# Promotion of Solar Desalination in the MENA Region

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**Abstract**

Desalination has become one of the sources of water supply in most of the countries in the Middle East and North Africa (MENA) region. All MENA countries lie in the Sunbelt region and have the space needed by solar technologies. Success in implementing solar technologies in desalination depends on the progress made or to be made to convert solar energy into electrical and thermal energies economically. This is because desalination processes need these types of energies. Since desalination is energy intensive, the wider use of solar technologies in desalination will eventually increase the demand on these technologies, making it possible to go for mass production of PV cells, collectors and solar thermal power plants. This would ultimately lead to the reduction in the costs of these technologies. Per unit, the energy consumed by the desalination processes has been reduced significantly in recent years meaning that, if solar technologies are to be used, less PV modules and area for collectors would be needed.

## 1. Introduction

Desalination of brackish and seawater has become one of the viable solutions for the water shortage in the Middle East and North Africa (MENA) region. Desalination processes are energy intensive. Some of the countries of the region are blessed with conventional sources of energy; oil and gas, while others are not. In the oil rich countries the water problem is solved by large desalination plants powered with conventional energy. In rural areas, one option is to develop small to medium scale desalination units that can treat brackish or seawater. In the non-oil producing countries, the small-scale units could use solar energy in order to limit the use of expensively purchased fossil fuels.

Solar energy coupled to desalination offers a promising prospect for covering the fundamental needs of power and water in remote regions, where connection to the public electrical grid is either not cost effective or not feasible, and where the water scarcity is severe. The MENA region has outstanding solar resources. This can be captured for use either by Photovoltaic (PV) devices or by direct absorption as thermal energy. The distribution of this resource is more evenly spread over the entire region than other Renewable Energy (RE) resources, which tend to be site specific. Vast areas are available for this resource to be utilized. The long-term development of this on a large scale will hinge on technical developments that will reduce the cost of electricity generated by PV or by solar thermal power plants. Although solar desalination systems cannot compete with conventional systems in terms of the cost of water produced, they remain applicable to certain areas and are likely to represent more widely feasible solutions in the near future.

Worldwide, several solar desalination pilot plants have been installed and the majority have been successful in operation. Virtually all of them are custom designed for specific locations. Solar desalination is an important challenge and much useful work has been done. However, in order to provide practical viable plants, much more remains to be done. Operational data and experience from these plants can be utilized to achieve higher reliability and cost minimization.

In this paper, desalination processes, the status of desalination, solar technologies, matching solar technologies with desalination processes, and the promotion of solar desalination in the MENA regions are addressed.

## 2. Desalination processes

Desalination is a separation process that produces two streams, fresh water and saline solution (brine). Saline water is classified as brackish water when the salt concentration, mostly sodium chloride, is between 1,000 ppm and 10,000 ppm, hard brackish water when the salinity is 10,000 ppm to 35,000 ppm, and seawater when the salinity exceeds 35,000 ppm.

Two main commercial desalination technologies have gained acceptable recognition throughout the world, namely those based on thermal or on membrane processes.

Membrane processes include Reverse Osmosis (RO) and Electrodialysis (ED). Whereas ED is more suitable for brackish water, RO can be used for both brackish and seawater. Thermal processes, on the other hand, are normally used for seawater desalination due to their high-energy requirements. Whereas membrane processes rely on an electricity source to drive the process, thermal processes need condensing steam.

Thermal processes, except freezing, mimic the natural process of producing rain, where saline water is heated, producing water vapor that is in turn condensed to form fresh water, thus producing fresh water by distillation. These processes include Multi-Stage Flash (MSF), Multi-Effect Distillation (MED), and Vapor Compression (VC) Distillation. In all these processes, condensing steam is used to supply the latent heat needed to vaporize the water. Very pure water can be produced from these processes with TDS< 25 ppm and sometimes < 10 ppm. Such quality water is needed in many industrial processes such as power plants, refineries, chemical and petrochemical industries. It can also be blended with existing water sources to increase local potable water sources and enhance their quality. Thermal processes are not sensitive to the type of feed water with regard to salinity and contamination, because the product water is the condensed water vapor, leaving all the impurities in the liquid phase. This makes thermal processes more suitable to water with high salinity and microbiological content.

