Al Khaimah IWP	Reverse Osmosis	22	2020
	Ghalilah	Reverse Osmosis	15	2015
	Ras Al Khaimah Desalination Plant	Reverse Osmosis	30	On Hold

*Unknown or not publicly available

Sources: Desalination, Statistics Centre Abu Dhabi, Dubai Electricity and Water Authority, Sharjah Electricity and Water Authority, Sembcorp, Fujairah Asia Power Company, ACWA Power, ZAWYA, Aquatech, Torishima

Network of Key UAE Desalination Plants



Introduction

Water is a deep source of concern for Gulf Arab states like the United Arab Emirates. The country's seven emirates confront a continuous need for greater access to water resources, which are required for human consumption, agricultural activities, and industrial processes. Water demand in the UAE is expected to grow 30% by 2030.[1] However, the country receives less than 100 millimeters per year of rainfall on average, and the groundwater recharge rate is less than 4% of the annual water used by the country. With minimal ground water and precipitation, the Gulf region relies on depleting aquifers, desalination, recycled wastewater, and imports. Desalination is one of the few long-term sources of fresh water able to meet demand from the population and economic activities of the Gulf states.

The Middle East and North Africa possesses approximately 55% of global desalination capacity, with the vast majority of desalinated water production taking place in the six Gulf Cooperation Council states.[2] The UAE is the second-largest producer of desalinated water in the world after Saudi Arabia, which produces around 1,452 million imperial gallons per day of desalinated water.[3] In 2017, the UAE produced nearly 1,193 million imperial gallons per day of desalinated water. The Gulf region also boasts some of the world's largest desalination plants in terms of output capacity. Saudi Arabia's Ras Al-Khair desalination plant, which provides water for Riyadh, is the world's largest plant. The UAE's Al Taweelah desalination complex remains under construction; however, it is expected to become the second-largest desalination plant in the world.[4] Desalination produces approximately 80% of the total drinking water in GCC states.[5] Almost all of the UAE's potable water – around 42% of the country's total water requirement – is the product of desalination.[6]

The UAE's heavy dependence on desalination poses risks. In particular, the sustainability of desalination activities – in terms of costs and environmental impacts – remains a key concern. However, the UAE is unlikely to drastically reduce desalination operations, given the lack of options to secure water resources. The process is also becoming costlier. Masdar, or the Abu Dhabi Future Energy Company, had projected that the costs of seawater desalination would increase 300% between 2010 and 2016, leading the renewable energy company to experiment with new, cost-effective desalination technologies.[7] Desalinating seawater along the UAE's coastline requires substantial energy inputs – often natural gas, liquified natural gas, or diesel. If the UAE reduced its dependence upon desalination operations, these energy inputs could be exported or sold domestically.

1 Masdar, *Renewable Energy Seawater Desalination* (Abu Dhabi: Masdar, 2018).

2 Waleed K. Al-Zubari, "Regional Water Governance and Cooperation in the Arab Region," *Emirates Diplomatic Academy*, October 2019.

3 "About: Water Production," Saline Water Conversion Company, accessed February 12, 2020.

4 "Does Size Matter? Meet the World's Largest Desalination Plants," *Aquatech*, January 15, 2019.

5 The Cooperation Council for the Arab States of the Gulf (GCC) General Secretariat, *Desalination in the GCC: The History, the Present & the Future* (Desalination Experts Group, Water Resources Committee, 2014), 20.

6 "Water: Desalination Plants," The UAE Government Portal, updated March 19, 2019.

7 Masdar, *Renewable Energy Seawater Desalination* (Abu Dhabi: Masdar, 2018); Sara Hamdan, "Abu Dhabi Company Searches for Greener Method of Desalination," *The New York Times*, January 23, 2020.

The desalination process also produces brine – a high-salinity byproduct that is often dumped back into the original water source. This process reduces the long-term viability of seawater desalination and threatens maritime ecosystems – a potentially expensive negative externality. To address the energy issues, emirate-level governments and public sector entities across the UAE are experimenting with solar-powered desalination facilities. Meanwhile, studies at inland storage ponds in the UAE and research at the American University in Sharjah have sought to reconsider brine disposal strategies and develop new brine-related technologies.[8]

Water resource management in the Gulf region is inherently geopolitical, and a lack of regional cooperation over water resources and desalination processes exacerbates competition over this limited resource. In 2013, GCC states agreed to jointly develop a $7 billion desalination plant along the Arabian Sea coastline to protect against contamination from a potential radioactive spill at an Iranian nuclear facility or oil spill in the Persian Gulf.[9] The initiative would have produced a shared water pipeline from a coastal location on the Gulf of Oman or Arabian Sea to Kuwait, but it has not resulted in any concrete progress over the past several years.[10] Qatar and Kuwait considered importing substantial amounts of water from Iran but ultimately discarded the plans. Concerns that the "hydrohegemonic influence of Iran" would create a risky external dependency likely played a role in why the import scheme failed to materialize.[11]

Desalinating seawater along the UAE's coastline requires substantial energy inputs – often natural gas, liquified natural gas, or diesel.

In 2019, a series of attacks on critical energy infrastructure in the Gulf states led to fears that desalination facilities could be targets for future attacks. Yemen's Houthi rebels launched a "projectile" targeting a Saudi desalination plant in Shuqaiq in June 2019, but this attack did not damage any infrastructure. Nevertheless, Iran and Iranian-linked groups in the region possess the capabilities to threaten desalination infrastructure in the UAE. A dramatic escalation in U.S.-Iranian tensions in early 2020 exacerbated these concerns.

