Desalination

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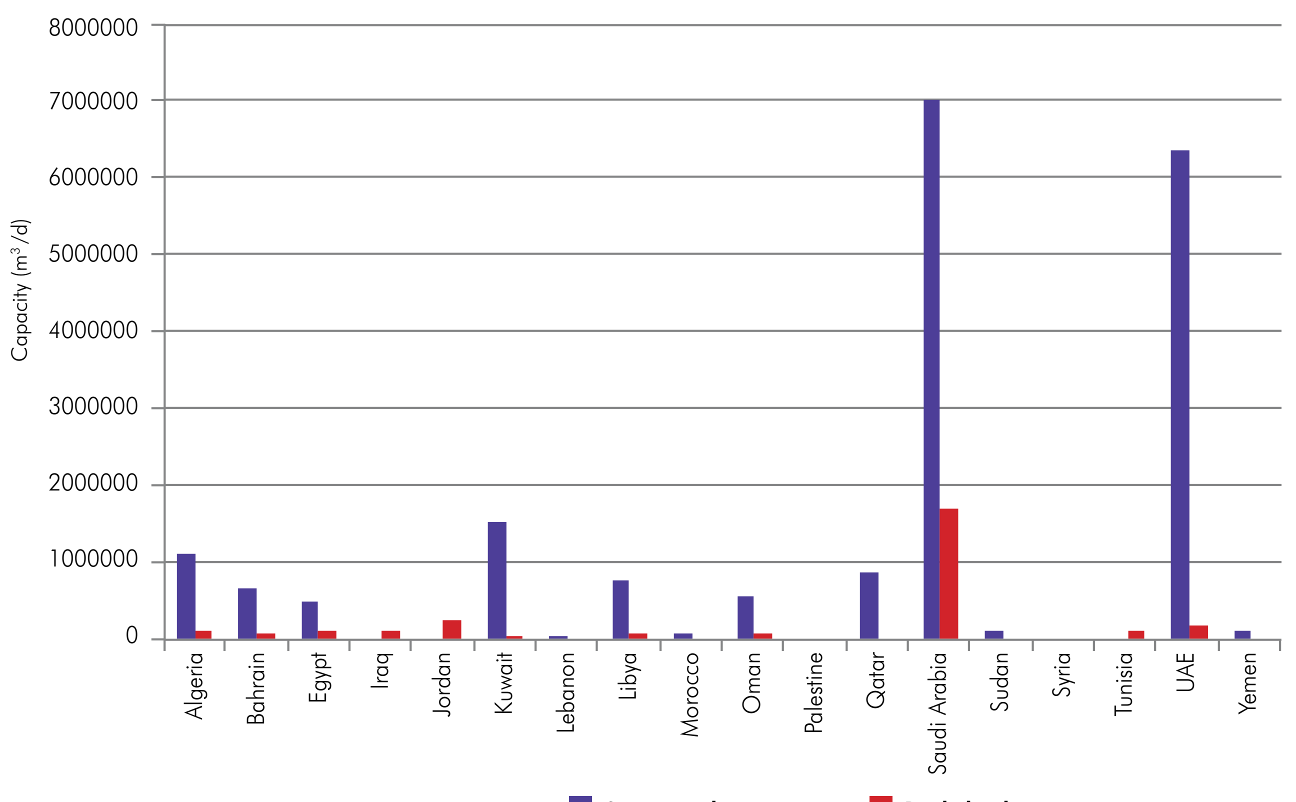
I. INTRODUCTION

Desalinated water represents a very small percentage of the water used in the world, however, it represents close to 100% of water supply for many Arab cities and for an increasing number of countries in the region. The cumulative capacity of all desalination plants contracted for in Arab countries since 1944 according to the Global Water Intelligence report is over 24 million m^3/day (GWI, 2010). This represents about 50% of total world's desalination capacity. The role of desalination as a major source of domestic water supply will continue to increase in Arab countries because of population growth, increased urbanization, industrialization, and depletion of non-renewable sources. However, reforms in policies and management practice are needed in most Arab countries in order to make desalination a sustainable water source. This paper highlights what reforms are needed and stresses the urgent need to put them in practice.

