Water Desalination Using Renewable Energy

INSIGHTS FOR POLICYMAKERS

Global demand for water continues to increase whilst freshwater sources are becoming more scarce due to increasing demand for natural resources and the impacts of climate change, particularly in semi-arid and costal/island areas. Desalination of seawater and brackish water can be used to augment the increasing demand for fresh water supplies. However, desalination is a very energy intensive process, often using energy supply from fossil fuel sources which are vulnerable to volatile global market prices as well as logistical supply problems in remote and island communities and are therefore not sustainable.

Until now, the majority of desalination plants have been located in regions with high availability and low costs of energy. Current information on desalination shows that only 1% of total desalinated water is based on energy from renewable sources. Renewables are becoming increasingly mainstream and technology prices continue to decline, thus making renewable energy a viable option. With increasing demand for desalinated water in energy-importing countries such as India, China and small islands, there is a large market potential for renewable energy-powered desalination systems worldwide.

There are two broad categories of desalination technologies. Thermal desalination uses heat to vaporise fresh water, while membrane desalination (reverse osmosis) uses high pressure from electrically-powered pumps to separate fresh water from seawater or brackish water using a membrane. Policy makers need to consider these diff erent technology choices for desalination and base their decisions on locally available renewable energy sources. For example, solar energy – in particular heat from concentrated solar power (CSP) for thermal desalination and electricity from solar photovoltaic and CSP for membrane desalination – is a key solution in arid regions (e.g. the MENA region) with extensive solar energy potentials, whilst wind energy is of interest for membrane desalination projects in coastal and islands communities.

While desalination is still costly, declining renewable energy technology deployment costs are expected to bring this cost down in the coming years. This is of particular interest to remote regions and islands with small populations and poor infrastructure for freshwater and electricity transmission and distribution.

Mapping water needs and renewable energy sources is a strategic tool for planning new desalination systems. Renewable energy-powered desalination could be a key enabler for continued growth, especially in those countries that rely on desalinated water for sustaining local communities and productive uses such as irrigation. As such, renewable energy generation should be seen as a valuable economic investment that reduces external, social, environmental and operational costs. Policy makers may therefore wish to take the evolving market opportunities and long term impacts of technology options into consideration when planning their capacity, infrastructure and sustainable water supply needs.

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TECHNICAL HIGHLIGHTS

■ **PROCESS AND TECHNOLOGY STATUS –** This brief focuses primarily on water desalination based on the use of renewable energy, i.e. *renewable desalination*. Global water withdrawals amount to around 4,000 billion m^3 per year and in some regions - especially Middle East and Northern Africa (MENA) - desalination has become the most important source of water for drinking and agriculture. Today's global desalinated water production amounts to about 65.2 million m^3 per day (24 billion m^3 per year), equivalent to 0.6% of global water supply. The MENA region accounts for about 38% of the global desalination capacity, with Saudi Arabia being the largest desalinating country. Major desalination technology options are based on thermal processes using both heat and electricity, and membrane technologies using electricity only. The dominant technology is Reverse Osmosis (RO), which accounts for 60% of the global capacity, followed by Multi Stage Flash (MSF), with a 26.8% share. The larger desalination plants can reach a capacity of up to 800,000 m^3 per day or larger. Renewable energy can play an important role in desalination. Renewable technologies that are suited to desalination include solar thermal, solar photovoltaics (PV), wind, and geothermal energy. Solar technologies based on solar heat concentration, notably concentrating solar power (CSP), produce a large amount of heat that is suited to thermal desalination. Photovoltaic- and wind-based electricity can often be combined with membrane desalination units (reverse osmosis, electrodialysis). As electricity storage is still a challenge, combining power generation and water desalination can also be a cost-effective option for electricity storage when generation exceeds the demand.

■ **PERFORMANCE AND COSTS –** Desalination requires a considerable amount of energy. Seawater desalination via MSF consumes typically 80 kWh of thermal energy (about 290 MJ) plus 2.5 to 3.5 kWh of electricity per m^3, while large scale RO plants requires only about 3.5 to 5.0 kWh of electricity per m^3. Currently, it is estimated that the global production of about 65.2 million m^3/d of desalinated water involves the use of at least 75.2 TWh per year, which equals about 0.4% of the global electricity consumption. The cost of desalination is largely determined by the cost of energy. Over the past years, the large use of desalination in some countries has led to significant cost reductions to a level of USD 0.5/m^3. Market prices for desalinated water are typically in the range of USD 1-2/m^3. As a consequence, desalination is still costly and affordable for high to middle income regions, not yet for poorest countries. The economics of *renewable desalination* depends in turn on the cost of renewable energy. Therefore, the cost of *renewable desalination* is still higher if compared to the cost of conventional desalination based on fossil fuels as the energy input. However, the costs of renewable technologies are quickly decreasing, and *renewable desalination* can already compete with conventional systems in remote regions where the cost of electricity transmission and distribution is higher than the cost of distributed electricity generation.