An updated view of the UAE's desalination system therefore is needed to better assess the risks confronting a water-scarce country that remains heavily dependent upon desalinated water to meet local demand. This paper begins by contextualizing the key desalination technologies in the Gulf states and then maps the desalination system in the UAE. A focus on federal and emirate-level strategies, government entities involved in desalination, major desalination facilities, and strategic reserve projects helps to shape the contours of the system. The paper introduces a threat assessment framework for conducting a risk-impact evaluation of intentional shocks to the UAE's desalination system. Finally, it highlights ongoing government efforts to mitigate internal and external threats to desalination operations in the UAE. Given the homogeneity of Gulf desalination systems, the paper's findings can help to inform other country case studies across the region.

8 Robert Matthews, "Impact of Middle East's Water Desalination in the Spotlight," *The National*, February 9, 2019.

9 Hussein Amery, "Water-Demand Management in the Arab Gulf States: Implications for Political Stability," in Jean Cahan, *Water Security in the Middle East: Essays in Scientific and Social Cooperation* (Anthem Press, 2017): 68.

10 "Gulf States Eye Arabian Sea for Safer Water Supplies," *Reuters*, July 18, 2013.

11 Hussein Amery, "Water-Demand Management in the Arab Gulf States: Implications for Political Stability," in Jean Cahan, *Water Security in the Middle East: Essays in Scientific and Social Cooperation* (Anthem Press, 2017): 70.

Contextualizing Desalination Technologies

There are two primary types of water desalination processes: those that are thermally driven and those employing membranes. In the Gulf region, most of the desalination plants utilize either multi-stage flash or multi-effect distillation technologies – both thermal processes – or reverse osmosis, which relies on membrane-based technology. Multi-stage flash and multi-effect distillation desalination are energy-intensive processes that heat water to generate steam; that steam is then used to heat the next batch of incoming water. In some cases, steam can be drawn from neighboring plants, often an independent water and power plant or independent water steam power producer. The development of desalination infrastructure tends to be concentrated in large industrial complexes so various energy, water, and power inputs and outputs can be utilized in a cost-effective and efficient manner.

Reverse osmosis desalination facilities leverage a membrane, or series of membranes, to filter out salts and other impurities. While less energy intensive, this process is capital intensive and does not handle high-salinity water, such as that found in the Gulf,[12] as efficiently as the thermal processes. While the UAE still relies heavily upon thermal desalination processes, the country is increasingly adopting reverse osmosis technologies. The Emirates Water and Electricity Company and Saudi-based ACWA Power agreed to build the world's largest seawater reverse osmosis desalination plant, which will be located at the Taweelah Power and Water Complex and is expected to be completed by 2022.[13] Othman Al Ali, the chief executive officer of the Emirates Water and Electricity Company said, "The choice of reverse osmosis seawater desalination technology will play a critical part in significantly reducing water production costs, contributing to our goals to build a more sustainable and efficient water and energy sector in the UAE."[14] Project planners expect that Abu Dhabi's share of desalinated water from reverse osmosis processes will increase from 13% to 30% once the project is completed in 2022.[15] Onsite solar generation capabilities will also help to lower the total energy consumption of the new reverse osmosis desalination plant.

The development of desalination infrastructure tends to be concentrated in large industrial complexes so various energy, water, and power inputs and outputs can be utilized in a cost-effective and efficient manner.

Energy costs play a central role in the development trajectories of desalination systems. The cost effectiveness of thermal desalination depends largely on the global price of crude oil and the opportunity cost associated with utilizing hydrocarbon resources for desalination. In thermal desalination processes, energy inputs can constitute more than half of total costs.[16] Such processes have traditionally been favored by hydrocarbon-abundant states, including

12 Stephen Leahy and Katherine Purvis, "Peak Salt: Is the Desalination Dream Over for the Gulf States?" *The Guardian*, September 29, 2016.

13 Teresia Njoroge, "UAE to Construct World's Largest Sea Water RO Desalination Plant," *Construction Review Online*, December 30, 2019.

14 Baset Asaba, "UAE Boosts Water Capacity," *Arabian Industry*, January 2, 2020.

15 "Does Size Matter? Meet Six of the World's Largest Desalination Plants," *Aquatech*, January 15, 2019.

16 Christopher Napoli and Bertrand Rioux, *A Framework for Comparing the Viability of Different Desalination Approaches* (Riyadh: KAPSARC, 2015), 8.

the Gulf states. For example, the majority of Abu Dhabi's operating desalination plants utilize multi-stage flash or multi-effect distillation technologies, and around 80% of Saudi Arabia's desalinated water comes from multi-stage flash (64%) and multi-effect distillation (16%) processes. Newly constructed plants, though, are moving away from thermal technologies. Abu Dhabi's Mirfa and Al Taweelah desalination facilities also utilize reverse osmosis methods. In 2013, the UAE's Masdar launched a renewable energy desalination pilot program in Ghantoot to study energy-efficient and cost-competitive desalination through reverse osmosis technologies and renewable energy. The research found that solar-powered reverse osmosis desalination is up to 75% more energy efficient than the thermal desalination processes employed in the UAE.[17] Dubai plans to save around $13 billion between 2017 and 2030 by powering desalination with solar power from the Mohammed bin Rashid Al Maktoum Solar Park.[18]