II. DESALINATION PRACTICES IN ARAB COUNTRIES

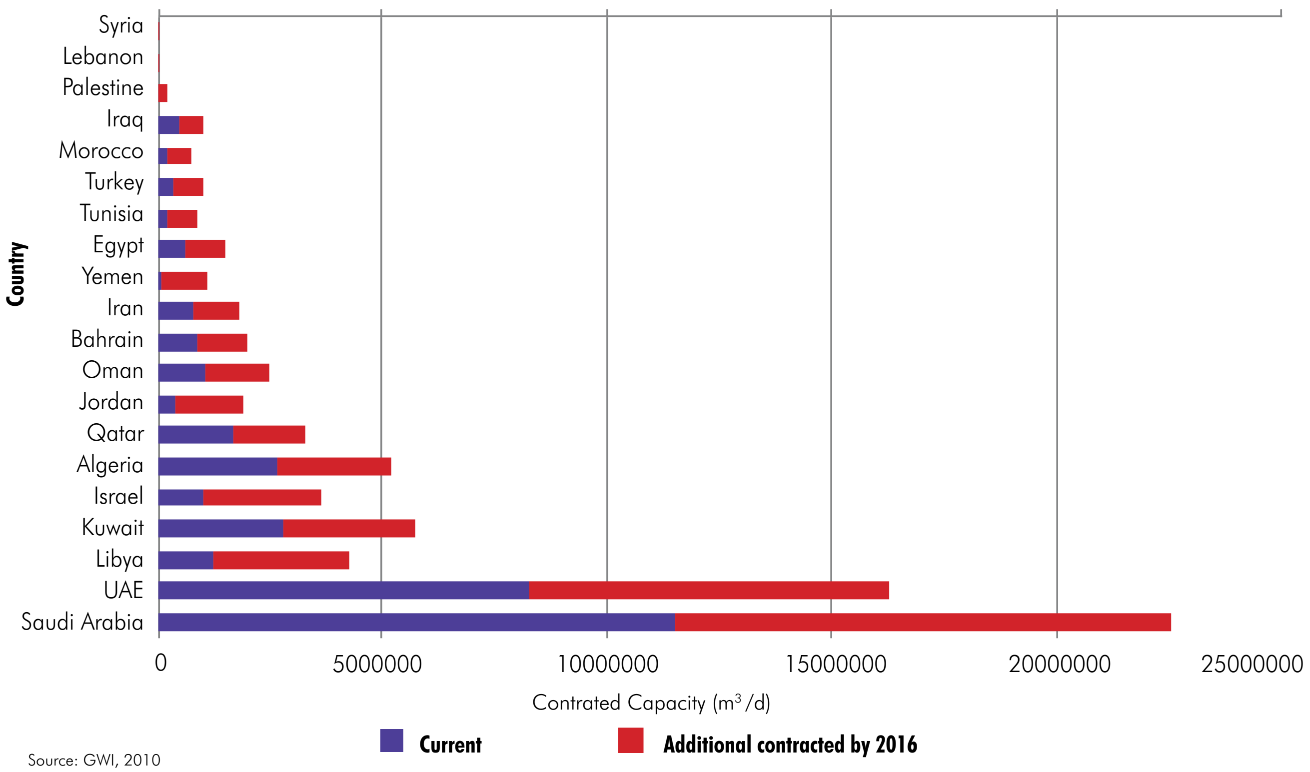
Water scarcity in the Arab region has brought desalination solutions thousands of years ago into Mesopotamia, Alexandria, and Palestine (Al-Sofi, 2000). In modern history, desalination came back to the Red Sea during the late 19th Century in cities like Sawakin, Abu-Qair, Aden, and Jeddah. According to Al-Sofi (2000), "In Jeddah, the first single effect distiller was deployed around 1895." It was known locally as Kindasa, and was refurbished after WWI and again after WWII, making Jeddah the first city to rely on seawater desalination for meeting its drinking water needs for more than 100 years. Similar units were deployed in Bahrain and soon after multi-effect distillers were installed in Kuwait, Dhahran, Ras Tanurah, and Al-khobar. Al-Sofi (2000) reports that "During the fifties, Multi Stage Flash (MSF) was applied commercially first in Kuwait." The first seawater desalination plant to employ reverse osmosis

FIGURE 1 TOTAL CUMULATIVE CONTRACTED CAPACITY OF DESALINATION PLANTS SINCE 1944 IN CUBIC METERS PER DAY



Source: GWI, 2010

FIGURE 2 ACCUMULATED CURRENT AND NEAR TERM TOTAL CONTRACTED CAPACITY IN MENA



Source: GWI, 2010

(RO) for municipal water supply outside the USA was commissioned in Jeddah in 1978.

