Sustainable Water Integrated Management - Support Mechanism (SWIM- SM)

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REVISED Final Report

ASSESSMENT OF BEST AVAILABLE TECHNOLOGIES FOR DESALINATION IN RURAL/LOCAL AREAS

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2	ASSESSMENT OF BEST AVAILABLE TECHNOLOGIES FOR DESALINATION IN RURAL/LOCAL AREAS	Dr Adil Bushnak	Hosny Khordagui, Stavros Damianidis and Vangelis Konstantianos

Contents

List of Abbreviations

ADS	Autonomous Desalination System
AGMD	Air gap membrane distillation
BAT	Best Available Technology
BOOT	Build, Own, Operate and Transfer
BOT	Build, Operate and Transfer
CDE	Core Desalination Experts
CDG	Core Desalination Group
CSP	Concentrating Solar Power
DC	Direct current
DCMD	Direct contact membrane distillation
DES	Desalination
EC	European Commission
ED	Electro dialysis
EDM	Electro dialysis metathesis
EDR	Electro dialysis Reversal
EIA	Environmental Impact Assessment
EMP	Environmental Mitigation Plan
EU	European Union
FPs	Focal Points
GOR	Gain Output Ratio
GWP	Global Water Partnership
HAWT	Horizontal axis wind turbines
HDH	Humidification-dehumidification
IT	Information Technology
IWRM	Integrated Water Resources Management

KSA	Kingdom of Saudi Arabia
LLNL	Lawrence Livermore National Laboratory
MAP	Mediterranean Action Plan
MD	Membrane Distillation
MECO	Mechanical Equipment Company
MED	Multiple Effect Distillation
MED-POL	Program for the Assessment and Control of Marine Pollution in the Mediterranean Region
MES	Multiple Effect Stack
MSF	Multi-stage Flash
MVC	Mechanical Vapour Compression
NF	Nano filtration
NGO	Non-governmental Organisation
PC's	Participating Countries
PPP	Public Private Partnership
PR	Performance Ratio
PV	Photovoltaic
RBO	River Basin Organisation
RES	Renewable Energy System
RO	Reverse Osmosis
SGMD	Sweeping gas membrane distillation
SMC'a	South Mediterranean Countries
SWIM	Sustainable Water Integrated Management
SWIM-SM	Sustainable Water Integrated Management-Support Mechanism
SWRO	Seawater Reverse Osmosis
TDS	Total Dissolved Solids
TL	Team Leader
TVC	Thermal Vapour Compression

TBT	Top Brine Temperature
UNEP	United Nations Environment Programme
VAWT	Vertical axis wind turbines
VMD	Vacuum membrane distillation
VSEP	Vibration Shear Enhanced Process
WESCO	Water and Environmental Services Co.
WP	Work Package

Executive Summary

Countries in the south of the Mediterranean Sea are facing increasing water scarcity. This scarcity is driving the need for augmenting conventional water supply with alternative water sources. Rural and remote areas are particularly disadvantaged because such areas are often located far away from municipal water supply systems and conventional water sources, and are often not connected to the electric power grid.

There is good potential for addressing the water scarcity problem in rural and remote areas through sustainable saline water desalination technologies. Seawater and brackish water desalination are well-established industries comprising a wide variety of available technologies with decades of accumulated experience.

Rural and remote areas have special requirements that influence the appropriate selection of technologies. These include technical requirements related to small-scale application using renewable energy sources, ease of operation and maintenance, and simple design; requirements dictated by geographical location; as well as socio-economic and socio-cultural requirements related to the communities that are intended to operate and benefit from the technology. Successful implementation and long term sustainability (operational and environmental sustainability) of desalination projects for rural and remote locations requires that all the relevant requirements be identified and addressed from the earliest stages of the project.

The present report provides a review of the Best Available Technologies (BAT) for desalination in rural areas suitable for the SWIM-SM participating countries (PC). The focus of the review is exclusively on sustainable desalination technologies. Both seawater and brackish water desalinations are considered.

The report begins with an overview and description of desalination process technologies, ones that are presently available as well as some that are expected to be available in the near future. The focus of the discussion is on relevance for application in rural and remote areas. This is summarized in Table 1 on page 30. Following that, a brief review of the main renewable energy technologies that are relevant for coupling with the BATs for desalination as well as a discussion of the main applicable process/renewable energy system (RES) combinations are provided. The major advantages and disadvantaged of each RES relevant to the present purpose are discussed. The main renewable energy sources available in the PCs are solar energy (solar thermal and PV), wind power, and geothermal energy.

Two main factors play the major role in narrowing down the choice of process technologies:

1) The salinity of the feed water;
2) The type of energy available at a given location.

For brackish water sources up to about 3000 ppm, either RO or ED can be recommended as a good choice of desalination process for the purpose. For brackish sources at higher salinities ED no longer becomes suitable, leaving RO as the best choice presently available. Both of these processes are driven by mechanical or electrical power, which means that either solar PV or wind power is a suitable choice for off-grid sites, depending on the quality of the source at the location.

The situation is less clearly defined in the case of seawater desalination. At present, it can generally be said that two desalination processes stand out as being the most reliable and mature processes; one from each of the two families of power-driven and thermally driven processes: RO and MED. The best choice among these depends largely on the type and quality of RESs available at the location in question.

If the wind energy quality at a site is high, then wind-powered RO needs to be considered.

When geothermal energy is available, the stable and continuous nature of this RES constitutes a very desirable feature that warrants its serious consideration. Geothermal energy allows 24-hour plant operation without the need for energy storage. In such case, a good choice of process at the present state of technology would be MED, but other choices are possible and should be considered for small capacities, such as MD and HDH.

In most of the PCs, the amount of sunny days is high, and thus solar energy can almost be considered as the

default RES. In such cases, there are two major possible alternatives:

1. PV-RO: The system needs to be over-sized to provide the required daily capacity during the sunshine hours (~9-10 hr. /day), since it is not economically feasible at present to store electrical energy long enough for night operation.
2. Solar thermal-MED: Thermal energy storage can easily be applied economically, and the system can be sized to the desired daily capacity as usual. Other choices of thermal process are possible for small capacities.

A detailed comparison between these two alternatives needs to be carried out in order to select the best option.

This selection process is elaborated further in Chapter 3, which provides a guideline and methodology for screening and selecting the most appropriate technologies for application to a particular case. It is emphasized that optimum technology selection is a very case-dependant issue, and it is thus difficult to specify a fixed solution or solutions that are universally applicable. Instead, the present report provides a methodology for selection that begins by defining the scale of the problem to be addressed by the technology and an identification of the renewable energy resources available.

The report also emphasizes the importance of identifying the requirements of the local community as a critical factor for success of project success. The modalities for assessing community requirements comprise the subject material of Chapter 4. These include groups of factors and requirements dictated by geography, demographic and socio-cultural considerations, water resource availability, appropriate pricing structures and financing schemes, as well as institutional and regulatory factors.

Finally, the report discusses aspects and recommendations for integration of BATs for rural and remote area desalination projects within the context of national Integrated Water Resources Management (IWRM) plans. This takes into account the main principles of IWRM, and outlines a number of opportunities for strategic level Environmental Impact Assessments (EIA), as well as synergies that can be realized by integrating with wastewater treatment and re-use.

1. Introduction

The Sustainable Water Integrated Management (SWIM) is a European Union(EU)-funded Regional Technical Assistance Program [1] that "aims at supporting water governance and mainstreaming by promoting sustainable and equitable water resources management to become a prominent feature of national development policies and strategies (agriculture, industry, tourism, etc)." [2]

Countries in the south of the Mediterranean are facing increasing water scarcity. This scarcity is driving the need for augmenting conventional water supply with alternative water sources. Rural and remote areas are particularly disadvantaged because such areas are often located far away from municipal water supply systems and conventional water sources, and are often not connected to the electric power grid. There is good potential for addressing the water scarcity problem in rural and remote areas through sustainable saline water desalination technologies. Seawater and brackish water desalination are well-established industries comprising a wide variety of available technologies with decades of accumulated experience. There are many advancements and evolution in desalination technologies. The numerous technologies and processes available have different characteristics, advantages and disadvantages that make each suitable for particular market segments or specific niches. Moreover, much of the cumulative technology experience is related to large urban supply plants that are either connected to the grid, or are themselves part of large power and desalination cogeneration plants. Rural and remote areas have special requirements that influence the appropriate selection of technologies. These include technical requirements related to small-scale application using renewable energy sources, ease of operation and maintenance, and simple design; requirements dictated by geographical location; as well as socio-economic and socio-cultural requirements related to the communities that are intended to operate and benefit from the technology. Successful implementation and long term sustainability (operational and environmental sustainability) of desalination projects for rural and remote locations requires that all the relevant requirements be identified and addressed from the earliest stages of the project.

To this end, SWIM-SM has commissioned the present report to provide a review of the Best Available Technologies (BAT) for desalination in rural areas suitable for the PCs. The focus of the review is exclusively on sustainable desalination technologies. LDK Consultants and European Union contracted Water and Environmental Services Co. (**WESCO**) to carry out a study to assess the BAT for desalination in rural areas suitable for the PCs.

The main goal is to produce a report reviewing and compiling the BATs, which can then be catered to the specificity of the PCs to supplement water supplies to remote communities, whether they are on coast or inland communities. Both seawater and brackish water desalination shall thus be considered. Prevailing socio-economic, political, and cultural constraints are to be taken into consideration.

The aim of the report is to provide PCs and decision-makers with an overview and assessment of the BATs on desalination in remote areas.

The report begins with Chapter 2, which provides a survey of the Best Available Technologies (BAT) for desalination, the main renewable energy technologies for desalination and an overview of the combination of the best available technology with the available renewable energy. Specifically Section 2.1 provides a description of the main desalination process technologies available today, along with a presentation of their relative merits. Section 2.2 provides a brief review of the main renewable energy technologies that are relevant for coupling with the desalination process best for implementation in remote rural areas. Finally, section 2.3 provides an overview of the main renewable energy/desalination technology combinations that are suitable for application in the PCs.

Chapter 3 provides Decisions, data and information before considering technologies for implementation of a desalination project. In short sections it provides the IWRM concept approach, the definitions on desalination capacities, the plant capacity calculation, the desalinated water quality, the demographic and socio-cultural considerations, the EIAS, the desalination project systems , criteria for site selection and budgeting and implementation costs etc.

Chapter 4 provides a guideline and methodology for screening and selecting the most appropriate technologies for application to a particular case. The chapter adopts a flexible approach that emphasizes that optimum technology selection is a very case-dependant issue, and it is thus difficult to specify a fixed solution or solutions that are universally applicable. Instead, the chapter provides a methodology for selection that begins by defining the scale of the problem to be addressed by the technology and identification of the renewable energy resources available. These elements set the stage for the remainder of the selection process outlined in Chapter 4.

Identifying the requirements of the local community and the modalities for assessing them are the subject of Chapter 5. These include groups of factors and requirements dictated by geography, demographic and socio-cultural considerations, water resource availability, appropriate pricing structures and financing schemes, as well as institutional and regulatory factors.

The final chapter briefly discusses aspects and recommendations for integration of BATs for rural and remote area desalination projects within the context of national Integrated Water Resources Management (IWRM) plans.

2. Survey of BAT for desalination with focus on rural areas and description of renewable energy technologies for desalination

Section 2.1 provides a description of the available desalination technologies and section 2.2 a description of the renewable energy technologies for desalination.

2.1 Description of available desalination technologies, their merits and weakness related to use in rural areas:

A wide variety of technologies for seawater and brackish water desalination exist today. Many of these technologies are already well established and mature; some are in advanced stages of development, while other new technologies based on innovative ideas and new scientific developments continue to emerge. This section will describe the process and salient features of various successful desalination technologies, as well as their merits and weak points related to their adaptation in rural areas.