Desalination also produces brine – a high-salinity concentrated waste. The brine from desalination processes is usually recycled back into the original water source. Returning this high-salinity byproduct back into the Gulf waters slowly reduces the future effectiveness of desalination and harms maritime ecosystems. Brine can reduce oxygen levels in the seawater near desalination plants and also introduce toxins, such as copper and chlorine, into the maritime environment. The UAE contributes 20.2% of the world's brine; together, the UAE, Saudi Arabia, Qatar, and Kuwait are responsible for 55% of the total share of brine worldwide.[19]

The cost effectiveness of thermal desalination depends largely on the global price of crude oil and the opportunity cost associated with utilizing hydrocarbon resources for desalination.

Gulf Arab states are taking some measures to address the issues posed by brine. In November 2019, the Saline Water Conversion Corporation, the Saudi state-run company overseeing much of the country's desalination, signed a memorandum of understanding with Japan's Toyobo Company for a joint pilot test of technology that efficiently uses concentrated brine from saltwater desalination plants.[20] In January, Saudi officials announced plans to construct a "solar dome" desalination plant at Neom – a tech-focused megaproject being constructed on the country's northwestern coast.[21] The solar dome technology aims to reduce brine and cut carbon emissions to zero. Continued innovation in this segment of desalination technology is directly relevant to Emirati officials overseeing the water portfolio.

17 "Ghantoot Desalination Pilot Plant," Masdar Website, updated 2020.

18 Derek Baldwin, "Solar Energy to Power Dubai Desalination Plants," *Gulf News*, February 14, 2017.

19 Edward Jones, Manzoor Qadir, Michelle T.H. van Vliet, Vladimir Smakhtin, and Seong-mu Kang, "The State of Desalination and Brine Production: A Global Outlook," *Science of The Total Environment* 657 (2019): 134.

20 "Toyobo and Saline Water Conversion Corporation Sign MOU on Joint Pilot Test Aimed at Accelerating Use of New Memberane Technology for Reusing Concentrated Brine," *PRNewswire*, November 1, 2019.

21 Vivian Nereim and Anthony Dipaola, "Saudis Plan 'Solar Dome' Desalination Plants at Neom Mega-City," *Bloomberg*, January 29, 2020.

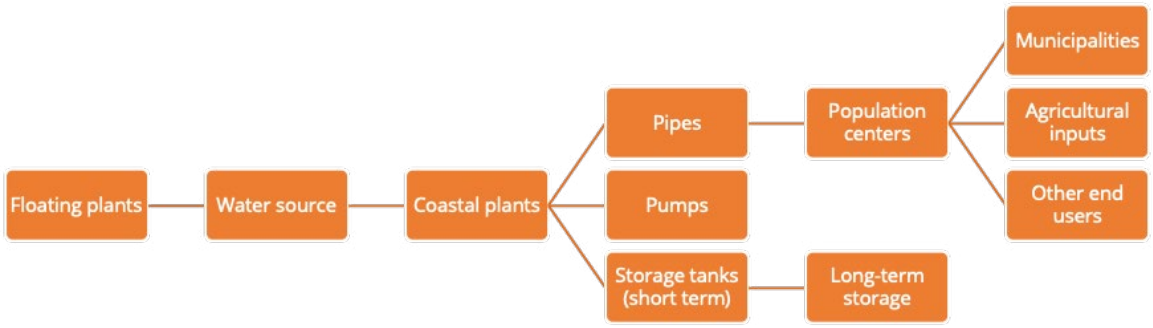
Delineating Desalination Systems in the Gulf

Thermal processes, membranes, and other innovative technologies are critical elements of desalination operations. However, the functioning of the wider desalination system depends upon a broader set of interrelated processes surrounding desalination operations themselves. A comprehensive view of desalination systems, therefore, must also incorporate the original source of water, transmission infrastructure, and end use.[22]

The UAE's desalination operations draw predominantly upon seawater from the Persian Gulf; however, the emirate of Fujairah utilizes water sources from the Gulf of Oman. In 2018, Abu Dhabi imported around 46.8 billion imperial gallons of desalinated water from Fujairah. Kuwait, Qatar, and Bahrain also share water resources in the Persian Gulf, whereas Oman's desalination facilities lie along the country's northeastern coast on the Gulf of Oman. Saudi Arabia accesses seawater from the Persian Gulf and the Red Sea to meet the country's water demand. Saudi Arabia also possesses floating desalination barges that move within water sources to meet varying water demand in the kingdom.