■ **POTENTIAL AND BARRIERS –** Desalination demand is projected to expand rapidly. The global demand is projected to grow by 9% per year between 2010 and 2016, with a cumulative investment of about USD 88 billion. In the MENA region, water demand is expected to increase from 9 billion m^3 in 2010 up to 13.3 billion m^3 in 2030 while groundwater resources are projected to decrease. As a consequence, desalination capacity in MENA region is expected to grow quickly from 21 million m^3/d in 2007 to nearly 110 million m^3/d by 2030, of which 70% in Saudi Arabia, the United Arab Emirates, Kuwait, Algeria and Libya. As desalination requires a considerable amount of energy, water production will contribute significantly the energy use in MENA countries. The total electricity demand for desalination in the MENA region is expected to rise to some 122 TWh by 2030, thus tripling compared with 2007 level. Desalination need is also expected to grow in Asia and the Caribbean region. China and India are high potential markets for desalination due to growing population and economy, and water shortage. The need for desalination grows much faster than the economy as a whole, and the associated energy need is projected to increase accordingly.

TECHNOLOGIES AND PERFORMANCE

The global water demand is continuously increasing due to population growth and economic development. Global water withdrawals exceeds 4,000 billion m^3 per year (Rosegrant et al, 2002) and about 25% of the world population encounters fresh water scarcity (UN OCHA, 2010). In response to the increasing demand, desalination has become the most important sources of water for drinking and agriculture in some world regions, especially Middle East and North Africa (MENA), and some of Caribbean islands, where water is particularly scarce. The International Desalination Association (IDA) reports that there are about 15,000 desalination plants worldwide, with a global capacity of

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about 72 million m^3/d (Figure 1). About 60% of feed water used in these plants is seawater (IDA in Black and Veatch, 2011). Over the past years, the deployment of desalination plants has been led by countries of the MENA region where approximately 2,800 desalination plants produce 27 million m^3/d fresh water (about 38% of the global capacity) from seawater (Fichtner, 2011). Major desalination technologies consist of thermal processes using either thermal energy (heat) and electricity as the energy input, and membrane-based processes using only electricity (Table 1). The dominant desalination processes in use today are based on Reverse Osmosis (RO) and Multi Stage Flash (MSF). They constitute 60.0% and 26.8% of the worldwide capacity, respectively (Figure 2). The choice between these technologies and their technical-economic feasibility depend on specific local conditions such as energy price, water quality, and the technical resources of the region.

■ **Thermal Desalination Technologies** - Thermal desalination involves distillation processes where saline feed-water is heated to vaporize, causing fresh water to evaporate and leave behind a highly saline solution, namely the brine. Freshwater is then obtained from vapor cooling and condensation. The **Multi Stage Flash (MSF)** process is divided into sections or stages. Saline water is heated at the boiling temperature between 90 and 110 C°, with a decreasing pressure through the stages. Part of the water flashes (quickly vaporizes) at each stage while the rest continues to flow through the following stages (Figure 3). As the MSF process can be powered by waste or by-product heat, the combined production (cogeneration) of power, heat and desalinated water in the same plant is a technical solution that in MENA countries can often satisfy the demand for power and water in a cost-effective and energy-efficient manner. In the case of heat derived from a steam turbine, the turbine loses a certain amount of its electricity generation output. With an installed capacity of about 17.5 million m^3/day (IDA in Koschikowski, 2011), MSF is the dominant desalination technology in the MENA region where fossil fuels are largely available at a low cost. Similar to MSF, **Multi Effect Distillation (MED)** is a multi-stage process variant in which vapor from each vessel (stage) is condensed in the following vessel and vaporized again at reduced ambient pressure. Unlike MSF, MED allows the feed water to be processed without the need to supply additional heat for vaporization at each stage. Another technology for thermal desalination is **Vapor Compression (VC)** distillation process, where the heat for water evaporation comes from compression rather than from direct heating. This process is generally used in combination with other processes (MED) to improve overall efficiency.