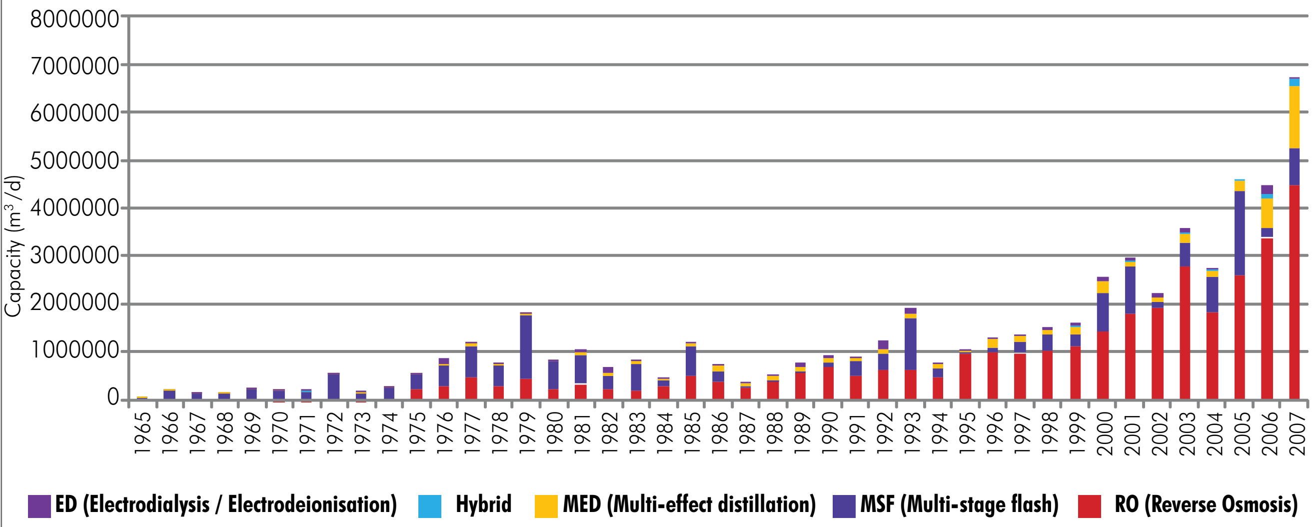
As outlined above, most present day commercial desalination technologies have been developed through large-scale applications in a number of Arab countries. Today, member countries of the Gulf Cooperation Countries (GCC), Algeria, Libya, and Egypt are the largest users in the region, as indicated by their total cumulative contracted capacity of desalination plants since 1944 in Figure 1.

The high rate of annual increase in contracted capacity will be maintained over the next decade (GWI, 2010), as shown in Figure 2. This large expansion requires a review of present policies and practices including how to increase local capacity, knowledge, and added value to the local economies.

Most large desalination plants are built by government utilities such as the Saline Water Conversion Corporation (SWCC), Abu Dhabi Water & Electricity Authority (ADWEA), and Dubai Electricity and Water Authority (DEWA), or by government water ministries. It is customary for governments to take a number of years before agreeing to a major water plant contract, followed by a multi-year construction period, while the demand growth in major cities continues to rise at a high rate. This leads to a time gap between demand peak and supply and causes known cycles of water shortage and over-capacity. This predicament could be addressed by introducing reforms to water plant procurement and announcing in advance any new or expanded capacity needed to be contracted in each city or region. More details on reforming this process will be discussed later in this paper.

Another policy reform that should be introduced is giving priority to reducing water leakage and unaccounted for water in the distribution system before building additional desalination capacity. Integrated water resources management (IWRM) principles provide a practical framework for introducing such practices. Before sinking large amounts of capital into augmenting supplies, less expensive investments that reduce water losses should be implemented first.

FIGURE 3 GLOBAL CONTRACTED CAPACITY BY TECHNOLOGY



Source: GWI, 2010

In the region, local capacity and knowledge are focused on operations and maintenance (O&M), but not on plant design, manufacturing, or construction even in countries heavily dependent on desalination for meeting a major percentage of their domestic water. Exceptional local talent is available but it is not adequate to meet the enormous demand for additional thousands of technicians and engineers needed every year to meet the growing demand for skilled labor in Arab countries. Without strong government support, the state of the desalination industry and business will remain fragile, meeting the same fate of other technology-based industries.

III. DESALINATION TECHNOLOGY TRENDS

Reverse Osmosis (RO) technology has been the most widely used process in the world over the past 25 years as shown in Figure 3. GCC countries tend to cogenerate electricity and water in large plants in order to increase fuel efficiency. This is why thermal desalination technologies are most common in these countries. However, when electric power is available or brackish water is the feed source, membrane technologies are used.

Commercial technologies used today in desalination can be grouped into two categories, namely, thermal and membrane, as follows:

Thermal:

MSF : Multistage Flash
MED : Multiple Effect Distillation
VC : Vapor Compression

Membrane:

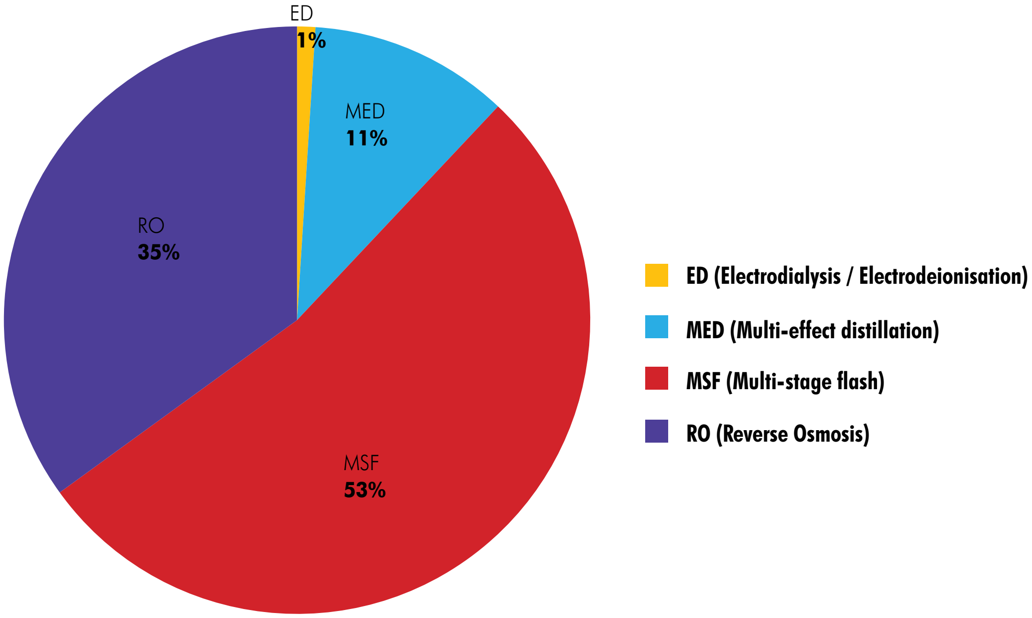
SWRO : Seawater Reverse Osmosis
BRO : Brackish Water Reverse Osmosis
ED : Electro-Dialysis
NF : Nano-Filtration

The choice of technology used for desalinating brackish water is dependent on the level of salinity. Reverse osmosis is used mostly today for higher salinity brackish water, while electro-dialysis is more efficient for lower salinity brackish feed.

Figure 4 provides a breakdown of the cumulative contracted capacity by technology in the MENA region since 1944. The multistage flash (MSF) process still dominates the market, although installed capacity for reverse osmosis has increased recently.

RO is increasingly used in the world today because of its lower cost and improved membranes. Hybrid technologies, e.g., MSF/RO or MED/RO, can be used in the future to increase efficiency when power generation is required. Future large cogeneration plants may combine NF/MSF/MED/RO if present pilots and technical solutions prove to be commercially competitive.

FIGURE 4 CUMULATIVE CONTRACTED CAPACITY BY TECHNOLOGY SINCE 1944 IN THE MENA REGION



Source: GWI, 2010

There are a number of new desalination technologies under development in many parts around the world. These new technologies include membrane distillation, carbon nanotube membranes, aquaporin (biomimetics) membranes, thin film nano- composite membranes, forward osmosis, and electro-dialysis/deionization. However, some desalination experts doubt that these technologies hold great promise for desalination of seawater (Hanbury, 2010).

IV. DESALINATION CHALLENGES

For Arab countries to make desalination a sustainable source of water, local challenges must be overcome and specific policy and management reforms must be implemented.

a. Managing Cost

Desalination is capital and energy intensive. The lower cost options are sensitive to operating skills and variations in feed water quality. The capital cost depends on water quality, production capacity, required infrastructure, plant efficiency, material selection, and other location factors. From my experience, the unit capital cost in 2010 for seawater desalination plants typically ranges from $1000 to $2000 /m^3/day of installed capacity. The unit capital cost for brackish water plants is estimated at 25%-45% of the above unit cost for seawater plants. The relative operating costs of the three main desalination processes is shown in Figure 5 for cogeneration plants. The operating cost of thermal plants is much higher than those shown below if waste heat or steam is not available on site. Desalination is usually the most expensive water source option among other local options.

The above analysis illustrates why cost management is a challenge for decision makers. A different policy discourse, as detailed below, can make a difference.

- The first source option that needs to be implemented is to reduce leakage in the distribution network along with promoting water saving policies and incentives before embarking on building new desalination plants. This course of action may take years to realize its advantages. However, it will bring about significant savings in capital costs resulting from reduced outlays for new water plants.
- Government agencies should consider a shift in their role from a procurer of desalination plants to a purchaser of water. This policy

FIGURE 5 RELATIVE OPERATING COSTS OF DESALINATION PROCESSES IN COGENERATION PLANTS

Source: GWI, 2010

shift would guarantee the most efficient technology and operation are deployed. It would also contribute significantly to the building of local skills and capabilities and the enlargement of the role of the private sector in the desalination industry. More critically, the role of government would shift to that of a regulator rather than an operator. To maximize the benefits of this policy, government agencies should make public the quantity of water they anticipate to purchase by year in each city.