The floating desalination barges operating along Saudi Arabia's coastline require flexible infrastructure, such as maritime logistics and transportation services, to deliver desalinated water to mainland tanks. Coastal desalination plants likewise rely on an extensive arrangement of pipes, pumps, and short-term storage tanks to deliver desalinated water to population centers or longer-term storage facilities. From these points, desalinated water is then distributed to end users. Human consumption is just one end use for desalinated water. Agricultural activities, which include animal husbandry, consume the largest portion of water resources in Gulf countries.[23]

Simplified Visualization of a Seawater Desalination System



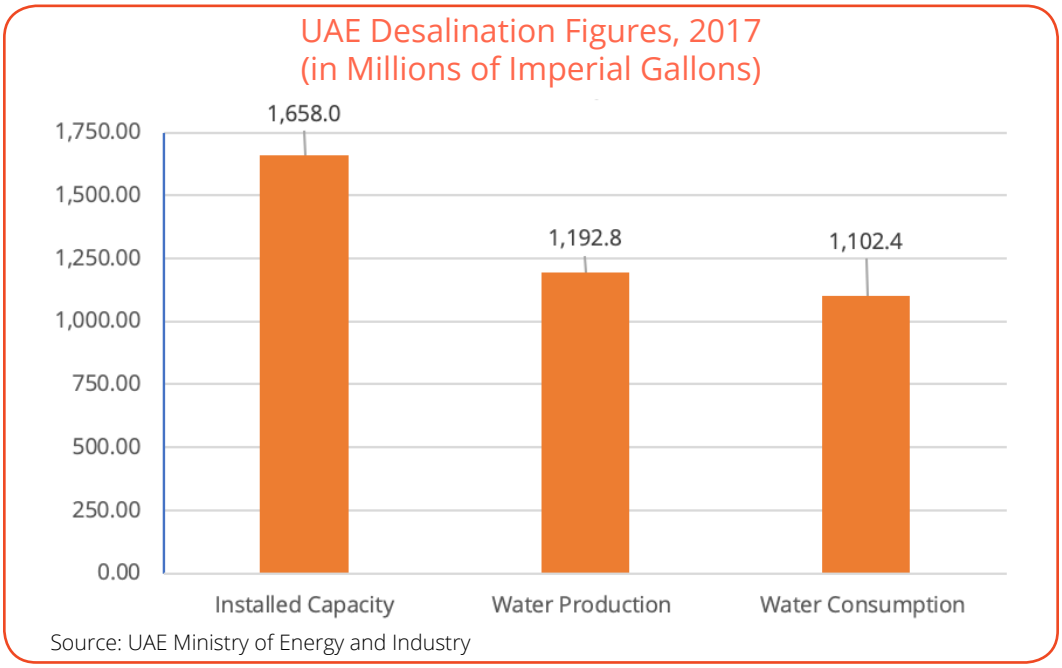
22 Christopher Napoli and Bertrand Rioux, *A Framework for Comparing the Viability of Different Desalination Approaches* (Riyadh: KAPSARC, 2015), 6.

23 Caline Malek, "Agriculture is the Largest Consumer of Water in Abu Dhabi," *The National*, January 22, 2013; Figures range from 72% in Abu Dhabi to 83% nationally in a 2008 survey, see Aquastat, *Irrigation in the Middle East Region in Figures: Aquastat Survey 2008* (Rome: Food and Agriculture Organization of the United Nations, 2009).

Efforts to recycle and reuse wastewater can reduce a country's reliance on desalinated water. In 2017, the UAE had 92 treated wastewater plants and reused nearly 75% of treated wastewater, up from 61% in 2013.[24] The Environment Agency-Abu Dhabi aims to recycle and reuse all of its wastewater for nonpotable end uses, such as irrigation, by 2020.[25] The water required for industrial activities, which often use recycled wastewater, is not treated and processed in the same plants as potable water.

Desalination in the UAE: A National Priority

The UAE produces around 14% of the world's desalinated water.[26] A growing population and economic growth ambitions suggest that the country will continue to rely upon desalination over the coming years. Nearly all of the UAE's potable water, around 42% of the country's total water requirement, is the product of desalination processes. In 2017, the country reported an installed desalination capacity of around 1,658 million imperial gallons per day.[27] Total desalinated water production for the same year reached 435,387 million imperial gallons, or an average of 1,192.8 million imperial gallons per day, which indicates a capacity utilization of 72%. Water consumption rates, which reached an average of 1,102.4 million imperial gallons per day in 2017, closely follow desalinated water production figures.



Source: UAE Ministry of Energy and Industry

24 UAE Ministry of Energy and Industry, *Annual Statistical Report: 2018* (Abu Dhabi: UAE Ministry of Energy and Industry, 2018), 52.

25 Anwar Ahmad, "Abu Dhabi to Recycle, Re-use All Waste Water by 2020," *Gulf News*, November 6, 2017.

26 "Water: Desalination Plants," The UAE Government Portal, updated March 19, 2019.

27 UAE Ministry of Energy and Industry, *Annual Statistical Report: 2018* (Abu Dhabi: UAE Ministry of Energy and Industry, 2018), 45-47.

Water security is closely linked to desalination, and therefore ensuring continuity in desalination operations is a strategic imperative of the UAE federal government. The UAE Ministry of Energy and Industry oversees the country's water portfolio, and an assistant undersecretary for electricity, water, and future energy affairs manages this critical ministerial agenda. In September 2017, the ministry released the "UAE Water Security Strategy 2036." The strategy aims to reduce the average per capita water consumption by 50% and increase the efficiency of water supply by adopting sustainable practices. In addition to other initiatives, Emirati officials hope to shrink public water demand by 21%; increase the economic value realized per unit of water use; reduce the country's water scarcity measurements; and increase the recycling and reuse of treated water to 95%. The country reused about 75% of treated wastewater in 2017.[28] Thus, the strategy tackles both supply and demand factors influencing water management processes in the country. Emirati officials expect that the strategy will result in 74 billion UAE dirhams (approximately $20 billion) of savings and a reduction of 100 million metric tons of carbon dioxide, which is a byproduct of seawater desalination.[29] Desalination plants, largely powered by natural gas, contributed nearly one-third of the country's greenhouse gas emissions in 2015.[30]