■ **Membrane Desalination Technologies** - Membrane desalination uses membranes to separate fresh water from saline feed-water. Feed water is brought to the surface of a membrane, which selectively passes water

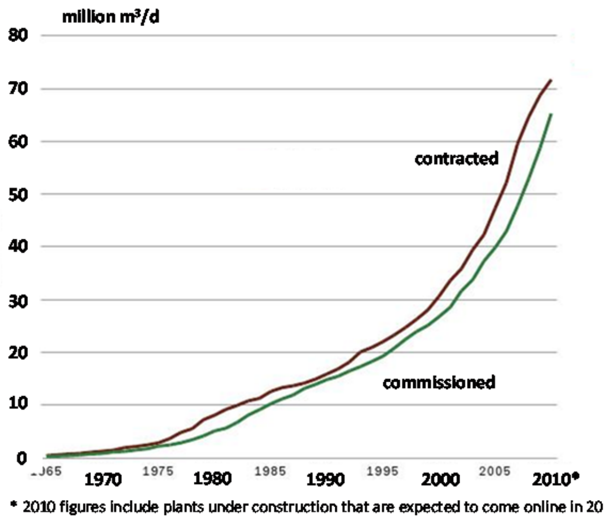

Figure 1 - Global desalination capacity 1965-2010 (IDA, 2011)

Table 1 - Major Desalination Technologies	
Thermal Technologies	Membrane Technologies
Multi Stage Flash, MSF	Reverse Osmosis, RO
Multi Effect Distillation, MED	Electrodialysis, ED
Vapour Compression, VC	

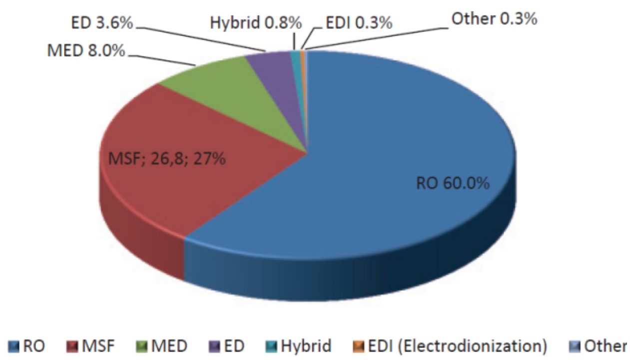

Figure 2 - Desalination Technology Market (IDA in Koschikowski, 2011)

and excludes salts. In the **Reverse Osmosis (RO),** the seawater pressure is increased above the osmotic pressure, thus allowing the desalinated water to pass through the semi-permeable membranes, leaving the solid salt particles behind (Figure 4). The RO plants are very sensitive to the feed-water quality (salinity, turbidity, temperature), while other distillation technologies are not so demanding in this respect (Goebel, 2003). High-salinity and high-temperature feed water can limit the osmosis process as they affect the osmosis pressure, requiring more energy. High-turbidity feed-water can cause fouling where membrane pores are clogged with suspended solids.

Typical seawater salinity which is suited to RO systems is around 35,000 ppm of dissolved solids contents. However, in some regions (e.g. Red Sea, Arabian Gulf), the total dissolved solids content is higher, i.e. 41,000 ppm and 45,000 ppm, respectively (Lenntech homepage). In these regions, seawater has high fouling potential (biofouling due to high content of organisms), and high surface temperature (Abs El Aleem et al., 1997). Therefore, an appropriate feed-water pre-treatment is needed prior to RO desalination. RO desalination is also suited and used for small-scale plants in rural areas or islands where there is no other water supply available. For example, most desalination plants in the Caribbean area use RO systems (CEHI, 2006). **Electrodialysis (ED)** is another membrane process which uses the electrical potential to move salt through the membrane, leaving freshwater behind. Currently, ED is widely used for desalinating brackish water rather than for seawater due to the fact that the energy consumption depends on salt concentration of the feed water (EU, 2008).

■ **Desalination based on Renewable Energy -** Desalination based on the use of renewable energy sources can provide a sustainable way to produce fresh water. It is expected to become economically attractive as the costs of renewable technologies continue to decline and the prices of fossil fuels continue to increase. Using locally available renewable energy resources for desalination is likely to be a cost-effective solution particularly in remote regions, with low population density and poor infrastructure for fresh water and electricity transmission and distribution. The present deployment of renewable-based desalination - i.e. less than 1% of desalination capacity based on conventional fossil fuels (EU, 2008) - does not reflect the advantages of this technology option. *Renewable desalination* is mostly based on the RO process (62%) followed by thermal processes such as MSF and MED. The dominant energy source is solar photovoltaics (PV), which is used in some 43% of the existing applications, followed by the solar thermal and wind energy (EU, 2008).

The right combination of a renewable energy source with a desalination technology can be the key to match both power and water demand economically, efficiently and environmentally friendly. Assessing the technical feasibility and cost effectiveness of *renewable desalination* plants requires a detailed analysis including a variety of factors such as location, quality (salinity) of feed-water input and fresh-water output, the available renewable energy source, plant capacity and size, and the availability of grid electricity. Operation and maintenance requirements, feed-water transportation and pre-treatment needs are also part of the decision-making process. Some technology solutions are better suited for large size plants, while others for small-scale applications (EU, 2008). Most common renewable options are shown in Table 2.