Thermal processes are robust, durable and, once in operation, require less maintenance. However, these processes, mainly MSF, require large amount of energy for their operation. In fact, up to 50 percent of the operating cost may be attributed to providing energy for the operation of the plant. As a result, many thermal plants are constructed in conjunction with power plants to utilize exhausted steam from the latter. The associated costs of high-energy consumption can have particularly strong restraining effects on small and medium sized plants. However, thermal processes can utilize low grade, low cost source of heat, which would otherwise be lost and discarded to the environment like stack gases, cooling water streams or low pressure exhaust steam. Heat from solar energy can also be used in such processes. In such cases, thermal processes that operate at low temperatures like the Low Temperature Multi Effect Distillation (LT-MED) and the Low Temperature Multi Effect Mechanical Vapor Compression (LT-MEMVC) can be used.

MSF and MED processes consist of a set of stages/effects at successively decreasing temperature and pressure. MSF process is based on the generation of vapor from seawater or brine due to a sudden pressure reduction when hot seawater enters to an evacuated chamber. The process is repeated stage after stage at successively decreasing pressure. This process requires an external steam supply, normally at temperature around 100 $^oC$. The maximum temperature is limited by the salt concentration to avoid scaling and this maximum limits the performance of the process. In MED, vapor is generated due to the absorption of thermal energy by the seawater. The steam generated in one effect is transferred to the next effect to heat the salt solution because the next effect is at lower temperature and pressure. The performance of the process is proportional to the number of effects. MED plants normally use an external steam supply at temperatures of about 70 °C. In TVC and MVC, after initial vapor is generated from the saline solution, this vapor is thermally or mechanically compressed to generate additional production.

Membrane desalination processes, do not involve phase change, are reverse osmosis (RO) and electrodialysis (ED). The former requires electricity or shaft power to drive the pump that increases the pressure of the saline solution to the required level. This required pressure depends on the salt concentration of the saline solution source which is normally around 70 bars for seawater desalination. On the other hand, ED only requires electric current to deionize the water. Both of them, RO and ED are used for brackish water desalination, but only RO competes with distillation processes in seawater desalination.

Energy consumption in desalination processes is variable. When stand alone, MSF and MED plants require 290 MJ/m$^3$. Correspondingly, 160 MJ/m$^3$ are required when connected to power plants. The electrical consumption in these plants is 3.6 and 2.3 kWh/m$^3$ in MSF and MED, respectively. In RO plants and for seawater, electrical consumption is about 10 kWh/m$^3$ without energy recovery, 2-5 kWh/m$^3$ with energy recovery depending on the type of energy recovery system used. For small plants, the power consumption may exceed 15 kWh/m$^3$. In the case of brackish water desalination, the requirement is 1-3 kWh/m3 for RO. For ED, the electrical consumption can vary from 0.5 – 10 kWh/m$^3$ depending on water salinity. Assuming product salinity of 500 ppm, for example,1.5 and 4 kWh/m$^3$ are needed for feed water salinity of 1,500 and 3500 ppm, respectively. For MVC, the requirement is 8.5 – 16 kWh/m$^3$ depending on the plant size.

## 3. Status of desalination

Desalination has become a viable solution to augment water supply in many MENA countries as well as other countries in the world. The growth of this business has been due to the high demand on water encouraged by falling desalination costs which are, for new projects, in the order of US$ 0.5/m$^3$ with RO and less than US$ 1.0/m$^3$ for thermal processes. Both prices are now achievable in large plants.