The strategy also seeks to enhance the country's water storage capabilities, which remain underdeveloped. Most of the water resources that the country produces through desalination need to be utilized immediately, leaving minimal maneuverability in the case of an emergency. Government authorities want to develop a water storage capacity that "lasts for two days under normal conditions, which would be equivalent to a capacity of 16 days in emergencies and enough to supply water for more than 45 days in extreme emergencies."[31] The UAE has gone to great lengths to increase its desalinated water storage capacity.Abu Dhabi completed the construction of the world's largest desalinated water reserve in Liwa, where natural aquifers store water in 315 recovery wells located as deep as 90 meters below the ground.[32] These water reserves can supply 1 million residents in Abu Dhabi with 180 liters of water per person for up to 90 days. The reserve facility is connected to the Shuweihat desalination plants as well as the UAE's national water grid. The project took around 15 years to complete. To tackle challenges with water storage, there must be greater connectivity between and integration of water entities in the country. However, the desalination system is fragmented by the existence of multiple water and electricity companies spread across the country.

Desalination plants, largely powered by natural gas, contributed nearly one-third of the country's greenhouse gas emissions in 2015.

The country's larger emirates, Abu Dhabi, Dubai, and Sharjah, contain separate authorities that oversee desalination. The Federal Electricity and Water Authority directs desalination operations in the smaller emirates of Fujairah, Ajman, Umm Al Quwain, and Ras Al Khaimah.

28 UAE Ministry of Energy and Industry, *Annual Statistical Report: 2018* (Abu Dhabi: UAE Ministry of Energy and Industry, 2018), 52.

29 "The UAE Water Security Strategy 2036," The UAE Government Portal, updated February 5, 2020.

30 Khaled Ballaith and Mohammad El Ramahi, "Desalination Innovation in the UAE," *Water Online*, April 8, 2015.

31 "The UAE Water Security Strategy 2036," The UAE Government Portal, updated February 5, 2020.

32 Binsal Abdul Kader, "Abu Dhabi Completes World's Largest Desalinated Water Reserve," *Gulf News*, January 15, 2018.

In 2013, the ruler of Ras Al Khaimah established the Ras Al Khaimah Electricity and Water Authority through royal decree, but the government authority does not appear to be very active. Indeed, Ras Al Khaimah's installed desalination capacity is 2.4% of that of Abu Dhabi.

These water-related government authorities and their subsidiaries are undergoing various consolidations and mergers. In 2018, Abu Dhabi folded the Abu Dhabi Water and Electricity Authority into the Department of Energy.[33] The ruler of Abu Dhabi also established the Emirates Water and Electricity Company as a replacement for the Abu Dhabi Water and Electricity Company. The new entity will operate under the umbrella of the Abu Dhabi Power Corporation and alongside the federal entity, the Federal Electricity and Water Authority, which oversees water and electricity affairs in the northern emirates.[34] In early 2020, the Abu Dhabi Power Corporation announced plans to take over the Abu Dhabi National Energy Company – commonly referred to as TAQA – in an asset swap deal that would create a $54.5 billion integrated utilities firm.[35] These consolidation efforts aim to better integrate water production and electricity generation across the country.

The bureaucratic structure of desalination-related entities may be fragmented, but the spatial organization of desalinated water production is relatively concentrated. Despite dozens of active desalination plants in the country, only a handful of facilities produce the bulk of the UAE's desalinated water. Abu Dhabi's Shuweihat facility houses two plants with a combined capacity of 200 million imperial gallons per day. The emirate's Al Taweelah facility contains four operating plants with a combined capacity of 307 million imperial gallons per day, and a reverse osmosis plant under construction is expected to add another 200 million imperial gallons per day to the facility's total desalination capacity. The Umm Al Nar independent water and power plant, also in Abu Dhabi, possesses an estimated capacity of 145 million imperial gallons per day. In neighboring Dubai, a cluster of approximately 10 plants in Jebel Ali can produce around 552 million imperial gallons per day. Two plants in Fujairah possess a total capacity of 260 million imperial gallons per day, while Sharjah's Layyah plant can produce another 63.5 million imperial gallons per day.[36] Several much smaller plants with capacities ranging from 15,000 imperial gallons to 7 million imperial gallons per day are scattered across the country and located on territorial islands of the UAE.[37]

Despite dozens of active desalination plants in the country, only a handful of facilities produce the bulk of the UAE's desalinated water.

33 "Abu Dhabi's Utility Folded Into New Energy Department – Spokesperson," *Reuters*, March 25, 2018.

34 "Emirates Water and Electricity Company Will Replace Abu Dhabi Water and Electricity Company," *Arabian Business*, November 28, 2018.

35 Davide Barbuscia, "Abu Dhabi Power to Take Control of Taqa in Asset Swap," *Reuters*, February 3, 2020.

36 "United Arab Emirates," Torishima, accessed February 26, 2020; The Cooperation Council for the Arab States of the Gulf (GCC) General Secretariat, *Desalination in the GCC: The History, the Present & the Future* (Desalination Experts Group, Water Resources Committee, 2014), 34-35.