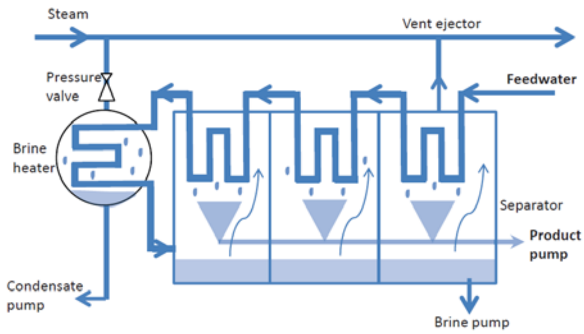

Figure 3 - MSF Desalination Process (Fichtner, 2011)

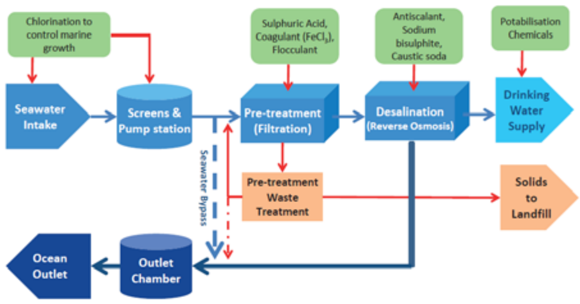

Figure 4 - RO Desalination Process (Fichtner, 2011)

Many of the existing *renewable desalination* systems are implemented in small capacities from a few m^3 up to 100 m^3/d. Only a few medium-size applications exist in the MENA region. The world's largest solar PV desalination plant using novel nano-membrane technology is under construction in the city of Al Khafji, in Saudi Arabia. It is a part of the project launched by KACST (King Adbulaziz City for Science and Technology) in cooperation with IBM. It will be implemented in three stages over 9 years. In the first phase, a desalination plant with a production capacity of 30,000 m^3/d will meet the needs of some 100,000

Table 2 - Combinations of renewable energy and desalination technologies (Al-Karaghouli et al, 2011)

Renewable Technologies	Desalination Technologies				
	MSF	**MED**	**VC**	**RO**	**ED**
Solar thermal	●	●	●	●	●
Solar PV			●	●	●
Wind			●	●	●
Geothermal	●	●	●	●	●

people. According to Arab News, Saudi Arabia uses 1.5 million barrels of oil per day at its desalination plants, which provide between 50% and 70% of the country's drinking water (Oxford Business Group, 2010). Other desalination plants powered by renewable energy can be seen in Cyprus, Egypt, Jordan, Morocco, Turkey, Abu Dhabi, and Canary Islands.

■ **Solar Thermal Desalination –** Seawater desalination via MSF and MED using solar heat as the energy input are promising desalination processes based on renewable energy. The desalination plant consists of two parts, i.e. solar heat collector and distiller. The process is referred to as *indirect* process if the heat comes from a separate solar collector or solar ponds whereas it is referred to as *direct* if all components are integrated in the desalination plant (Kalogirou, 2005). Particularly attractive is desalination associated with concentrating solar power (CSP) plants.

CSP plants (see ETSAP E10) collect solar radiation and provide high-temperature heat for electricity generation. Therefore, they can be associated to either membrane desalination units (e.g. reverse osmosis, RO) and thermal desalination units. CSP plants are often equipped with thermal storage systems to extend operation when solar radiation is not available, and/or combined with conventional power plants for hybrid operation. This paves the way to a number of design solutions which combine electricity and heat generation with water desalination via either thermal or membrane separation processes. CSP plants are also large enough to provide core energy for medium- to large-scale seawater desalination. In desert regions (e.g. MENA) with high direct solar irradiance, CSP is considered a promising multi-purpose technology for electricity, heat and district cooling production, and water desalination. An analysis by German Aerospace Centre (DLR, 2007) for the MENA region shows that the choice between the CSP-MED process and the CSP-RO may depend on feed water quality. The CSP-MED process is more energy efficient than the CSP-RO process in the Arabian Gulf where seawater has high salinity level. An example scheme of CSP-MED is shown in Figure 5.

■ **Photovoltaic Desalination –** Photovoltaic (PV) technology (ETSAP E11) can be connected directly to RO or ED desalination processes which are based on electricity as the input energy (Figure 6). Many small PV-based desalination systems have been demonstrated throughout the world especially in remote areas and islands, including Canary Islands (PV-RO, seawater, 1 -5 m^3/d), Riyadh, Saudi Arabia (PV-RO, brackish water, 5 m^3/d), and Ohshima Island, Japan (PV-ED, seawater, 10 m^3/d) (Kalogirou, 2005). The main issue of PV desalination is the (still) high cost of PV cells and batteries for electricity storage. Careful maintenance and operation of battery systems are also necessary. Further technology advances in electricity storage (ETSAP E18) associated to PV could lead to wider use of PV desalination.