2.1.1 Multi-Stage Flash (MSF)

In the MSF process, seawater is evaporated by flashing in stages of consecutively decreasing pressure. The seawater is first pressurized and raised to its maximum temperature, the *top brine temperature* (TBT), after which it is introduced into the first stage, maintained at a pressure that is lower than the saturation pressure that corresponds to the TBT. This causes the seawater to boil violently in what is called *flash* boiling. The vapour thus released, which is pure water vapour, rises to the top of the stage where it encounters a bundle of condenser tubes inside which cooler feed water flows on its way to the brine heater. As the distillate vapour passing through the demister reaches the condenser tubes it begins to condense and form water droplets, which in turn fall onto special trays that collect and transport the distillate water. The brine from the first stage subsequently enters the next stage where the pressure is again lower than the previous stage, and the same process is repeated along all the stages. What happens in the final few stages will depend on the type of flow configuration the plant has. There are two main types of flow configuration in MSF plants: once-through, and brine-recirculation plants. In the simpler, once-through configuration, all the stages are identical; while in brine-recirculation plants the last few stages comprise what is called the heat rejection section, and the flow of seawater in the stage condensers will be larger than the flow in condensers of the remaining stages, allowing better control over the temperature in the final stage, thus achieving a larger overall flashing range in the plant. The performance of MSF plants and thermal plants in general, is typically measured either by the ratio of mass of distillate generated by a unit mass of input steam, which called the *gain output ratio* (GOR), or the ratio of the mass of distillate water produced to the thermal energy of the steam required to produce it, which is called the *performance ratio* (PR). In some references, the PR is defined as a ratio of the thermal energy content of the distillate produced to the amount of thermal energy of the input steam. This latter definition of the PR has the attractive feature of being a dimensionless ratio, but appears to be less commonly used. The higher the GOR and PR, the more distillate it can produce using a given amount of input steam; i.e. the more efficient the unit is. However, more stages are required to achieve higher GOR and PR, which is associated with a higher capital cost. Simple schematics of MSF plant is illustrated in figure 1.

A small capacity MSF plant with a performance ratio of 6 requires around 70 -80kWh of equivalent thermal energy per kg of distillate water produced, in addition a power consumption of 4-6 kWh/m^3 for pumping and auxiliary systems[1]. A large size MSF unit with a PR of 9.5 consumes close to 38 kWh/m^3 of energy equivalent, compared to ≈4.5 kWh/m^3 for similar capacity SWRO units. It should be noted that in converting from thermal energy to equivalent power consumption the efficiency of conversion needs to be accounted for. Doosan Heavy Industries & Construction has fabricated the world's largest multi-stage flash (MSF) evaporator unit of capacity 91,000 m^3/d for Ras Al Khair seawater desalination plant in Saudi Arabia.

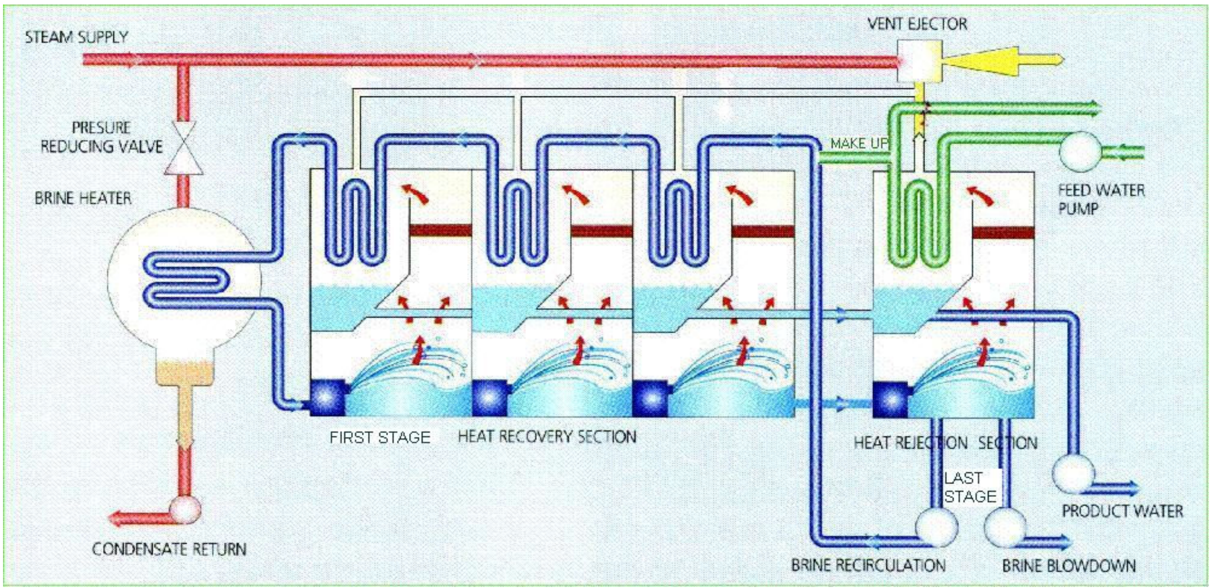

Figure 1: Schematic diagram of a simple MSF Unit

Merits:

- Matured technology with hundreds of installations in operation worldwide for several years with successful record of accomplishment.
- The MSF process has the largest installed capacity among all desalination process due to scalability, robustness and reliability of the process.
- Requires minimum pre-treatment compared to RO process.
- Produces very low TDS water.
- Many reputed manufacturers like Doosan, Fisia, Aqua Tech, Hitachi Zosen, etc. can supply the unit.

Weak points related to the use of MSF Plant in rural areas:

- Very high specific energy consumption would be required for the small capacity units generally designed with low GOR and PR. It is cost effective only if low cost (free) steam/heat energy is available.
- Very low recovery (ratio of distillate produced to feed water supplied) in the range of 10 to 20%. High cooling water requirement makes it suitable for coastal areas only.
- The heating energy required has less dependence on the salinity of feed water and hence it is uneconomical for desalination of brackish water.
- Re-mineralisation chemicals requirement is high when compared to RO process.
- Small capacity units are expensive compared to RO and MED plants.
- Relatively precise pressures need to be achieved in the stages before the stable operation can proceed, which makes it difficult to match with a variable heat source such as solar energy without adding thermal storage [2]

2.1.2 Multi-Effect Distillation (MED)

The MED process is similar to the MSF process in that seawater is consecutively introduced into chambers of decreasing pressure, which serves to consecutively lower the temperature required to bring the water to boil; but the MED process differs in that boiling is mostly achieved on heat transfer surfaces (tube bundles) rather than by flash evaporation. A small amount of flashing does occur, but it has a small relative contribution to the total. Each one of the chambers is called an *effect*. A primary source of heat is needed to provide the steam for the first effect, the one at the highest temperature. In a typical plant, the seawater entering the first effect is sprayed down over a bundle of *evaporator* tubes, while the steam driving the boiling process flows inside the evaporator tubes. Such an arrangement is called a *falling film evaporator*.

The distillate vapour released from this evaporation process is at a higher temperature than the saturation temperature in the second effect, thus it is introduced on the tube side of the evaporator in second effect, where it condenses, giving up its heat to drive the evaporation of the rest of the seawater, coming from the first effect. This process is repeated in each consecutive effect. A separate condenser is required to condense the distillate vapour generated in the last effect, which also serves to preheat the feed seawater slightly and decrease the required heat input. The condensed distillate from each stage is collected in a common header and transported for post-treatment. Simple schematic of a MED-TVC plant is illustrated in figure 2.

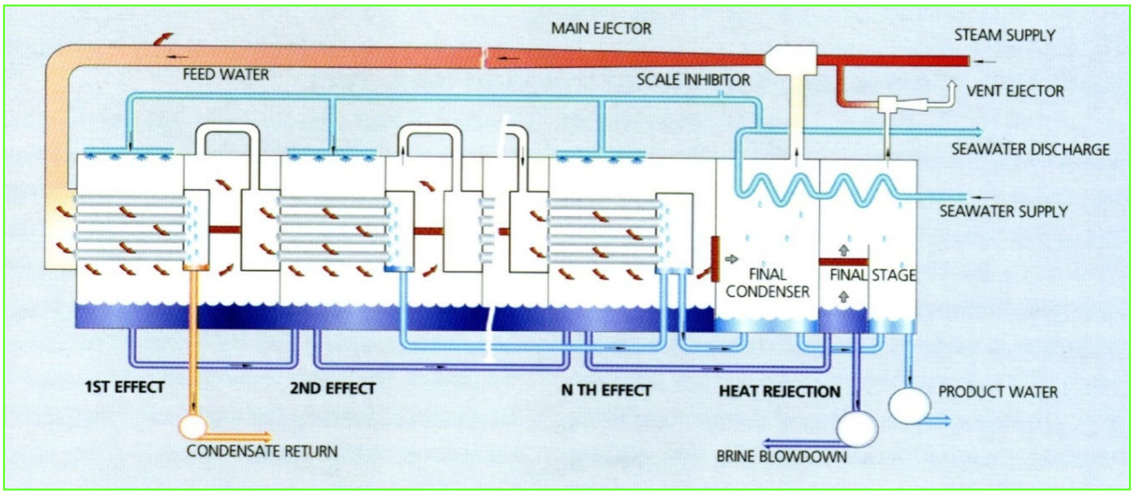

Figure 2: Schematic diagram of a simple MED-TVC unit

The GOR of an MED plant is tied to the number of effects as its theoretical maximum. This because the number of effects determines the number of times the energy imparted by the steam to the distillate can be reused to evaporate an additional similar amount of distillate. It is worth noting however that this restriction applies only to the basic MED process; the incorporation of TVC (described below) removes this limitation, making it possible to achieve a GOR higher than the number of effects. Doosan Heavy Industries & Construction is building the world's largest MED unit of capacity 68,000 m^3/d for Yanbu seawater desalination plant in Saudi Arabia.

MSF and MED plants with similar GORs will, by definition, have a similar specific consumption of thermal energy, but the specific power consumption of an MED plant is lower, at around 1.0-3 kWh/m3 [1]. However, it should be noted that MED plants achieve the same GOR achievable in MSF plants with a fewer number of effects.

Merits:

- Matured technology with hundreds of installations in operation worldwide for several years with successful record of accomplishment.
- Recently, very low temperature drops per effect have been achieved, approximately 1.5-2.5 deg C, which makes it possible to accommodate a relatively large number of effects. This leads to higher GORs, even with a low TBT around 70 deg C.
- The ability to operate using low-grade thermal energy input (~70 deg C) at higher thermodynamic efficiencies than MSF. This makes it a natural choice for coupling with thermal RESs such as solar thermal and geothermal energy.
- The MED process has the largest installed capacity among all thermal desalination process next to MSF due to scalability, robustness and reliability of the process.
- Requires minimum pre-treatment compared to RO process.
- Produces very low TDS water.
- Consumes less power than MSF process.
- Many reputed manufacturers like Doosan, Sidem, Aqua Tech, Sasakura, Entropie etc. can supply the unit.

Weak points related to the use of MED Plant in rural areas:

- Generally high specific energy consumption compared to RO. It is cost effective only if low cost or free heat energy is available.
- Very low recovery in the range of 15 to 25%. High cooling water requirement makes it suitable for coastal areas only.
- The heating energy required has virtually no dependence on the salinity of the feed water and hence it is uneconomical for desalination of brackish water compared to RO and ED.
- Small capacity units are expensive compared to RO plant.
- Re-mineralisation chemicals requirement is high when compared to RO process.

2.1.3 Vapour Compression Distillation

In the vapour compression process, which can have a single effect or multiple effects, the distillate vapour released from the evaporator is taken to a vapour compressor. By raising the pressure of the vapour in the compressor, the saturation temperature is raised. Thus, the compressed distillate vapour is used to drive the evaporation process in the same stage from which it was produced, while itself condensing at the higher saturation temperature corresponding to the compressor discharge pressure. There are two major types of vapour compression processes, based on the method of compression: mechanical vapour compression (MVC), and thermal vapour compression (TVC). In the former, a mechanical compressor is used to achieve the required compression; while in the latter a steam jet ejector is used for this purpose. The steam jet ejector is a convergent-divergent nozzle that uses medium pressure (2-10 bars) motive steam to entrain the distillate vapour from an effect and raise its pressure as it is discharged. The main input for each of these processes is different; in the case of MVC it is the mechanical power exerted by the compressor, while in the case of TVC it is the thermal power of the motive steam. Sometimes MVC plants require an auxiliary boiler for start-up and augmentation of the energy input.