37 For a list of smaller desalination plants in the UAE, see: The Cooperation Council for the Arab States of the Gulf (GCC) General Secretariat, *Desalination in the GCC: The History, the Present & the Future* (Desalination Experts Group, Water Resources Committee, 2014), 34-35.

Desalination remains an overwhelmingly state-led commercial activity, but private sector actors are playing an increasing role in desalination processes. Abu Dhabi began privatizing independent water projects and independent water and power plants in the early 2000s, but emirate-level government entities usually retained a majority stake of the projects.[38] In most cases, the joint ventures are required to sell their water and electricity back to government-owned entities. Abu Dhabi Power Corporation and Mubadala Investment Company own 60% of the Al Taweelah project, and Saudi-based ACWA Power holds the remaining 40% of equity interest.[39] The operators of the Shuweihat S2 plant in Abu Dhabi include International Power GDF Suez (50%), Marubeni (25%), and Osaka Gas Co. (25%).[40] Sembcorp Utilities owns 40% of the Fujairah IWPP in Qidfa,[41] whereas Saudi-based ACWA Power owns 40% of the Umm Al Quwain IWP near the emirate's border with Ras Al Khaimah.

The Vulnerability of the UAE's Desalination System

According to analysts, the desalination system in the UAE – and wider Gulf region – presents multiple targets for hostile actors.[42] Indeed, Yemen's Houthi rebels announced that they struck a Saudi utility station in Shuqaiq, Saudi Arabia with a cruise missile in June 2019.[43] A spokesperson for the Saudi-led coalition operating in Yemen confirmed that a "projectile" landed near the station's desalination plant but did not harm any individuals or cause any infrastructure damage.[44] Drones launched by Houthi rebels in August 2019 caused a fire at a liquid natural gas facility near the Shaybah oil field along Saudi Arabia's border with the UAE.[45] The attack, although on Saudi soil, indicated that hostile actors in the region would similarly be capable of launching an attack on Emirati infrastructure.

The UAE's desalination system could experience any number of external shocks or disruptions. Plants in particular "are easily sabotaged; they can be attacked from the air or by shelling from off-shore; and their intake ports have to be kept clear, giving another simple way of preventing their operation."[46] Moreover, the subsystems surrounding the source of desalinated water, desalination plants, distribution networks, and storage facilities that deliver water to end users all present opportunities for disruption.

38 "Water Management in the UAE," *Fanack Water*, October 17, 2017.

39 Deena Kamel, "EWEC and ACWA Secure DH3.19 Billion for Abu Dhabi Desalination Plant," *The National*, October 19, 2019.

40 "Shuweihat S2 IWPP Project in Abu Dhabi Reaches Full Commercial Operation," Marubeni, March 14, 2012.

41 "SembUtilities Acquires 40% Interest in Fujairah Independent Water and Power Plant in UAE," Sembcorp Industries, updated 2020.

42 Seth G. Jones, Danika Newlee, Nicholas Harrington, and Joseph S. Bermudez, Jr., "Iran's Threat to Saudi Critical Infrastructure: The Implications of U.S.-Iranian Escalation," *Center for Strategic and International Studies*, 2019; Najmedin Meshkati, "Gulf Escalation Threatens Drinking Water," *LobeLog*, June 26, 2019.

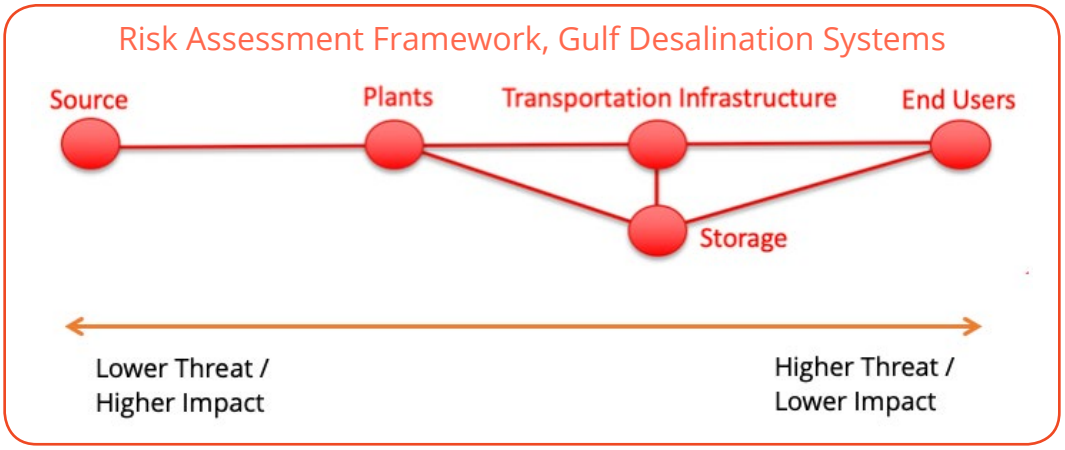
43 Stephen Kalin, "Yemen's Houthis Strike Saudi Utility Station, Coalition Responds," *Reuters*, June 19, 2020.