Figure 1 below, prepared using the data from Wangnick Report No. 17, shows the growth of desalination in GCC countries, MENA region, and worldwide up to December 2001. About 60% of the desalination capacity worldwide is taking place in the MENA region. The GCC countries and Libya have the major share. Actually, Saudi Arabia is ranked first worldwide, followed by USA, then UAE. Most of the desalination in GCC countries and Libya is done by thermal processes (MSF and MED), mainly MSF. Thermal processes have been used due to the low cost of energy in these countries and the problems faced by membrane processes in dealing with the high salinity of the Arabian Gulf water. Membrane processes were not so successful due to fouling and scaling problems. However, latest developments in RO process are making end users reconsider their options; several plants are coming up in the Arabian Gulf.

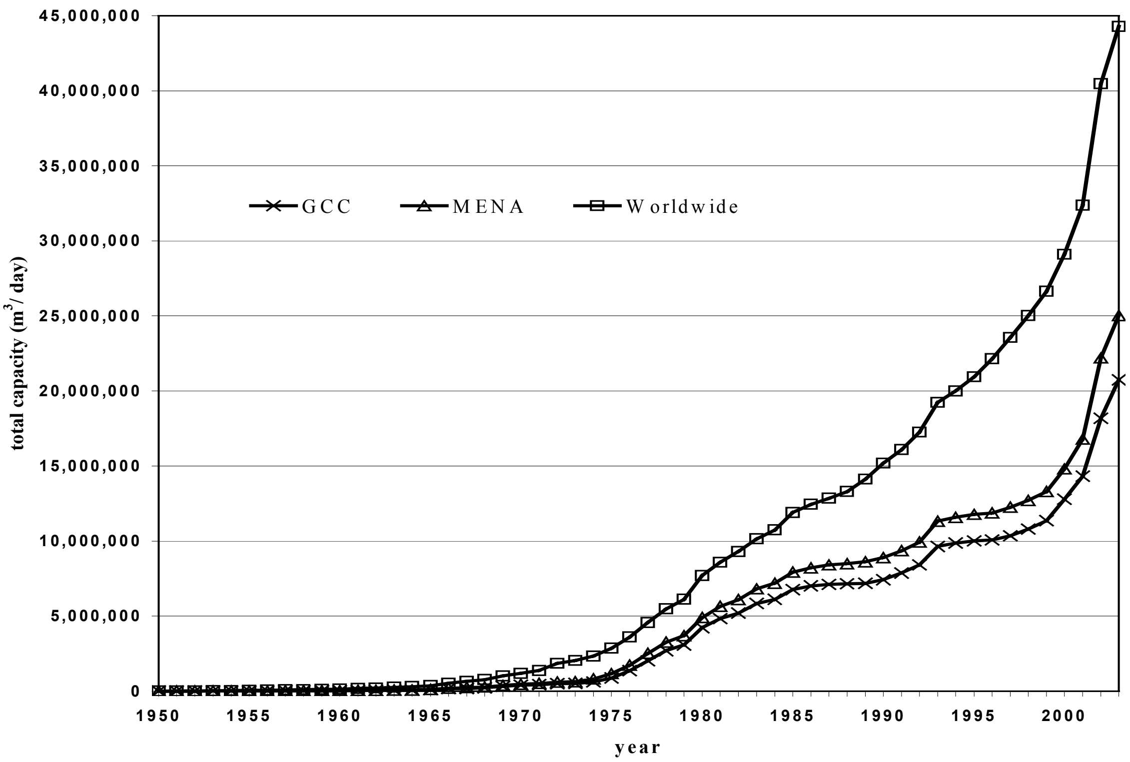


**Figure 1. Desalination growth**

The share of each process (desalinating brackish and sea water) in the GCC countries and Libya is: 73.5% MSF, 20.1% RO, 4% VC, 1.6% ED, 0.6% MED, 0.3% other. On the other hand, membrane processes are more widely used in other MENA countries for desalinating both brackish water and seawater; 60% RO, 14.2% ED, 11.2% MSF, 7.1% MED, 6.8% VC, 0.7% other. Worldwide, the MSF process represents more than 93% of the thermal process production, while RO process represents more than 88% of membrane processes production.