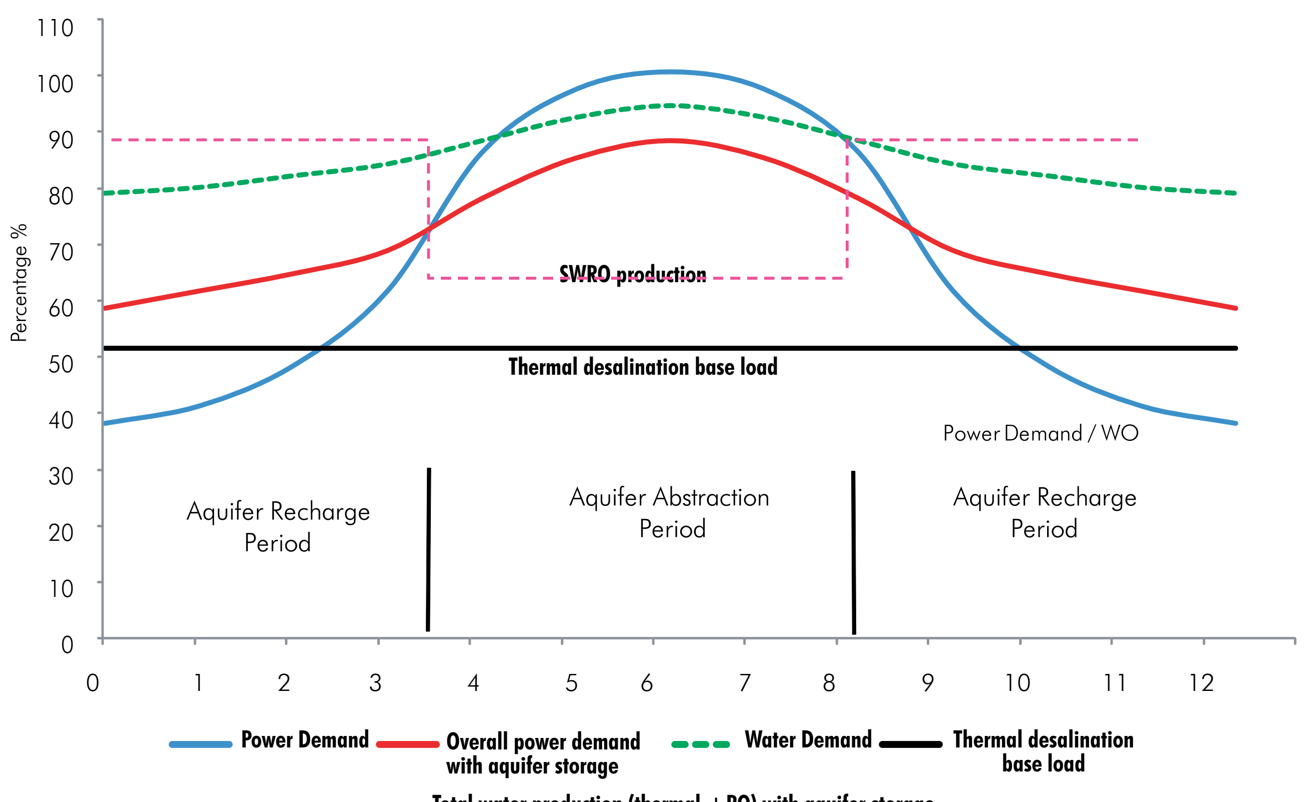
- If government organizations continue to be charged with building and operating large desalination plants, steps should be taken to manage these assets based on minimizing the life cycle cost of water. Government corporations should be set up for this purpose. Acting like business enterprises, these government corporations should be expected to value energy at world market prices and grant incentives to set up research and development (R&D) departments to promote in-house innovations in technology and operation. They should be expected to take some risk by piloting new technologies. Internal audits can be used to monitor their performance
- Governments should revisit the assumption that bigger plants reduce cost. Mega plants are usually built at locations remote form dense urban areas, particularly if cogeneration is used. The additional costs of transporting, storing, and distributing water could make smaller decentralized plants less expensive, strategically safer, and less disruptive. In addition, more bidders for smaller size plants will be able to compete for contracts, leading to reduced capital costs and shorter construction times.
- Recovering selective, high-value minerals and metals from the brine of mega desalination plants may increase the economic return on investment and contribute to reducing water cost.

b.Sustainable Desalination

To achieve financial and environmental sustainability for desalination as a water source the following challenges must be addressed:

- Water tariffs must be imposed to recover the total cost of water and wastewater including distribution, allocation, treatment, and environmental impact. To ensure water access to the poor, only targeted subsidies may be used.