■ **Wind Power Desalination –** The electrical and mechanical power generated by a wind turbine can be used to power desalination plants, notably RO and ED desalination units, and vapor compression (VC) distillation process (in particular, Mechanical Vapor Compression, MVC). In the MVC, the mechanical energy of the wind turbine is used directly for VC without further conversion into electricity. In general,

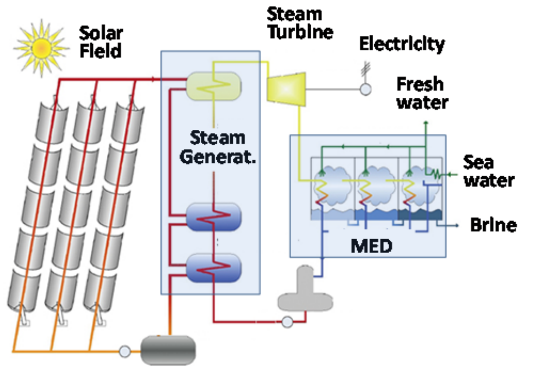

Figure 5 - CSP power plant with oil steam generator and MED desalination (Zachary et al, 2010)

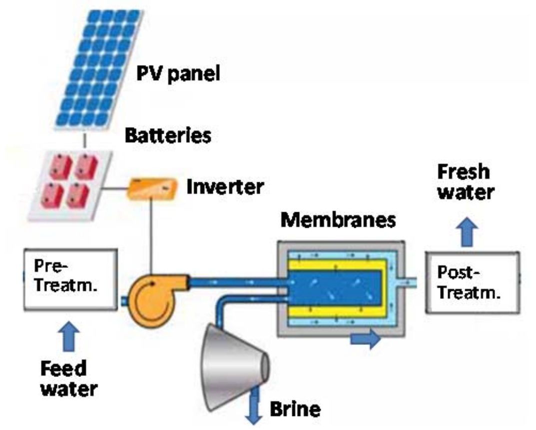

Figure 6 - Coupled PV and RO desalination plants (Al-Karaghouli et al., 2011)

wind power based desalination can be one of the most promising options for seawater desalination, especially in coastal areas with high wind potential. Various wind-based desalination plants have been installed around the world, including Gran Canaria, Canary Islands (Wind-RO, seawater, 5–50 m^3/d), Fuerteventura Island, Spain (Wind-diesel hybrid system, seawater, 56 m^3/d), and Centre for Renewable Energy Systems Technology in the United Kingdom (Wind-RO, seawater, 12 m^3/d) (see Kalogirou 2005 and Al-Karaghouli et al. 2009). Same as for PV and CSP, a drawback of wind desalination is the intermittence of the energy source. Possible combinations with other renewable energy sources, batteries or other energy storage systems can

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provide smoother operating conditions. Water desalination itself can provide an excellent storage opportunity in the case of electricity generation exceeding the demand (Gude et al, 2010).

■ **Geothermal Desalination –** As geothermal energy can produce electricity and heat, it can be combined with both thermal and membrane desalination technologies. Low-temperature geothermal energy, typically in the range of 70–90°C is ideal for MED desalination. A project in the Milos Island, Greece, has proposed a geothermal desalination system to produce 1,920 m^3/d of water. The plant consists of a dual system with hot water from geothermal wells being employed to run either an organic Rankine cycle (ORC) with a 470-kWe turbine for electricity generation and a MED desalination unit. The system can benefit the local community by producing desalinated water at a very low cost, i.e. USD 2/m^3 (Constantine, 2004). However, the exploitation of geothermal energy very much depends on the specific local conditions, with upfront investment costs that are usually high.

■ **Energy Implications of Desalination -** Desalination requires a considerable amount of energy. Membrane desalination (RO) requires only electricity while thermal desalination (MSF, MED) requires both electricity and thermal energy, and – in total – more energy than the membrane process. Seawater desalination via MSF consumes typically 290 kJ/kg of thermal energy plus 2.5–3.5 kWh_e/m^3 of electricity, while large-scale RO desalination requires around 3.5–5.0 kWh_e/m^3 of electricity (EU, 2008). Table 3 shows key, typical energy data for different desalination technologies. Taking into account the average energy demand of desalination processes (i.e. 5 kWh/m^3 for MSF, 2.75 kWh/m^3 for MED, 2.5 kWh/m^3 for RO, and 2.75 kWh/m^3 for ED, the global desalination capacity (i.e. 65.2 million m^3/day) requires the use of approximately 206 million kWh per day, equivalent to 75.2 TWh per year. Renewable energy, notably CSP with thermal storage systems, can significantly contribute to reduce the fossil fuels (and associated CO_2 emissions) used for desalination. Other variable renewable energy sources such as solar PV and wind power can also offer significant contributions if associated with energy storage systems. Desalination itself can be seen as a viable option to store renewable electricity which exceeds the demand.