## 4. Solar technologies

Desalination by means of solar energy is a suitable solution to provide fresh water to a number of regions. This solution becomes more competitive, especially for remote and rural areas where small quantities of water for human consumption are needed. Recently, more attention has been directed towards improving the efficiencies of the solar energy conversions, desalination technologies and their optimal coupling to make them economically viable for small and medium scale applications.

As discussed earlier, since the energy requirements in desalination processes play a major role, it appears attractive to consider solar energy for desalination. Solar energy can be converted to thermal or electrical energy. The thermal energy can be achieved in solar stills, collectors, or solar ponds. Electrical energy can be produced from solar energy directly by photovoltaic conversion or via solar thermal power plant.

### *4.1. Solar stills*

Solar stills have been in use for several decades. The solar still is a small production system, yielding on average 2 – 5 L/day. It can be used wherever fresh water demand is low and land is inexpensive. Many modifications to improve the performance of the solar stills have been made. These include linking the desalination process with the solar energy collectors, incorporating a number of effects to recover the latent heat of condensation, improving the configurations and flow patterns to increase the heat transfer rates, and using less expensive materials in construction to reduce the cost. Nevertheless these systems are not economically viable for large-scale applications.

### *4.2. Solar Collectors*

Solar collectors are usually classified according to the temperature level reached by the thermal fluid in the collectors as follows.

**Low temperature collectors** provide low-grade heat, only a few degrees above ambient air temperature and use unglazed flat plate collectors. This low-grade heat is not useful to serve as a heat source to conventional desalination distillation processes.
**Medium temperature collectors** provide heat of more than 43 $^{o}$C and include glazed flat plate collectors as well as vacuum tube collectors using air or liquid as the heat transfer medium. They can be used to provide heat for thermal desalination processes by indirect heating with a heat exchanger.
**High temperature collectors** include parabolic troughs or dishes or central receiver systems. They typically concentrate the incoming solar radiation onto a focal point, from which a receiver collects the energy using a heat transfer fluid. The high temperature energy can be used as a thermal energy source in thermal desalination processes or can be used to generate electricity using a steam turbine. As the position of the sun varies over the course of the day and the year, sun tracking is required to ensure that the collector is always kept in the focus of the reflector for improving the efficiency.

For large-scale desalination applications, these systems need large collector areas.

### *4.3. Solar Pond*

Solar ponds combine solar energy collection with long-term storage. Salt concentration gradient in the pond helps in storing the energy. Whereas the top temperature is close to ambient, a temperature of 90 $^{o}$C can be reached at the bottom of the pond where salt concentration is highest. The temperature difference between the top and bottom layer of the pond is large enough to run a desalination unit, or to drive the vapor generator of an organic Rankine-cycle engine. Solar ponds have a rather large storage capacity. This allows seasonal as well as diurnal thermal energy storage. The annual collection efficiency for useful heat for desalination is in the order of 10 to 15% with sizes suitable for villages and small towns. The large storage capacity of solar ponds can be useful for continuous operation of desalination plants.

It has been reported that, compared with other solar desalination technologies, solar ponds provide the most convenient and least expensive option for heat storage for daily and seasonal cycles. This is very important, both from operational and economic aspects, if steady and constant water production is required. The heat storage allows solar ponds to power desalination during cloudy days and nighttime. Another advantage of desalination by solar ponds is that they can utilize what is often considered a waste product, namely reject brine, as a basis to build the solar pond. This is an important advantage for inland desalination.

If high temperature collectors or solar ponds are used for electricity generation, a desalination unit can be attached to utilize the reject heat from the electricity production process.