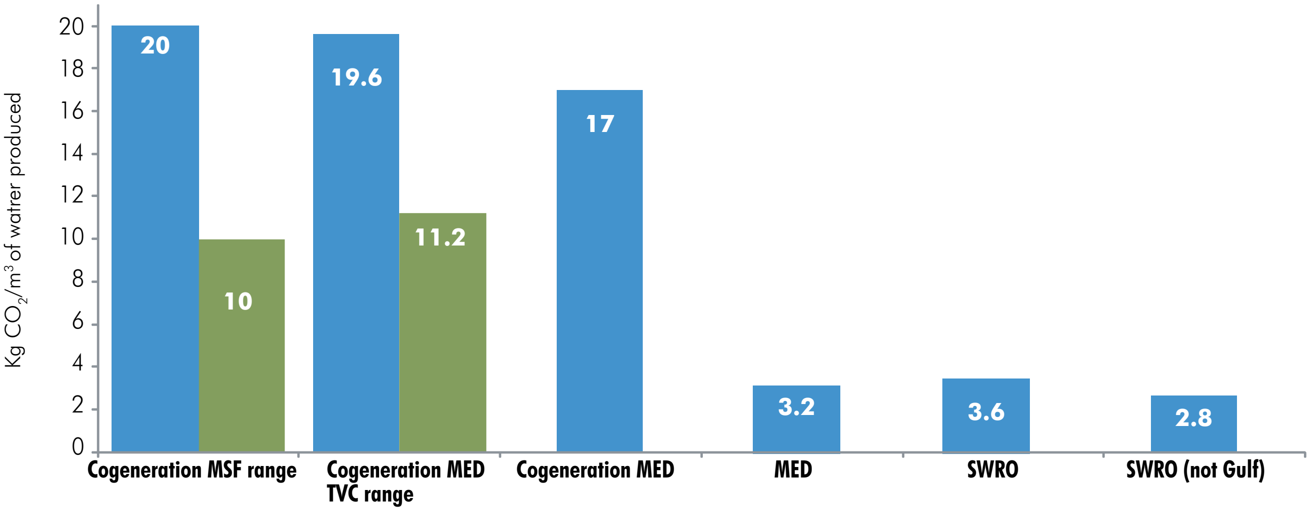
FIGURE 6 **OPTIMIZATION OF ENERGY SUPPLY USING AQUIFER STORAGE AND RECOVERY**



Source: Sommariva, 2010

- Using renewable energy sources abundantly available in Arab countries, such as solar power, for desalination can contribute greatly to achieving sustainability, reducing the carbon footprint, and transforming the local economy to knowledge based production with proper R&D incentives and support to small local businesses. Arab countries should cooperate regionally to maximize the use of their tremendous solar power, particularly for water supply.
- Energy efficiency should be a key criterion in commissioning new plants and upgrading old plants. However, energy efficiency will not be enabled if available fuel is accounted for at well below the market price, as is the case in most GCC countries. At present, 25% of Saudi oil and gas production is used locally to generate electricity and produce water (Al-Hussayen, 2009). With present demand growth rates, this fraction will be 50% by 2030 (Al-Hussayen, 2009). It is clear that the Saudi economy cannot prosper under this business as usual scenario.

FIGURE 7 CARBON EMISSIONS IN KG CO_2 PER UNIT VOLUME (M^3) OF WATER PRODUCED IN COGENERATION PLANTS



Source: Sommariva, 2010

- A source of energy efficiency is to use the large standby electric generating capacity available in most GCC countries to produce and store water during off peak hours as shown in Figure 6. Aquifer storage and recovery under or close to desalination plants should be investigated and developed to realize the potential of this solution. Water and power cogeneration experts believe that such an initiative makes sense in countries like the UAE but not in Saudi Arabia because the latter uses the electricity generated from its cogeneration plants for base load (Al-Sofi, 2010).
- Adopting a decentralized system of smaller desalination plants should be pursued in order to (a) increase the overall availability, (b) reduce transport, leakages, and associated distribution system costs, (c) achieve short implementation schedules for project sourcing, construction, and management, (d) ensure water security through multiple unit availability, and (e) provide opportunities to local contractors who would be able to manage smaller projects efficiently and economically as opposed to mega projects which require the logistical expertise of only global contractors.
- Governments should design incentives for local businesses to attract investments in manufacturing locally key components of the desalination plants such as the RO membranes, high-pressure pumps, and energy recovery devices. This can be achieved by initially assisting local manufacturers produce in accordance with international quality standards and by forcing turnkey contractors to procure locally.
- Governments should support local start-ups and investments in knowledge based sectors of the economy in order to cultivate innovation locally and to attain economic sustainability in strategic industries such as desalination and solar energy. Arab countries should be world leaders in products and services in these two strategic sectors because their economies are dependent on those two sectors and will be the first to benefit.

c. Environmental Concerns

Desalination plants pose a number of serious environmental concerns that need to be addressed.

- The main environmental impact of most desalination plants is related to the source of its energy and carbon footprint. Figure 7 shows the large variance in the carbon footprint of common processes used today in cogeneration plants. The carbon footprint of MSF plants ranges from 10-20 kg CO_2/m^3 and for MED/TVC the range is 11.2-19.6 kg CO_2/m^3 depending on the rate of the heat cycle (Sommariva, 2010). For single purpose thermal plants (not shown in Figure 7), the

FOG WATER IN SAUDI ARABIA AND RAINMAKING IN THE UNITED ARAB EMIRATES

Fog water collection is a scientific process employed in many places around the globe. The Saudi Fakieh Research and Development Center conducted a field project in three different locations within Asir region in Saudi Arabia. These were the Rayda Reserve, Al-Sahab Park (both in al-Sooda district) and the city of Abha.