DESALINATION COSTS

The cost of desalination is largely dominated by the energy cost. Therefore, the economic feasibility of desalination depends strongly on local availability and cost of energy (Zejli et al, 2002). Comparisons between different desalination technologies should be based on identical local conditions. Site-specific aspects which also have a significant impact on final costs include feed water transportation, fresh water delivery to end-users, brine disposal, and the size of the plant. As far as capital (investment) and operation and maintenance

Table 3 - Key, typical energy data for desalination technologies (Main source: EU, 2008)

	MSF	MED	SWRO[1]	ED
Operation temp., °C	90-110	70	Ambient	Ambient
Electricity demand, kWh/m^3	2.5 -3.5	1.5–2.5	3.5–5.0	1.5-4.0 feed water with 1500-3500 ppm solids
Thermal energy demand, kWh/m^3	80.6 (290 kJ/kg)	80.6 (290 kJ/kg)	0	0

SWRO: Spiral wound reverse osmosis

cost is concerned, a comparison of two most used conventional desalination systems, i.e. RO and MSF, to be installed in Libya (Al-Karaghouli, 2011) shows that the MSF plant requires higher capital costs while the RO plant requires higher operation and maintenance costs due to the plant complexity. Typical figures for the investment cost of new installed desalination capacity range between USD 800 and USD 1500 per unit of capacity (m^3/d), with large variations depending on local conditions (labour cost, interest rate, etc.). Typical operation and maintenance costs are estimated at about 2-2.5% of the investment cost per year. As for the overall desalination cost, significant reductions have occurred over the past years, but water desalination remains economically affordable only for middle-income countries and too expensive for poor countries. The typical production cost of conventional desalination plants based on fossil fuels ranges from USD 1 to 2 per m^3. Under most favorable conditions, i.e. modern large-scale plants, the cost can be as low as USD 0.5/m^3 (Moilanen et al, 2010). In a typical desalination plant, the energy cost accounts for about 30% of the total cost (with electricity price of USD 50-60/MWh).

In general, desalination based on renewable energy sources is still expensive if compared with conventional desalination as both investment and generation costs of renewable energy are higher. However, under certain circumstances - e.g. installations in remote areas where distributed energy generation (heat and power) is more convenient than centralized energy generation, transmission and distribution - renewable desalination could compete with conventional systems

Costs of desalinated fresh water from most common desalination processes based on renewable energy are shown in Table 4 (Papapetrou et al, 2010). Most of such technologies have already been demonstrated, except for Solar/CSP-MED. With the rapid decrease of renewable energy costs, technical advances and increasing number of installations, *renewable desalination* is likely to reduce significantly its cost in the near future and become an important source of water supply for regions affected by water scarcity.

POTENTIAL, SUSTAINABILITY AND BARRIERS

■ **Potential -** The global capacity of desalination plants including *renewable desalination* is expected to grow at an annual rate of more than 9% between 2010 and 2016, with a cumulative investment of about USD 88 billion. As seen in Figure 7, the market is set to grow in both developed and emerging countries such as the United States, China, Saudi Arabia (SA), the United Arab Emirates (UAE). A very significant potential also exists in rural and remote areas as well as islands (Figure 7, rest of world, ROW) where grid electricity or fossil fuels to generate energy may not be available at affordable costs. About 54% of the global growth is expected to occur in the MENA region (PikeResearch, 2010). The International Energy Agency projects that in the MENA region - because of the growing population and depletion of surface and groundwater resources - the total water demand will increase from 9 billion m^3 in 2010 up to 13.3 billion m^3 in 2030 (IEA, 2005). As a consequence, the desalination capacity in MENA region is expected to grow from 21 million m^3/d in 2007 to nearly 110 million m^3/d by 2030 (of which 70% is in Saudi Arabia, the United Arab Emirates, Kuwait, Algeria and Libya). This will contribute the surge in energy use in the region. The annual electricity demand for desalination in MENA region is expected to rise to 122 TWh by 2030, a factor of three higher compared with 2007 (IEA 2009). As already mentioned, solar energy, in particular CSP with thermal energy storage, shows a significant potential for combined production of electricity and fresh water in the MENA region. In the water demand scenario elaborated by the DLR (Figure 8), the CSP-based desalination is projected to become a major process for water production in MENA. This scenario involves the availability of surface- and ground-water according to mild-average climate change and desertification scenarios. On the other hand, matching the appropriate types of desalination technologies requires careful assessments. Membrane technologies are not well suited for seawater desalination in regions where seawater salinity is higher because they require energy-intensive pretreatment to avoid fouling.