44 "قيادة القوات المشتركة للتحالف تحالف دعم الشرعية في اليمن : سقوط مقذوف معادٍ أطلقته المليشيا الحوثية الإرهابية المدعومة من إيران بالقرب من محطة تحلية المياه بالشقيق," *Saudi Press Agency*, June 20, 2019

45 Jon Gambrell, "Yemen Rebel Drone Attack Targets Remote Saudi Oil Field," *Associated Press*, August 17, 2019.

46 John Bulloch and Adil Darwish, *Water Wars: Coming Conflicts in the Middle East* (London: Victor Gollancz, 1993).

Moving from the source of water input toward the final destination of desalinated water, the opportunities to disrupt the successful delivery of that output increase exponentially. However, as water moves away from the original source, the impact is reduced. Within this context, any event that negatively affects the suitability of water sources for desalination would have the largest potential impact on end users, given that a large number of geographically concentrated desalination plants utilize just a handful of common water sources. Yet the threat of an intentional incident that renders Gulf water sources unsuitable for desalination remains unlikely because it would indiscriminately affect all countries utilizing water resources along the Arabian and Persian Gulf coastlines.



Intended and unintended contamination of water sources can negatively impact public health and safety, and there have been several occasions upon which incidents rendered water sources along the coastlines of Gulf Arab countries unsuitable for desalination. When Iraq retreated from Kuwait in 1991, the Iraqi military destroyed desalination plants and dumped millions of gallons of oil into Gulf waters. U.S. officials accused Iraq of opening valves at the Kuwaiti Sea Island Terminal on the country's southern coast creating a 35-mile oil slick that encroached upon the Saudi coastline. The environmental damage so endangered Saudi Arabia's desalination processes that that United States bombed Kuwaiti oil stations to stem the flow of oil.[47] In 1997, a barge grounded near Sharjah and the ensuing diesel spillage entered the intake of a nearby desalination plant leaving Sharjah without water for a day.[48] There are therefore persistent concerns over threats to water sources in the Gulf: another oil spill, harmful algae blooms, or a nuclear incident.

47 Philip Shenon, "War in the Gulf: The Overview; U.S. Bombs Kuwait Oil Stations, Seeking to Cut Flow Into Gulf; More Iraqi Planes Fly to Iran," *The New York Times*, January 28, 1991.

48 Walid Elshorbagy, Abu-Bakr Elhakeem, "Risk Assessment Maps of Oil Spill for Major Desalination Plants in the United Arab Emirates," *Desalination* 228 (2008): 200-16.

Cyberattacks also could disrupt operations. In 2012 and 2017, Saudi Aramco suffered cyberattacks aimed at disrupting oil and gas flows. The earlier attack damaged 30,000 computers, but it did not result in a major disruption to oil production.[49] On July 25, 2019, unidentified hackers also penetrated Bahrain's Electricity and Water Authority and took control of several systems, managing to shut some of them down.[50]

The network of pumps, pipes, and smaller-scale storage tanks used to transport water from the coastal desalination plants to end users are additional areas where infrastructure is vulnerable. The delivery of desalinated water relies on thousands of miles of pipes, dozens of pumping stations, and hundreds of short-term storage tanks in each country. The length of water transmission pipelines in just Abu Dhabi, Al Ain, and Al Dhafra spans over 2,300 miles.[51] Abu Dhabi's Liwa Water Reservoir alone involves a nearly 100-mile pipeline consisting of around 9,000 welded pipe sections.

Conclusion and Policy Priorities

The threats confronting critical infrastructure in Gulf Arab states are multifaceted and complex; desalination systems are no exception. Burgeoning domestic demand for water resources risks overwhelming desalination capabilities, depleting financial resources, and straining natural ecosystems in the UAE. Desalination plants, while often the focus of discussions on critical infrastructure vulnerabilities in the Gulf, nevertheless are merely one link in a chain of interrelated processes that deliver desalinated water from seawater sources to an end user or destination. To fully comprehend the threats confronting regional desalination systems, due consideration must be given to increasing local demand for water resources as well as external threats to the source, desalination plants, transportation networks (pipes, pumping stations, and short-term storage tanks), and longer-term water storage facilities (tanks, aquifers, and reservoirs).

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The UAE government is taking decisive steps to better manage the country's water resources, which can help to reduce the dependence upon desalination operations. The federal government has pushed to replace wasteful flood irrigation methods with modern irrigation systems. Adoption of these systems, which include sprinklers and drip irrigation techniques, increased from 32% in 1999 to 91% in 2011. The Ministry of Climate Change and Environment has also promoted the use of hydroponic technologies by many of the country's commercial farms. The process, in which plants grow with little or no soil, can save up to 70% of water required for growing plants.[52]

49 "Saudi Arabia Says Cyber Attack Aimed to Disrupt Oil, Gas Flow," *Reuters*, December 9, 2012.

50 Bradley Hope, Warren P. Strobel, and Dustin Volz, "High-Level Cyber Intrusions Hit Bahrain Amid Tensions With Iran," *The Wall Street Journal*, August 7, 2019.

51 Statistics Centre, *Statistical Yearbook of Abu Dhabi 2019* (Abu Dhabi: Statistics Center – Abu Dhabi, 2019), 288.

52 "Sustainable Agriculture," The UAE Government Portal, updated January 6, 2020.