### *4.4. Photovoltaic*

Solar photovoltaic (PV) systems directly convert the sunlight into electricity by solar cells. Solar cells are made from semiconductor materials such as silicon. Other semiconductors may also be used. A number of solar cells are usually interconnected and encapsulated together to form a PV module. Any number of PV modules can be combined to form an array, which will supply the power required by the load. In addition to the PV module, power conditioning equipment (e.g. charge controller, inverters) and energy storage equipment (e.g. batteries) may be required to supply energy to a desalination plant. Charge controllers are used for the protection of the battery from overcharging. Inverters are used to convert the direct current from the photovoltaic modules system to alternating current to the loads. PV is a mature technology with life expectancy of 20 to 30 years. The main types of PV systems are the following:

**Stand-alone systems** (not connected to the utility grid) – They provide either DC power or AC power by using an inverter.
**Grid-connected systems** – These consist of PV arrays that are connected to the electricity grid via an inverter. In small and medium-sized systems the grid is used as a back-up source of energy, (any excess power from the PV system is fed into the grid). In the case of large centralized plants, the entire output is fed directly into the grid.
**Hybrid systems** – These are autonomous systems consisting of PV arrays in combination with other energy sources, for example in combination with a diesel generator or another renewable energy source (e.g. wind).

## 5. Matching Desalination Processes with Solar Technologies

The selection of the appropriate solar desalination technology depends on a number of factors. These include plant size, feed water salinity, remoteness, availability of grid electricity, technical infrastructure and the type of solar technology available. Among the several possible combinations of desalination and solar energy technologies, some seem to be more promising in terms of economic and technological feasibility than others. In addition to that, some combinations are better suited for large size plants, whereas some others are better suited for small-scale application. Before any process selection can start, the water resources should be investigated. Brackish water is more economical as the salinity is normally much lower (<10,000 ppm), and the energy requirement would be lower. In inland sites, brackish water is normally available whereas on a coastal site, seawater may be the only option.

Desalination processes require thermal and/or electrical energy, which can be provided by solar technologies as mentioned above. If thermal energy can be extracted, it can be directly used to drive a distillation process as MSF, MED, TVC or other solar distillation processes. MED plants are more flexible to operate at partial load, less sensitive to scaling, cheaper and more suitable for limited capacity than are MSF plants. Also MED has greater potential than MSF for designs with high performance ratio (PR) defined as the ratio between tons of the product to tons of steam used. However, all distillation processes remain energy intensive.

If electricity can be obtained, it is best suited to provide power for desalination processes, such as RO, ED, and MVC technologies. With regard to the process selection for seawater, RO has the lowest energy consumption. Nevertheless it requires skilled operators because mistakes in operations may ruin the membranes, and are dependent on the accessibility to chemical and membrane supplies. If these requirements are not a problem at the plant location, the RO process has been the choice in most instances. However, fluctuations of the available energy would ruin the RO system. Therefore, intermediate energy storage would be required, but would reduce the available energy and increase the costs. In remote areas, ED is most suitable for brackish water desalination because it is more robust and its operation and maintenance are simpler than RO systems. In addition, the ED process is able to adapt to changes of available energy input. On the other hand, although MVC consumes more energy than RO, it presents lesser problems from fluctuations of the energy source. MVC systems are more suitable for remote areas since they are more robust; they need fewer skilled workers and less chemicals than RO systems. In addition, they need no membrane replacement and offer a better quality product than RO.

The most promising and applicable combinations of solar technologies in desalination are shown in Table 1. Such systems should be characterized by robustness, simplicity of operation, low in maintenance, size compactness, ease of transportation to site, simplicity of pre-treatment and intake system requirements; all to ensure proper operation and endurance of a plant at the often difficult conditions of remote areas.

**Table 1. Matching solar technology with desalination processes**

| Form of energy | Feed water | Desalination technology |
|---|---|---|
| Thermal | Seawater | MED/MSF/TVC |
| Electrical | Seawater | RO/MVC |
| | Brackish | ED/RO |

MED= Multi-effect distillation, MSF= Multi-stage flashing, TVC=Thermal Vapor Compression, RO=Reverse Osmosis, MVC= Mechanical Vapor Compression, ED= Electrodialysis

Experience thus far has shown no significant technical problems in combining the technologies. The most popular combination of technologies is the use of PV with Reverse Osmosis (see Figs. 2 and 3). With distillation processes, large sizes are more attractive due to the relatively high heat losses in smaller units. Figures 2 and 3 show the relative distribution between desalination processes using renewable energy sources. As seen, solar energy is the most widely used among other renewable energies. The hybrid power supply systems shown are normally wind and solar, sometimes complemented with a diesel generator.