Researchers compared the economies of this process and other methods of obtaining water such as desalination and pumping out groundwater; their findings confirmed that the costs of fog water were much less than the other methods, not to mention producing better quality water.

The research team designed and constructed three standard fog collectors (SFCs), based on the design of the collectors previously used in Chile. Each SFC consists of a 1m x 1m cloth mesh of a certain shading degree, metal poles, a metal trough, conduits and pipes, and collection containers; in addition each unit was protected by a metal lattice cage around it. These three sites were chosen in the light of a field study of the locations where fog is common.

Water collection from fog, on a daily basis, started at the end of March 2006, with special attention to obtain the highest daily average amount of water collected from fog, especially in winter, since the season of thick fog starts usually with the beginning of winter.

By comparing the amounts of fog water collected in Asir Region with the yield of collecting devices in some other parts of the world, it was evident that al-Sooda volumes were the highest globally. This is due to the high elevation above sea level (2260 - 3200m), the geological and climate conditions, the location of the Asir mountain range near the Red Sea and the prevailing wind direction in the area (from the sea towards the mountain range).

It should be noted that water sources available in the area of the project are limited to desalinated water, groundwater and fog water. The average amount of collected fog water in the experiment area reveals the considerable economic benefits of this technology. In the absence of any large-scale fog water collection project, so far, a preliminary economic comparison shall be made between the provision of 28m^3 of desalination water for the inhabitants of the project area (al-Sooda) and the collection of an equivalent volume from fog, over a period of 12 years, which is the service life of the mesh used in the collectors.

Based on the adequate results of fog water collection in al-Sooda, and considering that fog is common in the area all year round, especially in winter when it becomes more dense with less rain, the study concludes with a recommendation that this method of obtaining water be deployed- even for potable water after proper treatment. Moreover, fog water collection had been used in other places in the world with lower altitudes and less fog than Asir region.

In the United Arabs Emirates (UAE), successful attempts have been made to raise precipitation levels by 10% through cloud seeding, by designated aircraft that disperse silver iodide powder into cumulus clouds, thus increasing water droplets and inducing the fall of rain.

UAE needs to increase its available water supply to meet the needs of its growing population, especially in the absence of any rivers or lakes, in spite of the fact that groundwater is found in desert oases such as in Al-Ain and Liwa. Water desalination plants are the major source for drinking water and irrigation, but are highly expensive and energy-guzzling.

A cloud seeding project is under way in the mountainous Al-Aiyn area, east of the capital Abu Dhabi, where most arable lands lie. In 2009, 97 aircraft flights were made to increase precipitation. However, rainmaking attempts will be enhanced since the UAE has recently bought of a fleet planes that it used to charter.

Abdul - Razzaq Sultan, Al-Bia Wal-Tanmia (Environment & Development) magazine

SOLAR DESALINATION PLANTS IN ABU DHABI

The Environment Agency-Abu Dhabi (EAD) established two pilot stations powered by solar energy for the desalination of highly-saline ground water. Dr. Mohamed Dawoud, Manager of Water Resources at EAD, says that using renewable energy sources in desalination is a significant turning point in the development of desalination industry in the region, because it will lead to lower costs and increased efficiency. The process involves solar energy collection technology and desalination units employing reverse osmosis membranes.

The real challenge, according to Dawoud, is to increase the efficiency of such solar collector systems and minimize the environmental impact. However, EAD is currently setting up a mechanism for the safe disposal of discharge water, by raising the two stations' efficiency by more than 80% and possibly using the high-salinity water in producing salts, livestock feed or agricultural fertilizers. This will eventually enhance the economic efficiency of such solar systems and minimize the environmental impact of dumping discharge water in the Gulf or injecting it in deep aquifers.

Al-Bia Wal-Tanmia (Environment & Development) magazine

carbon footprint is many multiples of these figures if waste heat is not available. It is also important to note that, in order to save capital cost, almost all thermal plants built in the GCC countries do not use a low heat cycle, which results in a higher carbon footprint. It is also useful to note that the carbon footprint of power generation plants ranges from 0.5-0.8 kg CO_2/kwh depending on the type of fuel used and plant efficiency (Sommariva, 2010).

- The impact of the reject water from thermal desalination plants has not been studied in depth at a regional level. There are concerns raised, however, about the effects of brine discharge on the marine environment. According to a World Bank (2007) report, "discharge of hot brine, residual chlorine, trace metals, volatile hydrocarbons, and anti foaming and anti-scaling agents are having an impact on the near-shore marine environment in the Gulf." The increasing number of plants on the Gulf and the rising temperature of its water warrant extensive studies and modeling to resolve future environmental challenges and possible solutions.