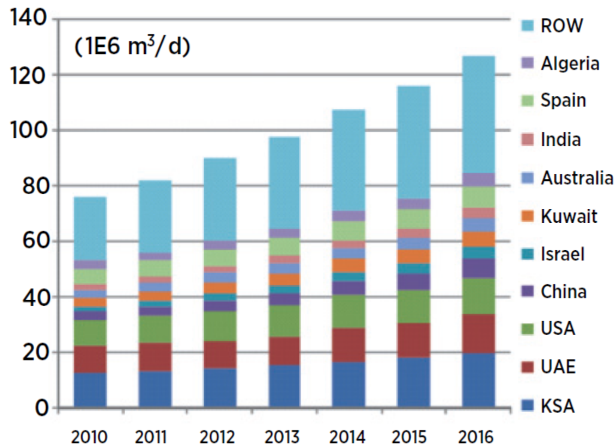
Desalination will also be crucial in countries such as Egypt which face serious water deficit due to population and economic growth. In Egypt, the growing water demand can no longer be met by the Nile water supply (Yousef et al, 2007). In 2025, Egyptian water demand is expected to reach the level 130 billion m^3/year, with more than 80% used for agriculture, while water supply is currently expected to remain at 73 billion m^3/year, leaving a huge deficit (Yousef et al, 2007).

China and India are also high potential markets for desalination due to population and economic growth along with water shortage. In China, the central government pays a lot of attention to desalination and cities in the east coast are implementing desalination plants to alleviate water scarcity (Haijun et al, 2008).

Table 4 – Cost of renewable desalination processes (Papapetrou et al., 2010, and European Union, 2008)

	Capacity (m^3/d)	Energy demand (kWh/m^3)	Cost (USD/m^3)	Develop. Stage
Solar stills	<0.1	Solar passive	1.3 – 6.5	Application
Solar Multiple Effect Distillation	1-100	thermal: 100 electric: 1.5	2.6 – 6.5	R&D/ Application
Solar Membrane Distillation	0.15-10	thermal: 150-200	10.4 -19.5	R&D/ Application
Solar/CSP-Multiple Effect Distillation	> 5,000	thermal: 60-70 electric: 1.5-2	2.3 - 2.9 (estimate)	R&D
Photovoltaic Reverse Osmosis	< 100	electric: BW: 0.5-1.5 SW: 4-5	BW: 6.5 – 9.1 SW: 12 -15.6	R&D/ Application
Photovoltaic Electrodialysis Reversed	< 100	electric: only BW:3-4	10.4 – 11.7	R&D
Wind Reverse Osmosis	50-2,000	electric: BW: 0.5-1.5 SW: 4-5	<100 m^3/d, BW: 3.9 – 6.5 SW: 6.5 – 9.1 1000 m^3/d 2 – 5.2	R&D/ Application
Wind Mechanical Vapor Compression	< 100	electric: only SW:11-14	5.2 – 7.8	Basic Research

Solar Stills: simple and old technology where the incident short wave radiation is transmitted and absorbed as heat;
Multiple Effect Humidification: use of heat from highly efficient solar thermal collectors to induce multiple evaporation/condensation cycles;
Membrane Distillation: thermally driven distillation process with membrane separation;
Reversed Electrodialysis: same principle as **Electrodialysis** (ED) except for the fact that the polarity is reversed several times per hour;
CSP: Concentrated Solar Power;
BW: Brackish Water; **SW**: Sea Water;
Note: cost calculated at the exchange rate of 1.3 from euro to USD.



KSA: Kingdom of Saudi Arabia

Figure 7 - Global installed desalination capacity, 2010-2016, (PikeResearch, 2010)

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Many Pacific islands also face water scarcity which poses food, economic, and health security issues. These countries are keen to accelerating renewable energy deployment to diversify their energy mix and reduce dependency on fossil fuels. Therefore, implementation of small stand-alone renewable desalination systems can provide viable solutions to both water and energy issues in the region.

Australia has recently pursued desalination technologies to meet its growing water demand. Most desalination plants are in Western Australia (WA) where the Government of Western Australia requires new desalination plants to use renewable energy. The landmark project was the Perth Seawater Desalination Plant (SWRO), which buys electricity generated by a wind farm north of Perth. The plant is designed to optimize the energy consumption and requires 3.4 kwh/m3, including overhead, and 2.2kwh/m3 for the plant only.

■ **Barriers –** Combining variable renewable technologies and desalination processes, which require a constant energy supply, involves technical, economic and organizational issues. Technical developments include a large availability of low-cost renewable energy and energy storage technologies to face the variable nature of renewable energy. A key issue is the disposal of brine. High-salt content brine is the desalination waste to be disposed of or recycled. At present, it is mostly discharged into the sea or diluted and sprayed in open space. However, the negative impact of brine on the ecosystems and the growing desalination capacity mean that a sustainable solution is needed for disposal and/or brine recycle to avoid environmental impacts (Gude, 2010). From an economic point of view, the identification of niche markets and proper policy frameworks may help attract private investors for *renewable desalination* to take off (Papapetrou, 2010). Not least, more co- operation and integration is needed between companies from the energy sector and companies from the water sector (Papapetrou, 2010), and more attention is to be paid on barriers for developing countries, including high investment and operation costs, and trained personnel to run the plants.