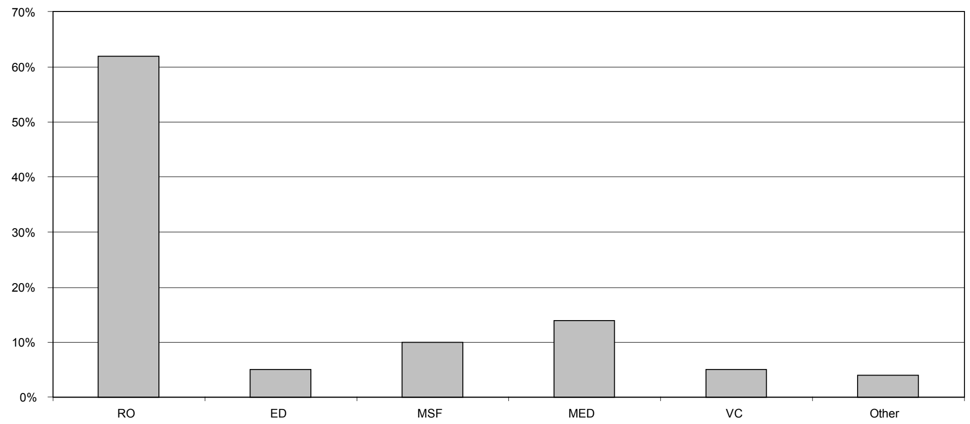


**Fig. 2. Desalination processes used in conjunction with renewable energy.**

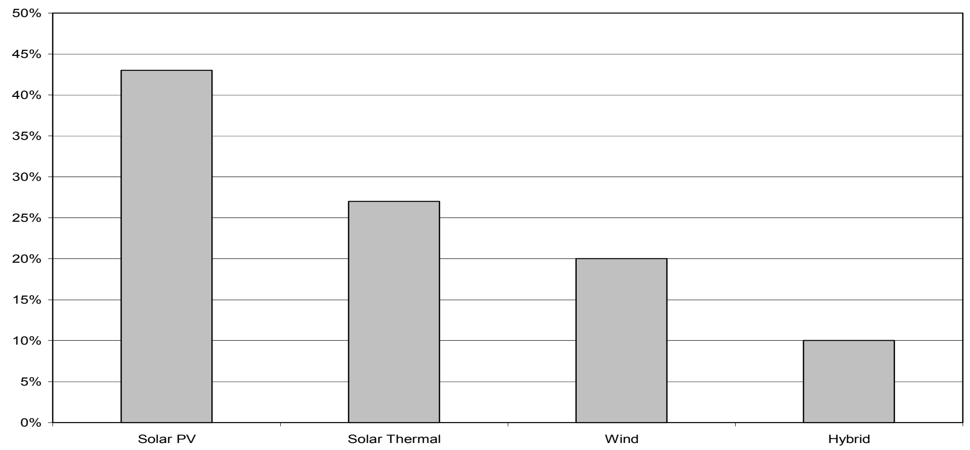


**Fig. 3. Renewable energy sources for desalination.**

Many small systems of direct solar desalination (e.g. solar stills) and several pilot plants of indirect solar desalination have been designed and implemented. Table 2 shows indirect solar desalination pilot plants implemented in the MENA region. Many plants also exist elsewhere, mainly in Europe. The pilot in Spain is included in the table, since water cost is reported for that plant. Table 3 shows RO-PV plants in the MENA region and one plant in Italy, since the water cost is also reported for that plant.