- The impact of SWRO brine on marine life can easily be minimized by proper dilution and outlet design. However, brine of BRO plants continues to have environmental and cost concerns. Reducing BRO brine and utilizing it for other benefits like energy production should be a priority.
- No immediate health concerns have been observed for decades in GCC countries linked to the quality of drinking desalinated water. However, more studies are needed to establish the health limits of certain minerals in local environments.
- Environmental laws regulating the building and operation of desalination plants exist in some Arab countries but they are not enforced. Resources should be allocated to ensure compliance by both private and government-owned facilities.

d. Capacity Development

Developing local capacity includes acquiring the ability to create leading edge knowledge and the capability to utilize this knowledge to add economic value through innovation and global marketing. It also includes nurturing local leadership and providing financial and logistical support to enable local human talent to create world-class value from their ideas. The following reforms can help realize the above:

Arab governments should provide generous financial support to help develop and pilot test new technologies. They should also endow local and regional universities with trust funds to jumpstart the establishment of new venture capital companies. This would bridge the existing gap between business and most universities in Arab countries. Some countries (e.g., Saudi Arabia) have large allocations for ambitious science and technology initiatives based on the above model. It remains to be seen how local universities will be able to convert their intellectual research ideas through entrepreneurship into high-value economic assets.

Most Arab countries do not have venture capital funds or government-supported funding for high-risk new technology firms. Tunisia, followed by Morocco, are the only exceptions. The vital role of government planning and support to build and enhance capacity for locally-based knowledge is best seen in Japan and South Korea which enabled their economies in a few decades to be world leaders in new industry and technology.

Arab governments should grant generous scholarships for promising students and offer financial support to allow local utilities build training centers. The Saudi government in partnership with local companies builds and equips such specialized training centers to increase job opportunities for citizens. The saline Water Conversion Corporation (SWCC) has the only desalination focused training center in the region.

The Arab Water Council is taking a proactive role in capacity building by establishing the Arab Water Academy (AWA) and the Arab Desalination Technology Network to facilitate networking, capacity building, and cooperation among desalination experts in Arab countries and the world at large. The Arab Water Academy, based in Abu Dhabi, is a good example of the benefits of regional Arab cooperation. The AWA has already started its capacity building programs in water governance. It has also organized in 2010 the first meeting gathering key leaders in charge of water organizations in Arab countries, which is expected to generate more useful inter-Arab initiatives and joint programs in capacity development.

The National Water Company in Saudi Arabia is embarking on an ambitious project to build a National Training Center in Jeddah to serve the whole region and be a world model in combining training with technology development to sustain knowledge and innovation in all water related fields including desalination.

V. RECOMMENDATIONS

The following actions are suggested to make seawater desalination a more sustainable source of water:

- Increase water tariffs to recover the total cost of water supply and wastewater services in order to achieve financial and environmental sustainability of water services provision. Smart, targeted subsidies directed to the poor, as opposed to general water subsidies, must be used in order to ensure conservation and social equity.
- Reduce network water leakage and unaccounted for water before augmenting supply by expanding the capacity of desalination plants or constructing new ones. This is essential to ensure conservation of natural and financial resources.
- Shift the role of municipalities and major water users to purchasing bulk water at a minimum unit price at specified quality and quantity instead of buying turnkey desalination plants. Governments should opt out of owning and operating physical desalination plant assets and assume a regulatory role. Public-private partnerships as well as water trust/waqf models should be expanded.
- Establish government utilities as independent water trusts (Waqf) or operate them as self-financed business corporations in order to provide reliable and sustainable water at minimum cost for present and future generations.

- Require all new desalination plants to reduce energy consumption and reduce carbon footprint per unit water produced. Arab governments should set a maximum limit on water carbon emissions.
- Developing new solar powered desalination technologies for small and large systems must be among the top priorities of Arab countries' research and development programs. Arab based technical solutions and products for solar desalination and cogeneration can provide a strong economic base for many countries in the region. Arab countries need to plan for exporting solar power for their future prosperity as much as they rely on oil and gas exports today.
- Establish and enforce existing environmental standards for all desalination plants whether they are owned by the private sector or public government entities. Air and water pollution from many government-owned and operated plants must comply with regulatory standards according to set deadlines.
- Governments must provide generous support to private investments in R&D, training, high technology venture capital, and knowledge based local industries. Such support should be integrated to achieve desired national local economic outcomes and meet export targets in strategic industries like desalination and solar power.
- Arab countries should develop joint R&D programs in desalination and renewable energy and maximize the value of new ideas and research findings emerging from new institutional knowledge hubs such as King Abdullah University for Science and Technology (KAUST) and Qatar Foundation.

VI. CONCLUSION

Desalination can be a sustainable source of water for Arab countries and a driver to a knowledge based economy if the reforms and recommendations outlined in this paper are implemented. Governments should start by implementing water tariff reforms, water conservation, and integrated water resources management programs. Solar powered desalination should be a priority for technology development for Arab countries. Water conservation and demand management for all water uses, especially agriculture, should also be a priority area for policy reform.

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