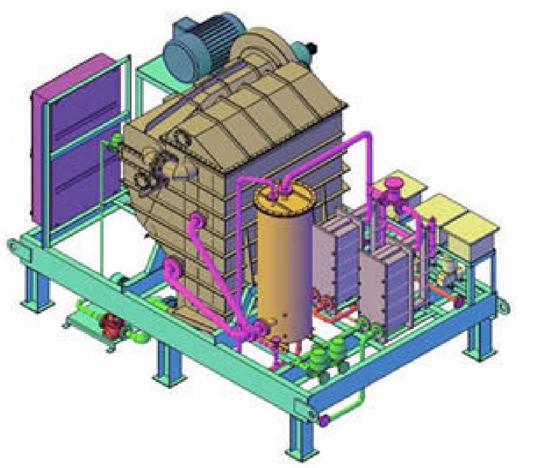

Figure 3: MECO's MVC unit

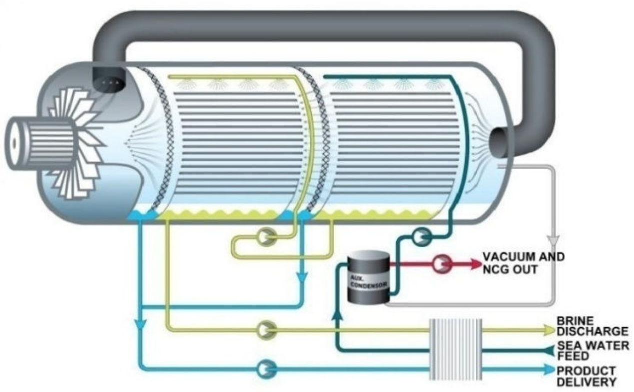

Figure 4: IDE's MVC unit

Merits of MVC:

- Established technology with many installations in operation with successful record of accomplishment.
- Compact compared to MED and MSF processes are still being manufactured in small capacity units.
- High recovery (up to 40%) compared MSF & MED process.
- Requires minimum pre-treatment compared to RO process
- Produces very low TDS water.

- Consumes very less steam under normal operation.
- Many reputed manufacturers like MECO, IDE, HamworthySerck Como GmbH, etc. can supply the unit.

Weak points related to the use of MVC Plant in rural areas:

- Relatively high specific power consumption (compared to RO) would be required for the small capacity units suitable for rural areas.
- Requires virtually the same specific power for seawater and brackish water desalination, which makes it an uneconomical choice for desalination of brackish water.
- Power intensive compared to MSF, MED and RO processes. 10.4 to 15 Kwh/m³ of electric power is required to run the vapour compressor. Hence, not desired where electricity tariff is high.
- Re-mineralisation chemicals requirement is high when compared to RO process.
- Small capacity units are expensive compared to RO plant.
- High scaling potential due to higher recovery and slight upset in acid injection will result in heavy scaling.
- Maintenance intensive and skilled technicians required for the high-speed vapour compressor.

2.1.4 Reverse Osmosis

The process of desalination by reverse osmosis is based on the use of semi-permeable membranes. Such membranes allow the passage of water, but are impermeable to salts. Under normal circumstances, when such a membrane is used to separate two solutions with different salt concentration, water flows from the low salinity side to the high salinity side. This is called osmosis, and is a process that is commonly found in nature. If, however, one applies sufficient pressure on the high salinity side, it is possible to reverse the direction of pure water passage, so that pure water flows from the high salinity side to the low salinity side. This is the principle behind desalination by reverse osmosis. The amount of pressure one needs to apply to bring about this reversal in the direction of water flow is determined by a property of the solution called the osmotic pressure, and it increases as the salinity of the solution increases. For this reason the pressure, and hence the pumping power required to desalinate seawater is much higher than that required to desalinate brackish water. It is important to note that continuous improvements in commercial RO membrane properties, and the various efficient systems for recovering energy from the high-pressure brine stream in seawater RO plants, have led to RO being the most energy efficient method for seawater desalination presently available.

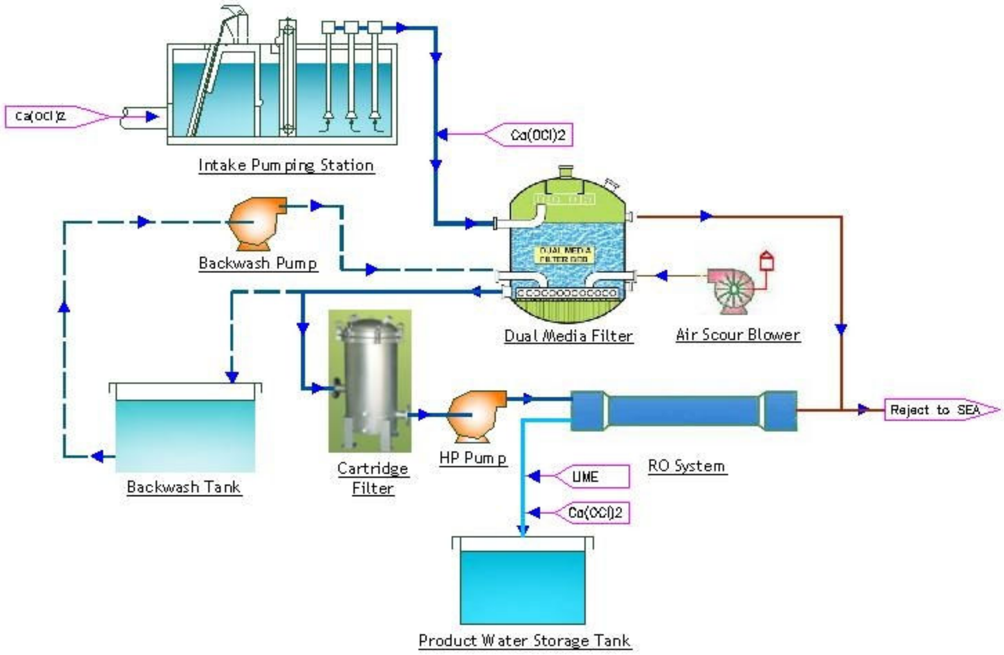

Figure 5: SWRO process schematics

Two types of RO membranes exist in the market; namely spiral wound and hollow fibre membranes. The spiral wound membranes are made by Hydranutics, Filmtec, GE, Toray, Koch, etc. and hollow fibre membranes are made by Toyobo. Hollow fibre membranes are only available for seawater application whereas spiral wound membranes are available for seawater and brackish water application.

Merits:

- Proven technology with good record of accomplishment.
- Can be used effectively for seawater, high salinity brackish water or brackish water
- Uses less energy than thermal processes.
- Lower capital cost than thermal processes.
- Requires less feed water than thermal processes
- Compact when compared to thermal process.
- Membranes made by different manufacturer are interchangeable, which avoids dependence on a single manufacturer.
- Can be started and stopped in short time.
- Development of new membranes with high productivity, less fouling and less energy consumption are driving further improvements in the process and makes it more attractive.

Weak points related to the use of RO Plant in rural areas:

- An elaborate pre-treatment system is required compared to thermal processes.
- Slightly complex to operate compared to MSF & MED process, requiring a higher level of skill on the part of the plant operators.
- Susceptibility to membrane fouling.

- Frequent variability in operating conditions and/or frequent start-up and shutdown cycles can shorten membrane life.

RO was estimated in 2011 to account for 65 % [33] of the global desalination production capacity and it is expected to reach 71.4% in 2016. Two of the recently developed membranes for the RO process are explained below

Thin-Film Nano composite membranes - NanoH2O

The use of thin-film nano-composite (TFN) membranes for water purification was first described for brackish water RO membranes in 2007[3]. The basic principle is that zeolite nano-particles were dispersed in the organic solution of an interfacial polymerization. As polymerization proceeds in the organic solution, nano-particles present near the aqueous-organic interface became incorporated within the polyamide layer. This resulted in increased permeability of the membrane, and altered surface properties potentially related to fouling and maintained salt rejection. Subsequent to that, the membrane has been improved for treating seawater. Since the membrane is essentially of flat-sheet type, the new TFN membrane is manufactured the same way as existing spiral wound RO membranes. Hence, production is not an issue. A new company, NanoH2O Inc., has been working towards the commercialization of the membrane[4] for various applications with specific emphasis on seawater applications. It was reported that the company shipped its first commercial seawater membrane product for testing by various consumers.

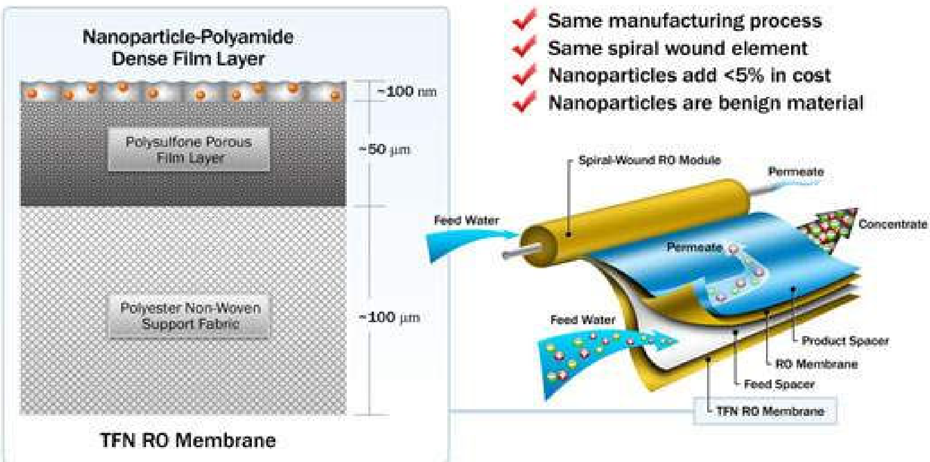

Figure 6: Nano membranes by Nano H_2O

RO membranes made of carbon nano-tubes

Several researchers are attempting to improve the performance of RO membranes by incorporating nano-materials. At least two such efforts are ongoing, one at Lawrence Livermore National Laboratory (LLNL), USA, and the other at University of California, Los Angeles, USA.

The LLNL team has discovered that carbon nano-tubes can be used to form membranes[5]. Initial laboratory scale results indicated that these nano-pores are capable of allowing large flows of water, while rejecting dissolved constituents. It is hypothesized that the water molecules behave different when confined to carbon nano-tubes – that they form tubular structures that pass through the nano-tubes. The dominant mechanism for dissolved constituents is not yet identified, although size exclusion and surface charge effects could play a role. Initial estimates indicate that energy consumption could be as much as 80% lower than that for typical RO membranes.

Now, NanOasis is commercializing the technology. Currently laboratory scale efforts are on going and it may be another year before a pilot or demonstration scale level study could be considered. Another company, Porifera, is also attempting to work on similar membrane using carbon nano-tubes.

2.1.5 Electro-dialysis

The idea of the electro-dialysis process is to use ion exchange membranes. Each such membrane allows either cations (cation permeable membrane) or anions (anion permeable membrane) to pass through it exclusively. Thus if a solution is placed between a pair of ion exchange membranes, and a DC voltage is applied across a set of electrodes placed on the outer sides of the membranes, salt ions will flow to the electrodes according to their charge. The central region will eventually be depleted of ions and its salinity will thus decrease. This is called an electro-dialysis cell. In practice, an electro-dialysis *stack*, created by placing a stack of alternating anions and cations exchange membranes in series, is usually employed to increase productivity. The ion-depleted channels in a stack constitute the desalinated product streams, while the adjacent channels contain the concentrated brine streams where ions from the neighbouring product channels migrate and accumulate.

In a variant of the ED process, called electro-dialysis reversal (EDR), the polarity of the electrodes is reversed periodically in order to reverse the flow direction, thereby inhibiting fouling and scale deposition and providing a self-cleaning mechanism [6].

The ED process is generally suitable for relatively low to medium feed salinity brackish water, not for seawater desalination. The need for good electrical conductance also means that ED is not suitable for treating feeds with salinity below 400 mg/l [2]. The energy required by the process depends on the feed salinity. The ED/EDR processes are mature and well established commercially.

An attractive feature of ED/EDR is that, because it uses a DC voltage, it is suitable for pairing with solar PV power without the need for DC to AC conversion. Electro-dialysis metathesis (EDM) is being developed which is a modification of electro-dialysis designed to increase product water recovery and it is explained below.