## 6. Limitations to the use of solar desalination processes in the MENA region

Most of the high demand on desalination has been in the countries that are rich in oil and gas, thus making the consideration of solar energy not so attractive. On the other hand, the high cost of solar technologies makes its consideration by non-oil producing countries also not a feasible alternative. Lack of funds for research and development in the region has not improved the development and cost reduction of solar technologies.

On the technical side, desalination systems have traditionally been designed to operate with a constant power input. Unpredictable and non-steady power input, force the desalination plant to operate in non-optimal conditions and may cause operational problems. Each desalination system has specific problems when it is connected to a variable power system. For instance, the Reverse Osmosis (RO) system has to cope with the sensitivity of the membranes regarding fouling, scaling, in addition to unpredictable phenomena caused by start–stop cycles and partial load operation during periods of oscillating power supply. On the other hand, the Vapor Compression (VC) system has considerable thermal inertia and requires considerable energy to get to the nominal working point. Thus, for autonomous systems, a small energy storage system (usually batteries), should be added to offer stable power to the desalination unit. Clearly this only applies to small electrically driven systems. Thermal storage can be added for thermal systems in the form of hot oil or hot water but is expensive.

Another limitation is the need for large surface area for solar still, PV modules, and collectors requiring large land areas leading to higher investment costs for the solar energy facilities, in spite of their low operational costs.

**Table 2. Solar distillation plants**

| Plant location, commissioning year | Desalination process | Capacity $m^3/d$ | Solar collectors, area ($m^2$) | Unit water cost |
|---|---|---|---|---|
| Abu Dhabi-UAE , 1985 | ME, 18 effects | 120 | Evacuated tube | 8 USD/$m^3$ |
| Kuwait, 1987 | MSF<br>RO | 25<br>20 | Solar electricity generation system | |
| Kuwait, 1980 | MSF auto-regulated | 100 | Parabolic trough, 220 | |
| Arabian Gulf, 1987 | ME | 6000 | Parabolic trough | |
| Area of Hzag-Tunisia, 1980 | Distillation | 0.1-0.35 | Solar collector | |
| Safat-Kuwait, 1983 | MSF | 10 | Solar collector, 220 | |
| Near Dead Sea, ~ 1987 | MED | 3000 | Solar pond, 250,000 | |
| Al-Ain-UAE, 1991 | ME, 55 stages; MSF, 75 stages | 500 | Parabolic trough | |
| PSA-Almeria-Spain, 1988 | ME, heat pump | 72 | Parabolic trough, 2672 | ~ 3.5 €/$m^3$ |

**Table 3. Reverse Osmosis plants driven by PhotoVoltaic cells in MENA**

| Plant location, commissioning year | Water type (salinity) | Plant capacity ($m^3$/day) | Photovoltaic system | Unit water cost |
|---|---|---|---|---|
| Jeddah-Saudi Arabia, 1981 | SW (42800 ppm) | 3.25 | 8 kWp | |
| Red Sea-Egypt, 1986 | BW (4400 ppm) | 240 | 19.84 kWp (pump), 0.64 kWp (control equipment) | |
| Doha-Qatar, 1984 | SW | 5.7 | 11.2 kWp | |
| Hassi-Khebi-Algeria, 1987 | BW (3200 ppm) | 22.8 | 2.59 kWp | |
| Lampedusa-Italy, 1990 | SW | 120 | 100 kWp PV | ~ 6.5 €/m3 |

SW = seawater, BW = brackish water.

## 7. Promotion of solar desalination in the MENA region

The use of solar energy in desalination introduces environmentally friendly technologies that produce minimum waste products, revitalizes rural communities by creating local industries and businesses, improves the quality of life for inhabitants living in rural areas, reduces mass migration of population from rural to urban areas, reduces the bill for imported primary energy recourses, and might contribute to solutions of problems in the agriculture sector. The following factors provide a catalyst for promoting solar desalination.