Demand for desalinated water, though, remains high in the UAE. Abu Dhabi slightly decreased its annual desalinated water production by 6% and imports from Fujairah by nearly 9% between 2015 and 2018.[53] However, during the same period, Dubai's desalinated water production grew 9%, and desalination production levels stayed more or less the same in Sharjah.[54] Strong population growth in the country is a key factor in water demand. Between 2000 and 2018, the UAE's estimated population increased from 3.1 million residents to 9.6 million.[55] While population growth began to slow after 2011, total demand for desalinated water continues to creep upward. Generous water subsidies have also encouraged overconsumption and disincentivized investments in efficiency measures.[56]

Ongoing campaigns and initiatives press residents and firms to cut down on water usage. Abu Dhabi's government launched the Demand Side Management and Energy Rationalization Strategy 2030, which seeks a 32% reduction in water consumption over the next decade, and the emirate's Department of Energy has retrofitted eight government buildings to use more sustainable practices.[57] The Abu Dhabi Distribution Company is also engaged in a project to supply 4.4 million imperial gallons of recycled water from Yas Island to Saadiyat Island.[58] However, tangible progress has been slow. The UAE's average per capita water consumption rate remains around 550 liters per day – among the highest rates in the world.

There have been some limited regional cooperation initiatives to meet the Gulf states' growing demand for resources and prevent disruptions to the functioning of critical infrastructure. The General Secretariat of the GCC established the ministerial-level Water Resources Committee to work alongside the GCC's electricity and water department. GCC states created an electricity interconnector – a coordination mechanism intended to prevent power outages. However, electrical integration has not reached its full potential,[59] and cooperation over water resources has met with even less success. The UAE's water grid is not connected to that of neighboring countries. Indeed, none of the Gulf countries' water grids are interconnected. A senior Kuwaiti official from the Ministry of Electricity and Water, though, suggested that GCC governments remain open to improving the interconnectivity of regional water grids in remarks given to reporters on the sidelines of the March 2019 MENA Desalination Projects Conference in Abu Dhabi.[60]

Strong population growth in the country is a key factor in water demand. Between 2000 and 2018, the UAE's estimated population increased from 3.1 million residents to 9.6 million.

53 Statistics Centre, *Statistical Yearbook of Abu Dhabi 2019* (Abu Dhabi: Statistics Center – Abu Dhabi, 2019), 285.

54 "Annual Statistics 2018," Dubai Electricity and Water Authority, 2018; "Annual Statistical Report," Sharjah Electricity and Water Authority, 2018.

55 "Population, Total – United Arab Emirates," The World Bank, accessed February 12, 2020.

56 Michael Gallaher, Tanzeed Alam, and Nadia Rouchdy, "The Impact of Electricity and Water Subsidies in the United Arab Emirates," *RTI International*, May 2017.

57 Kasun Illankoon, "Feature – Sustainable Facilities Management," *Construction Business News*, February 12, 2020.

58 Anwar Ahmad, "Tap Water in Abu Dhabi Homes Safe to Drink," *Gulf News*, January 14, 2020.

59 David Wogan, "The Costs and Gains of Policy Options for Coordinating Electricity Generation in the Gulf Cooperation Council," *Energy Policy* 127 (2019): 452-63.

60 "GCC Countries Mull Water Interconnectivity," *Utilities - Middle East*, March 12, 2019.

In the absence of greater interconnectivity of regional water grids, the UAE will continue to expand its water storage capacity. Storage facilities need to be fortified and secured to protect against contamination and evaporation. With a storage capacity of 5.6 billion imperial gallons, Abu Dhabi's underground reservoir in Liwa is the world's largest desalinated water reserve. Water storage capacity in Dubai is more limited: The emirate possessed the capacity to store 830 million imperial gallons at the end of 2018.[61] However, Dubai is in the process of increasing its total storage capacity. New reservoir projects in Al Lusaily and Hatta, which are intended to be completed by the end of 2020, will increase Dubai's storage capacity to 1,010 million imperial gallons.[62] Fortified and expanded water storage facilities that increase the available supply of desalinated water will offer UAE residents and businesses additional protection against threats to desalination systems in the coming years.

As one of the world's largest producers of desalinated water, the UAE has an opportunity to promote continued innovation in desalination technologies, brine reduction techniques, and new water management strategies. New desalination plants in the country increasingly utilize reverse osmosis technologies rather than thermal processes, which consume around 3.5 times as much energy.[63] Greater adoption of renewable energy-based technologies, such as those explored in Masdar's 2013 water desalination program, may reduce the high energy consumption and environmental footprint of desalination operations.[64] The better management of concentrated brine waste and recycling of wastewater can also help to improve the sustainability of desalination in the UAE. Progress on these fronts will require continued, state-led investments and time. Meanwhile, the country's residents and companies must also reduce their water consumption – a critical step toward limiting the population's vulnerability stemming from a dependence on desalinated water.

61 "DEWA Awards AED 157 Million Contract for 60-Million-Gallon Water Reservoir Construction in Al Lusaily," Dubai Electricity and Water Authority, November 19, 2018.

62 Oscar Rousseau, "Dewa Awards $43m Construction Contract for AL Lusaily Water Reservoir," *Construction Week Online*, November 20, 2018; "DEWA Awards $78m Contract for Construction of Hatta Reservoirs," *Arabian Business*, November 11, 2018.

63 Masdar, *Renewable Energy Water Desalination Programme: The New Frontier of Sustainable Water Desalination* (Abu Dhabi: Masdar, 2018).

64 Ibid.