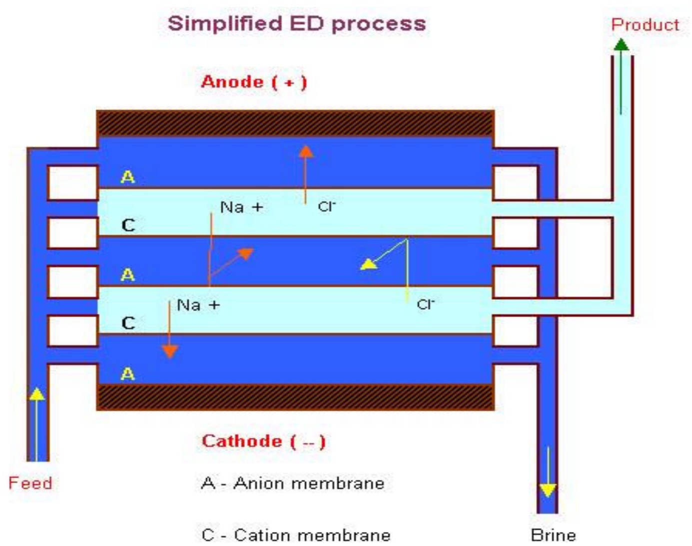

Figure 7: Simplified ED process

Merits of EDR process:

- Proven technology with good track record
- Recovery is as good as or better than RO process.
- Uses less energy than thermal processes.

- Tolerant to more feed water turbidity, silica, TOC, free Cl2,Fe & Mn compared to RO
- Lower capital cost than thermal processes.
- Requires less feed water than thermal processes
- Lower operating pressure required compared to RO process and for feed TDS <2000 ppm power consumption is lesser than RO process.
- Life of the EDR/ED membrane is more than RO membranes and the membrane is rugged compared to RO membranes.
- Compact when compared to thermal process.
- Can be started and stopped in short time.
- Development of EDR increased recovery, productivity, reduces fouling and lesser energy consumption makes it a preferred process out of the established desalination processes for brackish water desalination.

Weak points related to the use of ED/EDR Plant in rural areas:

- Best Suited for feed water TDS ranging between 400 and 3000 mg/l. Can be used effectively for brackish water; but not for high brackish water and seawater.
- Salt rejection (50 – 90%) is not as good as RO process (which is 90-99%)
- Non-charged particles cannot be removed so the process cannot remove silica, which can be removed 90%, by RO process.
- Power required is more than RO for feed TDS exceeding 3000 ppm.

2.1.6 Electro-dialysis Metathesis (EDM)

Electro-dialysis (ED) processes have been used for decades in industrial and municipal applications to remove ions from water. In ED, ions are transported under the driving force of an electrochemical potential gradient and separated from feed water by ion selective membranes. Electro-dialysis metathesis (EDM) is a modification of electro-dialysis designed to increase product water recovery and facilitate development of salt products from concentrate. The primary difference between EDM and ED is the number of cells in the repeating unit comprising the electro-dialysis stack. The basic unit of ED is a cell pair formed by two solution compartments separated by two ion selective membranes. The EDM repeating unit comprises four cells and four membranes: one dilute compartment, two concentrate compartments, one NaCl solution compartment, one anion exchange membrane, one cation exchange membrane, one monovalent selective anion exchange membrane, and one monovalent selective cation membrane (Figure8). This unique configuration of cells is designed to separate EDM concentrate into two streams of highly soluble salts: one containing sodium with anions and the other containing chloride with cations. This characteristic of EDM provides a significant advantage in maximizing recovery because the membrane fouling potentials of typical scalants such as $CaSO_4$ and $CaCO_3$ do not increase with recovery as is the case with RO, NF, and other forms of ED. Generation of two concentrate streams that are individually highly concentrated yet highly soluble facilitates conversion of concentrate to salt products. The two streams can be combined in a sequential series of treatment steps to generate salts products such as calcium sulphate, calcium carbonate, dolomite, magnesium hydroxide, sodium chloride, calcium chloride, and magnesium chloride. EDM was conceived in 1998 [7] and has since been evaluated extensively at pilot-scale[8]. EDM is currently being developed for full-scale application by Veolia. Although the EDM technology is new, it is nevertheless simply electro-dialysis with an innovative arrangement of membranes. Electro-dialysis is a matured technology with large-scale installations dating back to the early 1960's. Two concentrate streams are produced during desalination with EDM. The amount of concentrate generated, however, might be only 20 percent of the concentrate generated by RO because of higher EDM recovery. As previously noted, there is potential to develop salt and brine products from EDM concentrate to eliminate waste disposal. This emerging technology is expensive and can be used where zero discharge is preferred.

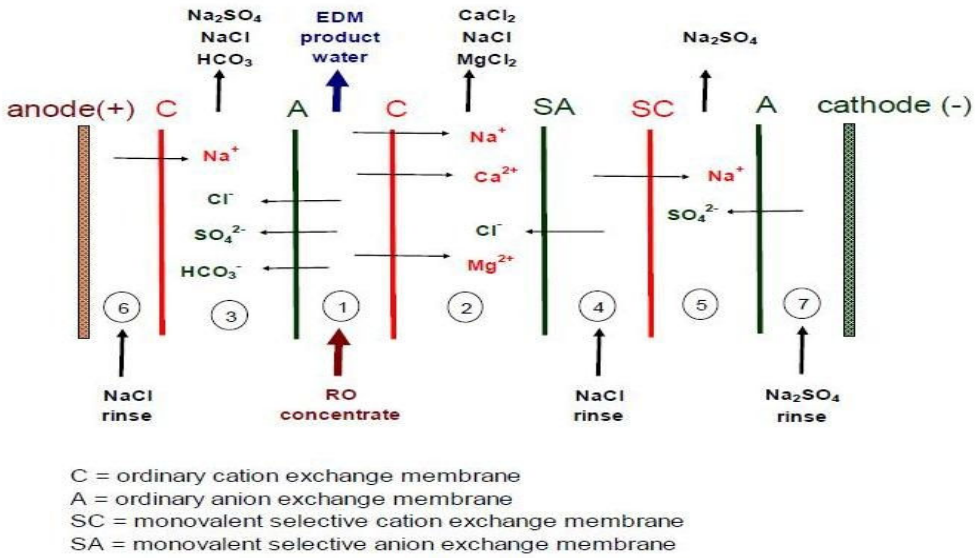

Figure 8: Electro-dialysis Metathesis Schematics

Merits of EDM process**:**

- Improved version of ED process with higher recovery compared to RO process
- Can be used where zero discharge is preferred. Salt and brine products can be developed using this process.

Weak points related to the use of ED/EDR Plant in rural areas:

- Emerging technology and expensive process.
- Needs skilled operation staff.

2.1.7 Membrane distillation (MD)

Membrane distillation is a thermally driven process that uses a *hydrophobic* membrane, one that is impermeable to liquid water, to distil the saline feed water. A source of heat is required to heat the feed water to temperature in the typical range of 70-90 ^{0}C. As the heated feed flows along the membrane surface, the hydrophobic nature of the membrane allows water vapour released because of the elevated temperature to pass through the membrane, but not the saline liquid feed. The distilled water vapour accumulating on the other side of the membrane is then condensed by various possible means to provide the required distilled product water.

There are four major variants of the MD process:

1. Direct contact membrane distillation (DCMD);
2. Air gap membrane distillation (AGMD);
3. Vacuum membrane distillation (VMD);
4. Sweeping gas membrane distillation (SGMD).

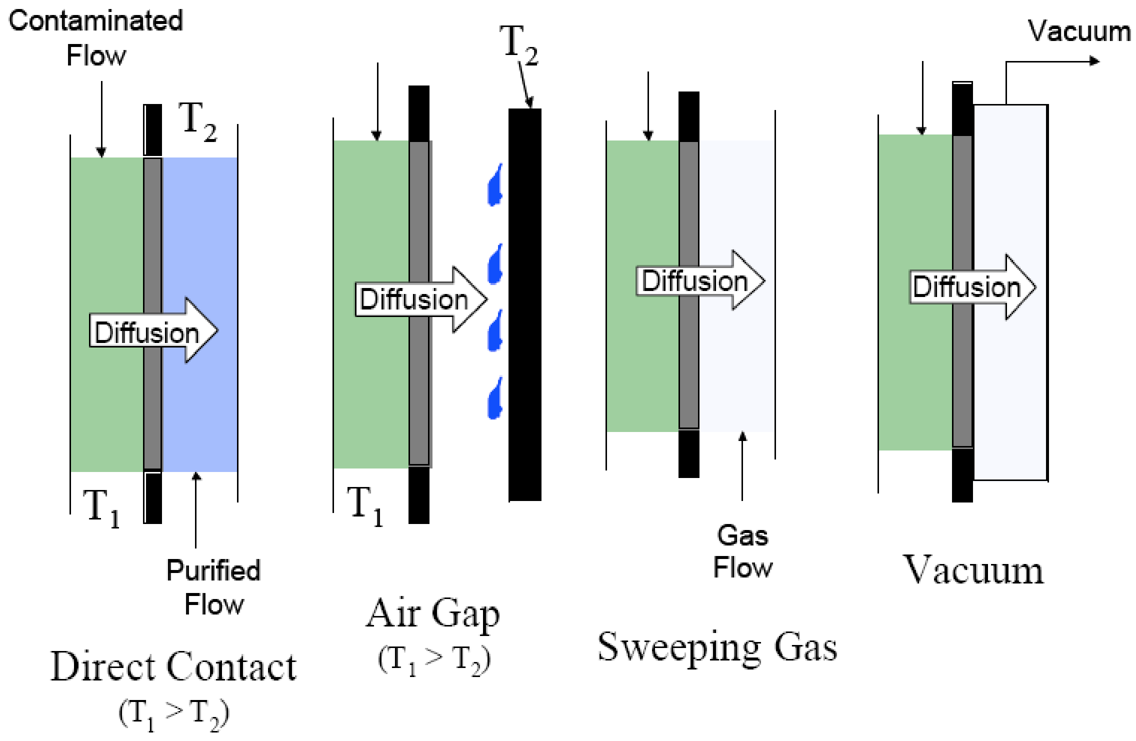

Figure 9: Different membrane distillation process

In DCMD, cooled distillate condensate is re-circulated into the distillate side of the membrane, so that vapour passing through the membrane from the feed side comes into direct contact with the liquid condensate stream, where the vapour condenses. In AGMD on the other hand, the feed and cooling water streams are separated by an air gap where the distillate vapour accumulates and condenses on the outer wall of the cooling water channel. In the VMD configuration, a vacuum is applied to the distillate side of the membrane to enhance the flux of distillate vapour. In this case, the distillate is accumulated in the vapour phase and conveyed to an external condenser where condensation takes place to provide the distilled product water. The similar objective of enhancing distillate vapour flux motivates the SGMD design, but in this case, it is achieved by the use of a flowing gas that entrains the distillate vapour.

Even though the MD process was invented in the 1960’s, it has not to this date enjoyed wide-scale commercial application. This is primarily due to the relatively high energy consumption and relatively low membrane productivity compared to RO [9]. Recently, MD has gained increased interest because of improvements in membrane characteristics and the potential for coupling with low-grade heat sources.

One exciting development that should be watched closely is the MD-based system developed by the German company Memsys [10]. The company developed a variant of the MD process that combines features of MED in a process they termed vacuum multi-effect membrane distillation (V-MEMD). Each MD-based effect utilizes a plate and frame module that can easily be stacked to achieve a multiple effect flow configuration. The MD effects resemble the AGMD configuration, but the condensation of vapour in the air gap is used to heat the water in the adjacent effect, while applying progressively increasing levels of vacuum, as in MED. This re-utilization of the latent heat of condensation, in several effects, is key to achieving higher GORs than previously possible in MD.

A 1 m^3/d pilot unit was installed last year in Singapore. The unit is reported to have a GOR of 4.2, which is remarkable for the MD process. Memsys claim that larger units with a GOR of 10 are possible. Another pilot project planned for a remote location in Western Australia called Tjuntjunjarra has recently been announced [11]. The 1 m^3/d unit is to be partly powered by waste heat from small-scale power generators and partly powered by the sun.