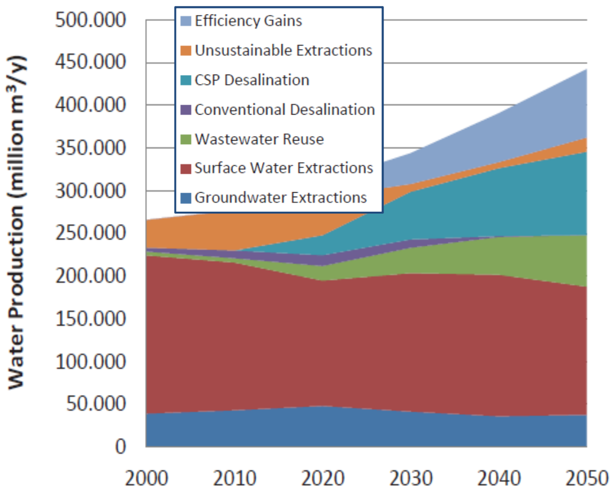

Figure 8 - Water demand scenario in MENA, 2000–2050 (Trieb et al, 2011)

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Table 5 – Summary Table - Key Data and Figures for Conventional and Renewable Water Desalination

Conventional Water Desalination					
Energy input	Fossil Energy (heat and/or electricity)				
Output	Fresh water				
Technology Variants	**Thermal Processes**			**Membrane Separation Processes**	
	MSF	**MED**	**VC (MVC)**	**RO**	**ED**
Energy input	Heat & Electricity	Heat & Electricity	Heat & Electricity (mechanic. power)	Electricity	Electricity
Feed water	More than 60% seawater (SW) plus brackish water (BW); Some high-salinity seawater may need pre-treatments for membrane separation				Mostly brackish water
Energy use	290 kJ /kg plus 2.5-3.5 kWhe/m^3	290 kJ/kg plus 1.5-2.5 kWhe/m^3	na	0 kJ$_t$/kg 3.5-5.0 kWhe/m^3	0 kJ$_t$/kg 1.5-4.0 kWhe/m^3
Operation temperature, °C	90-110	70	na	room temp.	room temp.
Plant lifetime, year	na	na	na	na	na
Capacity factor, %	na	na	na	na	na
Market share, %	27	8	na	60	4
Global capacity (2011)	72 million m^3/day (about 65 million m^3/day in operation) over about 15,000 plants				
Average plant capacity	4000-5000 m^3/day				
Largest plant capacity	800,000 m^3/day				
Major producers	MENA (Saudi Arabia), United States, China. About 38% of the global capacity (2,800 plants) in MENA				
Emissions	Emissions are associated to the primary energy used to power desalination plants				
Waste	Brine (high-salinity waste water)				
Desalination Costs	**Typical current international values for new installed capacity (2010 US$)**				
Capital cost per unit of capacity	$ 800 -1500/m^3/day, Large variations depending on local labor cost, interest rate, and technology				
O&M cost per year	1.5-2.5 % of the investment cost per year				
Fresh water production cost	USD 1-2/m^3 (USD 0.5/m^3 for large size plants), largely depending on energy cost and plant location				
Projected Market Growth					
global desalination capacity	+ 9% per year between 2010 and 2016 (54% in MENA reaching 110 million m^3/d by 2030)				
Investment	USD 88 billion. between 2010 and 2016				
Major producers/users	Saudi Arabia, UAE US, China, rural remote areas and islands in the rest of world				

Renewable Water Desalination								
Technology Variants	**Solar stills**	**Solar MED**	**Solar Membrane Distillation**	**Solar CSP/MED**	**PV/RO**	**PV/ED**	**Wind/RO**	**Wind/MVC**
Development status	Application	Appl./ R&D	R&D	R&D	Appl./ R&D	R&D	Appl./ R&D	basic R&D
Energy input, kWh$_e$/m^3+kJ$_t$/kg	Solar passive	1.5 +100	0 +<200	1.5-2.0 + 60-70	0.5-1.5 BW 4.0-5.0 SW + 0	3.0-4.0 BW + 0	0.5-1.5 BW 4.0-5.0 SW + 0	11-14 SW + 0
Typical current capacity, m^3/day	0,1	1-100	0.1-10	>5000	<100	<100	50-2000	<100
Market share of renewable desalination	<1% of the global desalination capacity (62% based on RO, 43% powered by PV)							
Production cost, USD/m^3	1.3-6.5	2.6-6.5	10.4-19.5	2.3-2.9	6.5-9.1 BW 11.7-15.6 SW	10.4-11.7	3.9-6.5 BW 6.5-9.1SW	5.2-7.8

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