- Plant location: Many arid regions in the MENA countries are coastal areas and solar energy is available.
- Seasonal changes: Often freshwater demand increases due to tourism, at times when solar energy availability is high.
- Energy availability: Conventional energy supply is not always possible in remote areas due to difficulties in the supply of fossil fuel or non-availability of grid electricity. In such cases, the use of solar energy permits sustainable socioeconomic development by using local resources.
- Self-sufficiency: Solar energy allows energy diversification and avoids external dependence on energy supply for the non-oil producing countries.
- Technology: The development and commercialization of desalination systems driven by solar energy make possible technology exportation and cooperation among MENA countries and Europe.
- Environmental impact: Seawater desalination processes are energy intensive. Therefore, the environmental effects of the fossil fuels consumed are important. When considering that the total worldwide capacity of desalinated water is more than $30x10^6$ $m^3$/day, reduction in fossil fuel use is important.
- Economics: In remote areas, fresh water requirements make it necessary to transport fresh water at high costs and associated improper hygienic conditions.
- Operation and maintenance: The operation and maintenance of solar energy systems are normally easier than conventional energy ones, making them more suitable for remote areas.
- Promising commercial perspectives: Cost reduction in solar energy systems has been significant during the last decades. Therefore, future reductions in conjunction with the rise of fossil fuel prices could make it possible for seawater desalination driven by solar energy to become competitive. Realistically, using solar technologies in desalination will increase the demand on these technologies, making it possible to go for commercialization and mass production. This would ultimately lead to reduction in the cost of these technologies.

Steps that can be taken to promote the utilization of solar energy in desalination.

- Promote ways to enhance understanding of the role that solar energy could play in supplying electricity and water in the region, particularly for rural and remote areas. Add to this, the role it plays in preserving the environment and in contributing towards the reduction of unemployment.
- Urge non-governmental organizations in the MENA region and in Europe to enter into partnership, share the knowledge and experience available with each other, and establish innovative programs for the promotion of the use of solar energy in desalination.

- Favor the access, transfer and sharing of knowledge on solar energy applications in desalination using state of the art communications technology.
- Promote and harmonize co-operation in training and research, as well as in the transfer of research disclosures to industry at the regional, interregional and international level.
- Demonstrate how the wide use of solar energy in desalination can be cost effective, as it reduces the dependence on imported energy (for some countries of the region), save foreign exchange, and that it will be able to extend the energy supply base without heavy investment.
- Identify and define selected strategic projects of regional importance which will trigger use of solar energy in desalination, thus open competitive and sustainable markets for solar energy and desalination technologies, equipment and goods.

There should be encouragement from countries that are now oil-rich to subsidize desalination powered with solar energy. For remote areas, the cost of extending the electrical grid, or to transport oil fuel, may justify the use of solar energy to power desalination plants and to supply electricity.

## 8. Conclusions

Desalination is needed in the MENA region which is endowed with high solar irradiation. Current solar technologies, photovoltaic and solar thermal systems, can be matched to existing desalination processes. Desalination, being energy intensive, can be a mean of promoting solar energy technologies. This can play a major role in enhancing the development and expansion in the industry of solar technologies.

## 11. References


1. L. Garcia-Rodrigues, Seawater desalination driven by renewable energies: a review, ***Desalination*** 143 (2002) 103-113.
2. E. Tzen and R. Morris, Renewable energy sources for desalination, ***Solar Energy*** 75 (2003) 381-393.
3. L. Garcia-Rodrigues, Renewable energy applications in desalination: state of the art, ***Solar Energy*** 75 (2003) 381-393.
4. European Commission, Desalination guide using renewable energies, 1998.
5. K. Wangcick, 2002 IDA Worldwide desalting plants inventory, Report No.17, July 2002.
6. B. Berkovski, World solar summit process, progress report, UNESCO, January 1996.
7. K. Quteishat, V. Reddy, M. Abu-Arabi, The interaction of energy and desalination, International seminar on water and energy, Marrakech, Morocco, 2002.
8. L. Huanmin, J.C. Walton, A.H.P. Swift, Desalination coupled with salinity-gradient solar ponds, ***Desalination*** 136 (2001) 13-23.