Preliminary estimates of the cost of membrane modules are currently at 1000 €/m^3/d [11], but the technology is still at a very early stage of commercialization, and the company has plans to scale up the process to the range of 1000-2000 m^3/d, which is expected to drive down cost.

Merits:

- Ability to utilize low-grade heat (solar collector, geothermal, waste heat, etc.)
- Use of multiple stages can reduce energy requirements.
- Less organic fouling propensity compared to RO
- Less pre-treatment compared to conventional membrane desalination processes
- The only membrane process that can maintain process performance (such as water flux and solute rejection) almost independently of feed solution TDS concentration.
- MD membranes are more chemically inert and resistant to oxidation than traditional RO and NF membranes, which allows for more efficient, chemically aggressive cleaning
- Produces higher-quality water than NF/RO, EDR and CD.

Weak points related to the use of MD Plant in rural areas

- Still under development. Knowledge about the following has not been established: treatment efficiencies of larger-scale installations, economics, short- and long-term performance, and fouling/scaling of MD.
- Requires special hydrophobic membranes. Commercially available hydrophobic membranes have not yet been optimized for the MD process. This is an area of active R&D.
- Membrane modules for MD have not undergone extensive optimization and may require larger footprints than a pressure-driven system with equivalent capacity.
- Contamination of distillate occurs when the membrane fouls and wets the membrane pores.
- Use of multiple stages can reduce energy requirements but increases capital cost associated with membrane.
- Presently expensive compared to RO and EDR process.

2.1.8 Thermo-Ionic™ Desalination (Saltworks Technologies Inc.)

Saltworks has developed a patented desalination process that uses thermo-ionic gradient to treat high salinity water. A simplified schematic of the process is shown in Figure 10 below.
The primary driving force for desalination is concentration gradient energy (i.e., latent chemical potential energy) between two solutions. Hence, to treat a saline water source, another source with higher salinity is required (referred to a "concentrate"). This is initially achieved by concentrating the feed saline water to a salt concentration of 18%. Evaporation processes such as spray pond or cooling tower could be used to concentrate the feed water. Adding heat to raise the temperature by 5 to 15 deg C higher than ambient temperature also boosts evaporation rates and performance. The heat source could be solar or waste process from a nearby industrial process. The concentrate and the feed saline water are fed to the patented Saltworks proprietary modular desalting device in two streams – one as feed water to be treated and another as "dilute" water. The dilute water and the concentrate (indicated as hyper concentrate) are separated by ion exchange membranes.

Because of the electrochemical potential difference, ions move from hyper saline solution into the dilute solution on either side. Thus, the hyper saline solution loses salt and the dilute solution gains it. However, since only cations (on left side) and anions (on right side) are moving into the dilute streams, these streams need to draw counter ions to maintain charge balance. These counter ions are drawn from the feed water, thereby desalinating it. As in EDR process, periodically ionic current direction is reversed during operation to descale the system

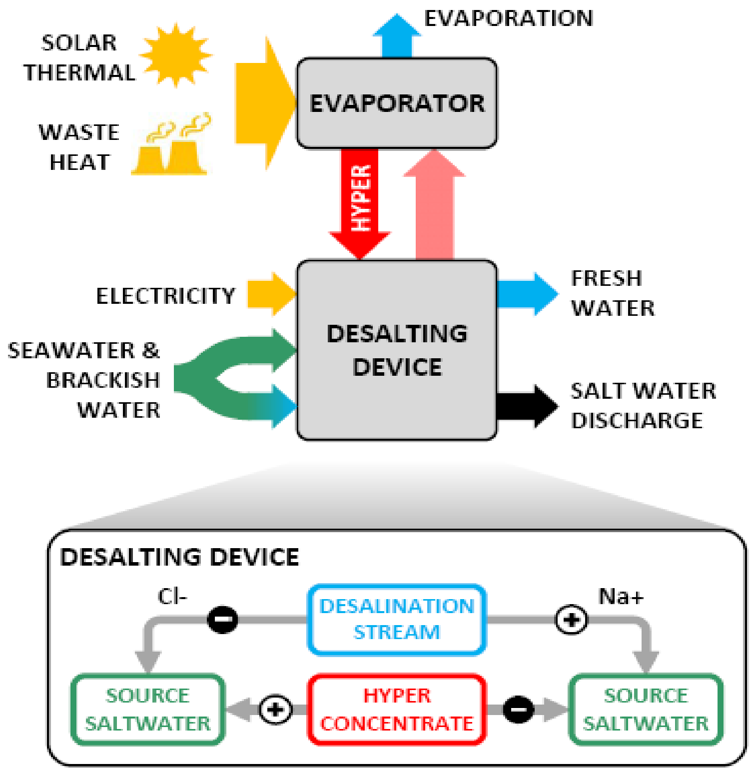

Figure 10: Schematics of Saltworkstechnology [34]

Merits:

- Ability to utilize low-grade heat (solar collector, waste heat, etc.)
- Less organic fouling propensity compared to RO
- Less pre-treatment compared to conventional membrane desalination processes

Weak points related to the use of Thermo-Ionic desalination in rural areas

- Still under development. Knowledge about the following has not been established: treatment efficiencies of larger-scale installations, economics, short- and long-term performance, and fouling/scaling of membranes.
- Since the technology is developed by Saltworks most of the information on the desalting device is kept confidential.
- Desalting device not undergone extensive optimization and may require larger footprints than a pressure-driven system with equivalent capacity.
- Expensive compared to RO and EDR process.

2.1.9 Forward Osmosis

Forward osmosis process uses the natural osmosis to achieve desalination. Isobaric solutions with different solute concentrations (salinity) have different chemical potentials. Chemical potential gradients are the result of differences in solute concentration and hydraulic pressure. When they are separated by a semi-permeable membrane, that allows only transport of water, and they exert a driving force for ion transport by diffusion. Water is transported from the dilute solution side to the more concentrated solution side, a process referred to as osmosis.

In the forward osmosis process, the osmotic pressure of the fresh water is increased by addition of various solutes (Figure 11). In FO terminology, the concentrated solution on the permeate side of the membrane is referred to as the draw solution. Once the osmotic pressure of the fresh water (after addition of solutes) is greater than that of the saline water, pure water diffuses from the saline waterside to the fresh water side. Hence, the driving force is the osmotic pressure itself and not hydraulic pressure as in a conventional reverse osmosis process. The viability of the process is dependent on the selection of the solute that is added to the fresh waterside and ability to remove it from the fresh water and reuse it, once saline water is desalinated. A good draw solution has high osmotic pressure and an easily separable solute. The solutes under consideration include salts that can be precipitated out, gases such as ammonia and carbon dioxide, and nano-particles [12]. Currently, the most preferable method appears to be ammonia-carbon dioxide draw solution as it imparts a high osmotic driving pressure and later can be decomposed to ammonia and carbon dioxide gases upon moderate heat (near 60 °C).

In ammonia-carbon dioxide FO system, the salt species formed include ammonium bicarbonate, ammonium carbonate and ammonium carbamate [13]. Of these, ammonium carbonate is by far the most soluble. Removal and recycling of draw solutes is achieved through use of distillation column. Depending on the thermal energy available to heat the solution, one or several distillation columns would be required.

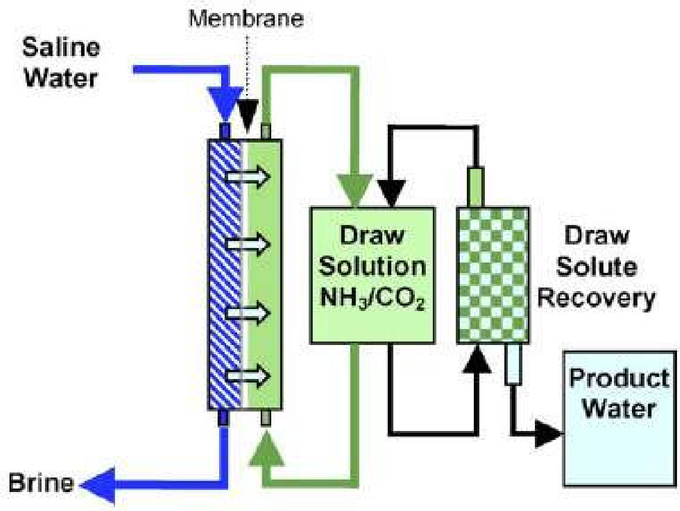

Figure 11: Simplified process schematics of FO

Oasys (Osmotic Application Systems) is currently developing this technology and is one of the early companies. Because it is in the process of developing and commercializing the technology, not much information has been provided.

QuantumSphere Inc. filed for a US patent in January 2009 for its water purification process, which, it claims, serves as a more energy-efficient alternative to desalination methods now commonly used. The QuantumSphere forward-osmosis process uses certain organic solutions to separate water from salty or polluted water in an osmotic purification process. They indicate that the organic solution can increase the osmotic pressure of draw solution by 5 to 10 times higher than seawater. The process uses a semi-permeable membrane to separate water from salt water into a special organic solution across the membrane.

Manipulated Osmosis Desalination (Modern Water)

Manipulated osmosis desalination (MOD), being commercialized by Modern Water, is based on forward osmosis principle. Indeed, it is the first forward osmosis process that has been commercialized. As discussed earlier, forward osmosis process requires addition of a solute to pure water to result in osmotic pressure greater than the saline water source to be treated. Typically, this solution is referred to as draw solution. As the feed water is desalinated, the draw solution is diluted. The solute that was added to the draw solution is then removed to get purified water. The solute can be reused.

Modern Water refers to this solute as "osmotic agent". The forward osmosis system is linked to generation system that treats the diluted draw solution to obtain product water and concentrated draw solution that can be reused in the forward osmosis process. In the first stage, feed water is fed under low pressure to the manipulated (forward) osmosis membranes

(Figure 12).

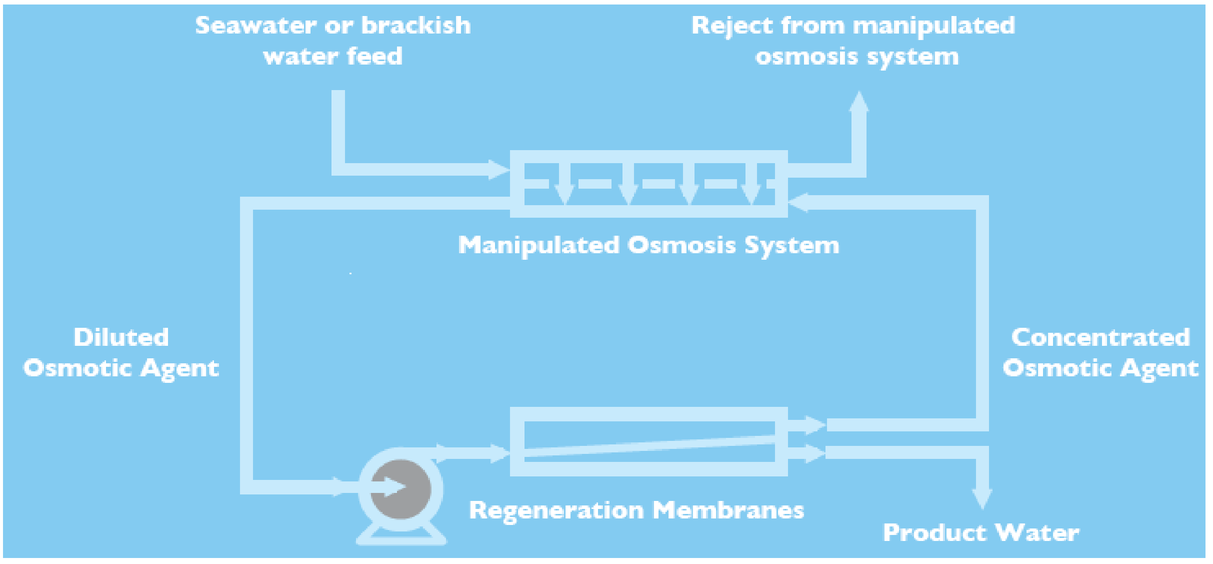

Figure 12: Modern Water's Manipulated Osmosis Desalination Process

These membranes are reported to be resistant to fouling and oxidizing agents. The osmotic agent, on the other side of the membrane draws fresh water from the seawater due to a difference in osmotic pressure. The fresh water dilutes the osmotic agent. In the second stage, permeate is extracted from the system. The pure water is removed from the dilute osmotic agent, which is regenerated (or concentrated) for reuse in the first stage. This can be achieved in a number of ways depending on the proprietary osmotic agent selected. As one example, RO process is used in the second stage example to extract the fresh water and concentrate the osmotic agent.

Merits of FO process:

- Operates at low pressure, which results in much lower energy consumption compared to conventional membrane and mechanical/thermal evaporative desalination technologies
- Membrane compaction is not typically an issue
- Less fouling propensity compared to RO

Weak points related to the use of FO Plant in rural areas

- Still under development. Knowledge about the following has not been established: treatment efficiencies of larger-scale installations, economics, and short- and long-term performance and fouling/scaling

- Requires special membranes. Existing commercially available RO membranes are not suitable for FO because such membranes have a relatively low product water flux, which can be attributed to severe internal concentration polarization in the porous support and fabric layers of RO membranes
- Use of ammonium carbonate as draw solution may provide desired osmotic pressure. However, diffused ammonia to the permeate stream should be removed using a low cost technology (such as waste heat to strip ammonia).

2.1.10 Solar Stills

The solar still is probably the simplest type of seawater distillation system. It consists of a basin containing saline water with a transparent glass roof, often in the shape of an inverted V. The basin is lined with a dark material to maximize the absorption of solar radiation. This arrangement creates a greenhouse effect, whereby the glass allows incoming solar radiation to pass through, but the infrared radiation returning emitted from the still is mostly blocked by the glass, thus trapping the heat inside the still. The resulting temperature rise causes the saline water to evaporate, and the vapour rises, condenses on the glass roof, and flows down into collection gutters at the lower edges of the roof. The typical output of a well-designed solar still is around 3-4 l/m^2d[2], [14]. The cost of building solar stills is in the range of US$ 50-150/m^2[14]. The Water cone, a small portable solar still, shown in figure-13, produced by Mage Water Management produces 1-1.5 l/d of distilled water, corresponding to a maximum rate of 8.8 l/m2/d. Solar stills are acceptable to produce small quantities of water for basic needs but not economical for large production for all daily needs. SolAqua supplies Rainmaker^{TM}550 (figure 14) as do-it-yourself kit.

Figure 13: Water Cone

Figure 14: Solar Distiller: Rainmaker^{TM} 550

2.1.11 Humidification/Dehumidification (HDH)

Humidification-dehumidification (HDH) desalination mimics the natural water cycle to desalinate the water. Normal atmospheric air is used as the medium to convert seawater to freshwater. HDH desalination involves two processes. Saline water is first converted to water vapour by evaporation into dry air in an evaporator (humidification). This water vapour is then condensed from the air in a condenser to produce freshwater (dehumidification). Heat for evaporation can be obtained from various sources, including solar, thermal, geothermal, and combinations of these. A simplified process schematic of HDH is presented in Figure 15

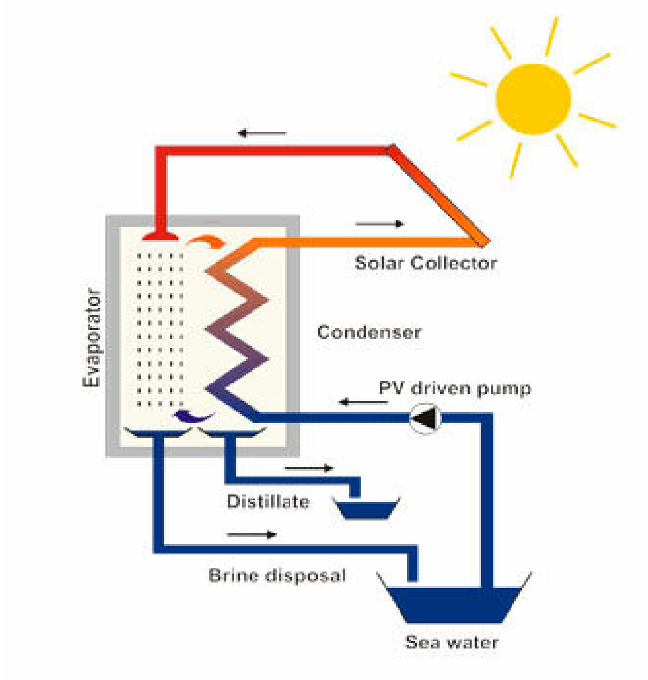

Figure 15: Simplified process schematics of HDH

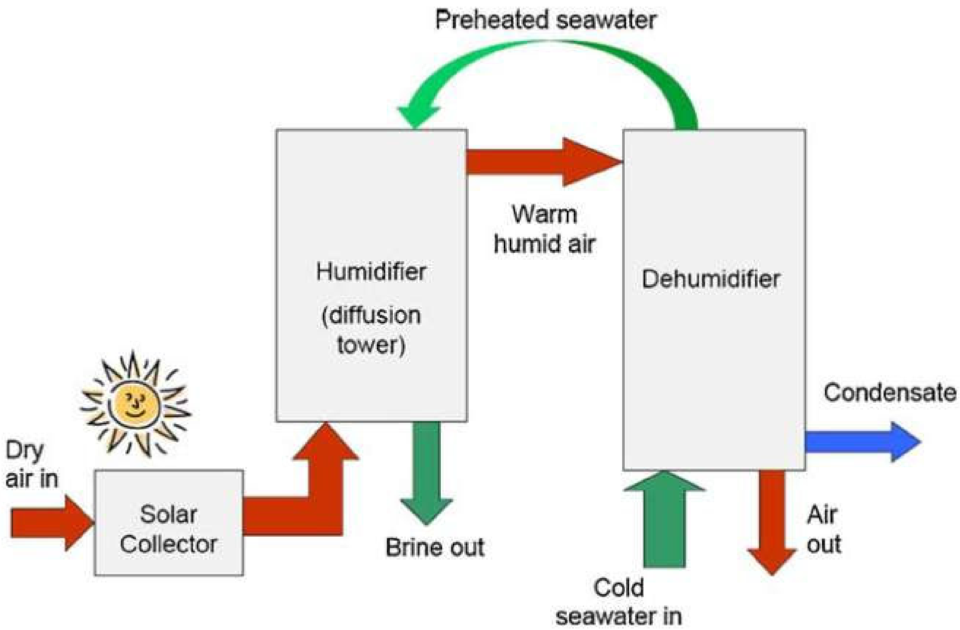

Figure 16: Simplified process schematics of HDH with solar heat transferred by air

The HDH process illustrated above in figure 16 is simple distillation system that can be driven by solar thermal energy and is suitable for small-scale applications. The thermal energy from the sun is used to heat the saline water in the dehumidifier, which is then sprayed down a packed column against an upward draft of dry air. The air, having been humidified by the water vapour, is then conveyed to a condenser where the moisture carried by the air condenses on the outer surface of the tubes and accumulates at the bottom. The latent heat associated with the vapour condensation is used to preheat the saline feed water flowing inside the condenser tube. This feature represents an advantage of the HDH process over the simple solar still, where the latent heat of condensation is usually not recovered.

HDH systems can be classified under three broad categories. One is based on the form of energy used such as solar, thermal, geothermal, or hybrid systems. This classification highlights the most promising aspects of the HDH concept: the prospect of water production by use of low-grade energy, especially from renewable sources. The second classification of HDH processes is based on the cycle configuration (such as closed-water open air [CWOA]). The third classification of the HDH systems is based on the type of heating used: water- or air-heating systems. Energy requirements of HDH include latent heat of vaporization, energy transport air, and cooling energy to condense the vapour. As a result, it is an energy-intensive process. Approximately, 650 KWh/m^3 of energy is required for vaporization, with additional energy required for mechanical equipment (Huehmer and Wang, 2009).

The expected output of an HDH system is in the range of 20-30 l/m2/day of solar collector area [14]. Commercial HDH systems are available from a German company called Mage Water Management[15].

To enhance heat recovery, Muller and Holst have proposed the concept of multi-effect HDH. Air from the humidifier is extracted at various points and supplied to the dehumidifier at corresponding points. This enables continuous temperature stratification, resulting in a small temperature gap to keep the process running. This in turn results in a higher heat recovery from the dehumidifier. In fact, most of the energy needed for the humidification process is regained from the dehumidifier, lowering the energy demand to a reported value of120 kWh/m^3. This system is being commercially manufactured and marketed by a commercial water management company, Tinox GmbH.

Merits:

- Low-grade thermal energy is used to drive the process, which makes it suited for PCs rural areas where electricity is not available.
- Simple design and relatively cheap materials of construction make it suitable for small capacity stand-alone in rural areas units, with higher output per unit area than simple solar stills

Weak points:

- Difficult or impractical to scale up capacity.
- High heat energy requirement makes it an uneconomical process for anything beyond small-scale units driven by renewable energy or waste heat. Multi-effect HDH that requires less energy is still under development stage.

Table 1: Comparison of desalination technologies in reference to rural areas

Table 2: Comparison of desalination technologies in reference to rural areas

Process	**Capital Cost**	**Energy consumption**	**Other O&M cost**	**Major merits**	**Major Weak Points**	**O&M Skill required (scale 1-5)**	**Type of energy required**
Multi-Stage Flash (MSF)	High	High	Low	1. Mature and proven technology 2. Robust and reliable 3. Less pre-treatment required. 4. Suitable for high TDS feed	1. High Feed water Requirement. 2. More brine to be disposed. 3. High specific energy consumption	2	Heat + power
Multi-Effect Distillation (MED) Thermal Vapour Compression (TVC)	Medium	High	Low	1. Mature and proven technology 2. Robust and reliable 3. can use low-grade heat 3. Less pre-treatment required. 4. Suitable for high TDS feed	1.High specific heat consumption 2. Low recovery ratio, when cooling water is accounted for.	2	Heat + power
Mechanical Vapour Compression (MVC)	Medium to high	High	Low	1. Mature and proven technology 2. Robust 3. Compact 4. Suitable for high TDS feed	1. High scaling potential under variable conditions. 2. Mechanical compressor requires skilled O&M	4	Power
Reverse Osmosis	Medium	Low	Medium	1. Mature and proven technology 2. Reliable 3. Compact 4. High recovery ratio 5. Less start-up and shutdown time 6. Suitable for high TDS feed	1. Pre-treatment requires careful design. 2. Susceptible to various types' membrane fouling. 3. Variability in operating conditions and/or frequent start-up/shutdown cycles shorten membrane life	3	Power
Electro-dialysis (ED & EDR)	Low	Low	Low	1. Mature and proven technology 2. Reliable 3. Compact 4. High recovery ratio 5. Less start-up and shutdown time	1. Suitable for TDS up to 3000 mg/l.	3	Power

				6. Less pre-treatment required			
Membrane distillation (MD)	High/ medium	High	Low	1. Ability to use low grade heat 2. Operates at low pressure 3. Compact 4. High recovery; needs less feed water for a given output. 5. Less pre-treatment required 6. Suitable for very high TDS feed	1. Technology is still under development 2. High specific heat consumption.	2	Heat + minor power
Electro Dialysis Metathesis (EDM)	High	High	NA	1. Improved version of ED. 2. Recovery more than RO possible and can be used for zero discharge. 3. Compact 4. Less pre-treatment required.	1. Emerging technology.	4	Power
Thermo-Ionic™ Desalination	High	High	NA	1. Ability to use low grade heat 2. Compact 3. High recovery and needs less feed water for a given output. 4. Less pre-treatment required	1. Emerging technology. 2. High specific heat consumption. 3. Proprietary design and information kept confidential	4	Power + Heat
Forward Osmosis	NA	Low (prospective)	NA	1. Operates at low pressure and hence consumes less power. 2. Less pre-treatment required.	1. Emerging technology. Process optimisation is going on	4	Power (+heat in some cases)
Solar Stills	V. low	High	V. low	1. Uses solar energy 2. Simple and easy to operate	1. Large area required. 2. Not practical for large capacity.	1	Solar (Heat)
Humidification/ Dehumidification (HDH)	Medium	High	Low	1. Can use low-grade thermal energy. 2. Simple design using cheap material	1. Suitable only for small capacities. 2. Requires large area	3	Heat + power

NA: not available/ not established

2.2 Description of renewable energy technologies for desalination BATs

2.2.1 Solar energy

There are two main classes of solar energy technologies: solar thermal energy and solar photovoltaic (PV). As the name implies, solar thermal technologies capture the heat from solar radiation, either for direct use in a particular heat-driven process, or for power generation through a steam power cycle, and subsequent use of the generated power in a mechanically or electrically driven process. Solar photovoltaic (PV) technology is based on the direct conversion of energy from solar radiation into DC electrical power using panels of semi-conductors.

Because of the relatively low temperatures required in thermal desalination, non-concentrating collectors represent the more relevant class for coupling with thermally driven desalination processes. Concentrating collectors are mostly intended for power generation, a technology known collectively as Concentrating Solar Power (CSP), where attaining high temperatures in the working fluid is important for thermodynamic power cycle efficiency. CSP is a very promising area of technology for renewable desalination, but probably more so for the medium to large capacity ranges of desalination plants. The relative sophistication of CSP plants make them less suitable for autonomous desalination units in remote and rural areas.

Another type of solar thermal technology is *solar ponds*. A solar pond utilizes a salinity gradient over the depth of a pond or lake as a means of trapping incoming solar energy.

An attractive feature of solar ponds is that they combine the functions of a solar collector and a thermal storage system together [6].

One of the main advantages of solar thermal energy is that it is more amenable to storage than solar PV. It is easier and less costly to store thermal energy than it is to store electricity.

Solar photovoltaic (PV) technology is based on the direct conversion of energy from solar radiation into DC electrical power using panels of semi-conductors. This conversion is based on the photovoltaic effect; a property that some semi-conductors have in which light photons excite the electrons of the semi-conductor in to a higher energy state, leading to the creation of a DC voltage or current. Multiple PV cells are connected together to form solar panels. Connecting solar panels in series is used to increase the generated voltage, while connection in parallel can be used to increase the current. QuadraSolar claims that they have achieved 30% PV and 35% thermal efficiency.

2.2.2 Wind energy

Wind turbines are used to convert part of the kinetic energy in the wind into shaft power, which can either be used to drive an electric generator, or directly coupled to a mechanically driven process. The theoretical maximum efficiency of this conversion is 59.3%, while the efficiency actually achieved by real turbines is in the range of 35-48% [2]. This is only the efficiency of extraction of kinetic energy from the wind and conversion to shaft power; it does not account for other losses further down the line, such as losses in mechanical drive train and electric generator losses.

Wind turbines can be classified into horizontal axis wind turbines (HAWT), and vertical axis wind turbines (VAWT). The horizontal type (figure 18) is the more common type. In this arrangement (HAWT), the rotor shaft and electric generator are housed at the top of the turbine tower. HAWTs must be directed towards the wind to be effective. The MagLev VAWT is a magnetically-levitated low-RPM high-torque power output turbine, virtually silent and vibration-free. It is virtually maintenance-free because it is frictionless and can be mounted on building top. There are no transmission gears necessary for the conversion of the kinetic energy into electricity. With their magnetically-levitated low-RPM high-torque power output and virtually maintenance-free operation, the MagLev Wind™ Turbines (figure 17) are perfectly suited to satisfy the demand for a cost-effective sustainable energy source on many roof tops. MagLev Wind™ Turbines are currently available with outputs ranging from 2.5kW up to 50kW. 1 MW MagLev Wind™ Turbine is being designed for larger commercial and industrial buildings

Figure 17: MagLev Vertical Axis Wind Turbine   Figure 18: Horizontal Axis Wind Turbine Farm

2.2.3 Geothermal

Geothermal energy is thermal energy that that originates from the Earth's interior. The source of this energy is mostly from the decay of radioactive matter in the Earth's core.

Geothermal energy sources at accessible depths vary in nature based on their temperature, which can range from 20 deg C to more than 300 deg C, and the state in which the water is available, which can be liquid or steam. High temperature geothermal sources, above 150degC, are used for power generation using a Rankine cycle, which can in principle be used to drive power-driven desalination processes. Lower temperature sources are best suited for direct coupling to thermal desalination processes. When high pressure steam is available, it can be used to directly drive a turbine for power generation or in direct coupling with a mechanically-driven desalination process [6], [16].

It is believed by some investigators that geothermal energy is one the most promising options for renewable energy desalination [16]. Geothermal reservoirs provide a continuous supply of thermal energy at fixed conditions throughout the day and year. This is highly desirable from the point of view of the desalination process, for which variability causes various difficulties and complications that need to be addressed in system design. Energy storage is not required, for example, as it might be with other resources. However, the disadvantages of geothermal energy are hazardous gases and minerals. They can come up from underground along with the steam. One of the most common substances to be released is hydrogen sulfide, which is extremely difficult to dispose of safely. Other minerals that can be troublesome are arsenic, mercury, and ammonia. A number of barriers for the adoption of geothermal energy for desalination have been identified in the literature [16]. These include:

- The technology has not yet been developed commercially, primarily because the associated cost of desalinated water by this means is not competitive with more established approaches.

- The very site-specific nature of geothermal energy resources makes it difficult to prescribe standard or modularised designs. This factor drives up the cost of developing such projects compared to some of the other, modular options available.

2.2.4 Waste Heat Availability

Even though not strictly a renewable energy, the possibility of waste heat availability in some situations must not be overlooked. This can be from a local off-grid power generation unit such as a gas turbine or a diesel engine. In such case, a number of thermally driven desalination processes can be set up to take advantage of this wasted resource without significantly increasing the demand on the locally generated power. An example of such a set-up is the 5000 l/d MD plant in the island of Pantelleria, Italy, which derives 80% of its required power from the waste heat of a diesel power plant, and the remaining 20% from solar collectors [17].

2.3 Process/RE resource combinations

Considering the various desalination technologies, and the various renewable energy technologies presented above, a wide variety of combinations is possible. It is unlikely that a single pair can be identified as being superior in all situations, and a rational choice of technologies will depend on many factors. In this section, some of the main combinations that are commonly adopted or which have been considered are presented. One of the difficulties and barriers for desalination by renewable energies is that the two elements: RES technology, and desalination technology have generally been developed separately, this has an impact on the reliability and modularity on the overall system and the ease of deployment[14].

2.3.1 Solar thermal-MED

The MED process is a mature thermal process that possesses many attractive features that favour its selection in combination with solar thermal energy. Compared to MSF, the fact that the same GOR can be achieved with fewer effects leads its relative simplicity and easier scalability. This makes the MED process more suitable for small-scale autonomous systems than the MSF process. In addition, as was previously mentioned, the power consumption of MED for pumping and auxiliary systems is lower than that of MSF, which is especially important when the source is solar thermal energy because a separate means of providing the required electric power is necessary.

A notable variant of the MED configuration is the Multiple Effect Stack (MES). Figure (15) shows a schematic of a four-effect MES plant. Seawater is introduced at the top of the stack and sprayed on the evaporator tube bundle forming a thin film. The heat input to the process is in the form of steam flowing inside the tubes of the first effect, giving up its latent heat to the evaporating film of seawater outside the tubes as it condenses. The process carries on at progressively lower pressures, in the same way described previously for the basic MED process.

The MES configuration is remarkably stable in operation and has the ability to adjust automatically even to sudden changes in the input steam conditions[2]. This feature makes it particularly attractive for pairing with a variable energy source such solar thermal. Moreover, being a once-through process where the highest seawater temperature coincides with the lowest seawater/brine salinity minimises the risk of scale formation without excessive anti-scalant requirements. Product water quality is typically is less than 5 ppm TDS throughout the life of the plant. Therefore, the MES variant of the MED process appears to be the most suitable for use with solar energy[2].

A 14-effect vertically stacked MED plant with a nominal capacity of 72m^3/d was installed at the Plataforma Solar de Almería in Spain during the 1990’s. The plant derived its input from parabolic trough collectors (PTC) with one-axis solar tracking having a total area of 2762 m^2, and included a 155 m^3 thermocline thermal oil energy storage tank. The heat transfer medium was synthetic oil, serving both to transfer heat from the collectors and to store energy. The heat was used to generate low-pressure steam at a temperature of 70degC. A performance ratio (in this case define as kg distillate per 2330 kJ thermal energy input) that varied slightly around 10 was achieved [2], [14].

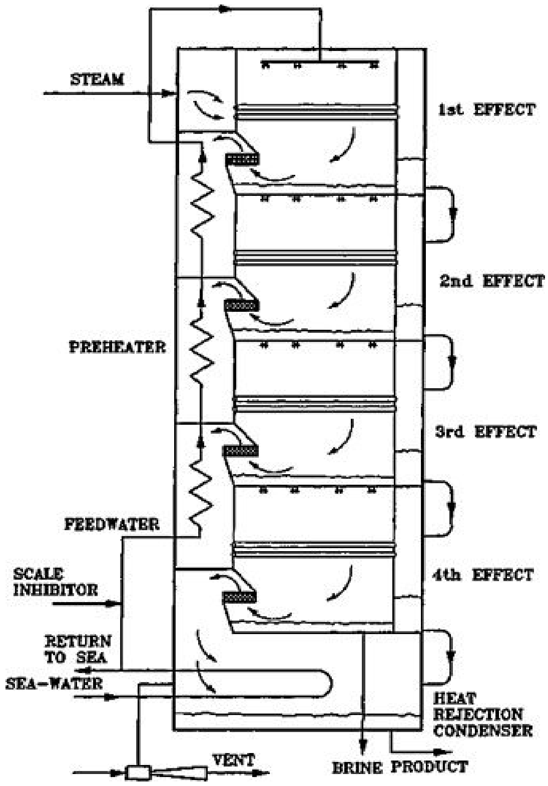

Figure 19: Schematic diagram of the Multiple Effect Stack (MES) flow configuration

2.3.2 Solar thermal-HDH

The HDH process is a good choice for application with solar thermal energy when a simple and relatively cheap option is desired. The cost of water produced is estimated to be in the range of 2-5 €/m^3. The HDH process is more efficient than a solar still, and produces more output water per unit area of collector, in the range of 20-30 l/m^2/d. Thus, it can more easily be scaled up to around 100 m^3/d capacity. With the application of multiple-staging, the thermal energy consumption can be brought down to the range of 100 kWh/m^3[14]. It also has the feature that the humidification process opens up the possibility for green house application, which can be desirable for some rural communities [16], [18–20]. Refer figure 15 for Simplified process schematics of HDH. A 1 m3/d multiple effect HDH unit in Oman is shown in figure 20.

Figure 20: A 1 m3/d multiple effect HDH unit in Oman

2.3.3 Solar thermal-MD

The Solar-MD combination has some advantages for small-scale autonomous units up to about 10 m^3/d. Among these advantages is the ability of MD to operate using low-grade thermal energy as low as 60-70degC (of course higher temperatures increase unit productivity). The process also adjusts continuously to variable input conditions and does not require a fixed operating point. The hydrophobic nature of MD membranes makes them substantially less prone to fouling and scaling than RO. The process does not use expensive metallic heat transfer surfaces, and the low operating pressures involved mean that expensive high-pressure piping is not needed. Such factors are expected to aid in bringing down the cost of MD-based systems when the problem of high-energy consumption can be effectively tackled. There seems to be some good progress achievable soon in this area with the multiple effect configuration (V-MEMD) developed by Memsys (presented earlier), making possible GORs in the range of 10, as in MED, but with substantially cheaper materials of construction.

The Fraunhofer Institute for Solar Energy Systems and its spin-off company SolarSpring GmbH have been developing since 2001 autonomous solar thermal driven Membrane Distillations units intended for remote areas. Two different system designs are available: the Oryx 150, a simple direct-couple (no energy storage) system with a nominal capacity of 150 l/d; and a larger two-loop system rated at 1-1.6 m^3/d. The energy storage in the two-loop system allows 24-hour operation, thus achieving a higher specific output capacity.

Figure 21: The Solar Spring Oryx 150 unit installed on the rooftop of a health centre in a rural area of Tunisia.

Figure 22: A view from the backside of the Oryx 150 unit. The spiral-wound MD module is the blue vessel on the right.

2.3.4 PV-RO

Due the maturity of both technologies involved – reverse osmosis and PV panels, the PV-RO combination is probably the most common and matured renewable energy desalination combination. The PV-RO system consists of a photovoltaic field that supplies electricity to the desalination unit. Since PV panels supply DC power, while RO pumps require AC power input, a DC/AC converter is required.

The specific cost of water produced in PV-RO plants is in the range of 3.5 –7 €/m³ for brackish and 9 –12 €/m³ for seawater RO units [14]. Notably, as the ProDes Roadmap [14]points out, water cost is disproportionately higher for systems with capacities lower than 5 m³/day. However, for higher capacities the water production cost should come down considerably. Both being matured technology, and RO being one of the lowest power consuming processes this should be easily achievable.

The fact that RO and PV are both mature technologies it means that there are a large number of suppliers for each of these technologies in many countries, and it should be easy to reliably source the necessary subsystems.

Figure 23: A 2.1 m^3/h nominal capacity brackish water PV-RO plant in Tunisia, installed by the Canary Island Institute of Technology, Spain.

Ghermandi et al. [21] have pointed out that despite the lack of a standard design, the most commonly employed design consists of the following subsystems:

1. Solar sub-unit (PV panels)
2. Water extraction unit
3. Pre-treatment unit
4. High-pressure system (pump, motor and Energy recovery device)
5. RO membranes
6. AC/DC converter
7. Electrical storage

2.3.5 PV-ED

At present there is little experience using ED systems with renewable energy (RE)[14]. Only a few pilot units for R&D purposes are in operation. According to the ProDes Roadmap, the main barriers for this system are the limited availability of small-sized commercial EDR units and that they can only be used for brackish water desalination.

It is worth noting however that ED is a mature technology that is well suited for brackish water desalination, and it is relatively robust compared to RO (in terms of fouling resistance), which suggests that there might be some potential prospects for this technology when considering a brackish water plant.

2.3.6 Wind-RO

Wind-powered RO is a common renewable energy desalination combination, since both are mature technologies. Due to the highly fluctuating nature of wind energy, even more than PV, an energy buffer in the form of a battery set and a dedicated control system are required to stabilize the energy supply.

The cost of water produced by this technology combination is in the range of 3-7 €/m^3 for small RO plants up to around 100 m^3/day. For medium capacity RO plants in the range of 1000-2500 m^3/day, the estimated cost is in the range of 1.50–3 €/m^3.

2.3.7 Wind-MVC

Wind-driven MVC units have been considered[22], but have presented some problems and require further development before they can be applied commercially. One of the main difficulties is that the MVC process is usually designed to operate at a fixed point, and requires substantial time to reach the design point, which makes it difficult to couple with a variable energy supply. Furthermore, the frequent starting and stopping were found to cause severe scaling and total jamming-up of the system [22].

2.3.8 Geothermal MED

The relative advantages of MED, a thermally driven process, as mentioned in Section 2.1.2, makes it a natural choice for pairing with a geothermal energy source. A number of such projects are reported in the literature.

An 80m^3/day pilot geothermal desalination plant based on the MED process has been installed in Kimolos Island, Greece [23]. Geothermal water at a temperature of 61-62degC from a 188m well is used to drive a 2 effect vertical tube MED plant from Alfa Laval. The estimated water cost was reported to be 1.6€/m^3[23].

Another reference [24] reports on a project in Milos Island, Greece, aiming to construct a dual-purpose geothermal plant for generating 470kW electric power and producing 1800-1900 m3/day of distilled water. The planned desalination process was MED-TVC. The report describes extensive geothermal exploration studies and a detailed design plan, but it is not clear if the plant was actually constructed and what the current status of the project is.

A more recent prototype geothermal desalination system intended to take advantage of the abundant geothermal energy in Mexico is described in [25]. The system described uses a novel distillation system that resembles the MED process but with some modifications.

2.3.9 Geothermal HDH and other thermal processes

Although the MED process, including its variants, is the one most frequently considered process for pairing with low temperature geothermal energy, other potential combinations are possible. An experimental investigation combining a geothermal source with the HDH process is described in [18], [26]. The HDH process can be linked to the operation of a greenhouse, a very attractive combination for agricultural use in small communities located in arid regions. A case study examining the possibility of applying this solution in Algeria is reported in [19].

Another interesting combination that is not adequately explored is the direct desalination of low to medium temperature (60-90degC) high-salinity groundwater using membrane distillation.

3. Decisions, data and information before considering technologies for implementation of a desalination project

Desalination should be considered as part of a holistic approach for the overall sustainable development of rural and remote areas and only after less expensive technically efficient alternatives have been ruled out. Desalination projects require high level of technology, high capital cost, high-energy demand and high operating costs. The total production costs (including capital, energy and operational costs plus taxes if any) compared to conventional water resources is generally high and it is required that these costs must be paid by the water consumers, or through subsidies. Therefore, before deciding on the technology to be adopted and with which type of renewable energy source will be combined a number of studies must be carried out which will justify the implementation of the desalination project, will justify the size of the proposed desalination plant, the quality of the product water, site availability etc? For these studies, the following are outlined.

3.1 Integrated Water Resource Management Plan or diagnostic study

Water shortage in rural and remote areas could be the result of real water scarcity or a result of many other reasons such as drought, bad water management, structural deficiency, water demand increase due to change of inhabitants habits, population growth, wasteful use of water, inefficient water use, system losses not accounted, and in many cases due to non rational water resources management plans.

The decision to embark on desalination for the supply of water in remote or rural areas must be taken within the framework of an Integrated Water Resources Management Plan, in which all possible options for the supply of water to the remote rural area were examined. The Integrated Water Resources Management Plan should consider the nature of water demand, the efficiency of water consumed, the efficiency of water use, whether the water demand is justified or can be reduced by water demand methods, the water supply systems capabilities (capacity and efficiency of each system such as reservoirs, pipelines conveyance capacity, pumps and water distribution systems), the water available of the system and how this is allocated to the various consumers. All available options for the supply of the justified quantities of water to the remote or rural areas from existing systems should be examined, including desalination as an alternative option. If an Integrated Water Resources Management Plan is not available or the area is a remote area without connection to any nearby water supply system, a diagnostic study should be carried out to identify the real water problem of the area. The major question to be answered following conclusion of the diagnostic study is whether the water demand cannot be reduced and not supplied from renewable or other water resources and that the only option is the production of desalination water to satisfy in a satisfactory manner the water demand.

3.2 Capacities of Desalination Plants

3.2.1 Definitions

The Desalination Plant Capacity is defined as the quantity of water produced on an hourly, daily, monthly and annual plant capacity. For each capacity, the following is defined.

- **Hourly Production**: This is the plants maximum capacity depending fully on the structural plant capabilities. Hourly production may vary depending on the seawater temperature and other parameters. This parameter is largely the decisive parameter for defining the capital cost. Of course the desalinated water cost is not exclusively decided by the Capital cost but also by the operation and energy cost parameters and for minimizing this cost an optimization of the hourly production against total production cost of desalinated water must be carried out taking into account hours of daily production, power costs under a certain power supply pattern etc.

- **Daily Production:** The Maximum daily production is the product of the hourly production multiplied by the number of hours the plant will be in operation at full power supply. In case of Solar energy supply the daily production will be the product of the hourly production multiplied by the number of hours of power supply from the solar system. A Plant with an hourly production of 10 m3/hr supplied with power supply from a grid will most probably have a daily production of 240 m3/day, where when the supply is from a solar power system the daily production will be around 80-100 m3 assuming that the solar system will supply power during the daytime. In case the desalination plant is provided with energy from solar system in daytime and grid energy at night may increase its production considerably.

- **Monthly Production:** This is the sum of daily productions calculated for each day. Daily production may be different for different days depending on seawater temperature, or due to plant stoppage for maintenance purposes, or due to power supply restrictions or relaxations.

- **Yearly Production:** The annual production is the sum of the monthly productions and this give the annual quantity of desalinated water produced. The annual quantity is used to calculate the capital cost of water, which is one of the components of the desalinated water cost.

3.2.2 Desalination Plant Capacity

The desalination plant capacity in remote rural areas will be required to make up the difference between the daily, monthly and annual water demand and the daily, monthly and annual water availability of the existing water supply system. In the decision of the Desalination Plant capacity, the planners must take into account the marginal capital cost of each additional m3/day they add to the plant hourly capacity and how much quantity of desalinated water this additional hourly capacity will produce per year. It must be remembered that the hourly capacity of the plant will also set the renewable energy capacity and if this very high, the cost may be prohibitive. The Desalination Plant hourly production is definitely a very serious parameter for setting the cost of the Project and the planners must carry out optimization studies taking into accounts all the parameters that affect the capacity, mainly the hours of plant operation per day and energy cost. The desalination plants combined with renewable energy resources will constitute an optimization challenge for any water resources engineer for minimizing the cost of both the desalination Plant and that of the renewable energy source.

3.3. Desalinated water quality

Water quality characteristics are related to health, aesthetics and taste parameters and these are set by the requirements of the users. The Product Water to be used for drinking purposes must have the characteristics of a drinking water specified in the relevant national or international directives or standards. Similarly, if water will be used for irrigation then the water quality must have those characteristics that do not affect the crops to be irrigated as are defined in every irrigation manual. Water that will be used initially for drinking purpose and the waste produced will be treated and recycled for irrigation purposes the desalinated water quality characteristics must be such that it does not contain any toxic ions such as boron.

3.4 Demographic and socio-cultural considerations

The following demographic and sociocultural considerations should be taken into account before and after taking the decision to implement the Desalination Plant in a remote or rural area.

a. **The Socio-technical-institutional interdependence:** Interaction between Three elements: people, technologies & organizations must be fully understood & accounted for. The desalination technology must be explained to the people to enable them to understand that it is similar to a physical process that takes place in the environment or in other words, it is part of the water cycle. They must also be explained how this technology and the project be implemented, such as from where the raw water will be supplied (seawater or brackish), where the brine will be disposed, how much energy will be used, the capital, operational and energy costs, how much the water will cost and who will construct and who will operate it, their role in the decision making and their role in the construction and operation and what is expected from them too. It must be emphasized that the project will be a success only if they will really support it.

b. Involvement of beneficiaries: The organization/people that would operate a desalination plant should origin from the same local community served by the plant. If possible, they should be involved even from the planning phase of the plant, but it would be also necessary to participate at least from the construction up to the operation of the plant.

c. **Involvement of adversely affected people:** Usually objections for the implementation of desalination plants are coming from people adversely affected, such as the owners of the land on which the plant will be constructed or even worse neighbours whose properties may suffer devaluation before of the project or even fishermen who think that the fish will be affected by the brine discharge and the seawater abstraction. All these concerns must be analysed and discussed with the interested persons within the framework of the Environmental Impact affected study and must be taken into consideration when compensating for the appropriation of the lands.

d. **Learning:** Opportunities for learning, raising awareness & training need to be provided from the earliest stages of a project to maximize benefits. On the job training of operators is a very significant aspect of the project's sustainability.

e. **Independence & autonomy:** Technological solutions, however cleaver & innovative they might be in the eyes of the decision-makers, must not be imposed on a community that finds them objectionable.

f. **Sustainability:** Average income per family, poverty levels, affordability, willingness to pay for desalinated water & government subsidies, play a major role in sustainability.
If actual income of the locals does not justify the implementation of the project the state' must make a contribution which must secure the project implementation with the locals undertaking the O&M Costs. The best system for subsidy must be implemented for securing the best scenario for project implementation and sustainability.

g. **Flexibility & Process orientation:** The general conditions for water supply in rural areas can change relatively quickly, and are generally very site-specific. These conditions must be taken into account during the calculation of the water demand and any flexibility must be included in the design of the desalination Plant.

h. **Realism:** Project objectives & expectations must be realistic & feasible to avoid failure. Project objectives must be agreed with the consumers and those preparing the planning of the project together with the project sponsors.

3.5 Cultural, religious & gender related issues:

a. Often a new technology introduced into a community for the first time is perceived as an alien intrusion that is incompatible with long-standing traditions, social structures and responsibilities of the community. The technology should be explained in simple terms so the community will understand and accept it as a simple physical process.

b. Despite the important role women play, men take charge of decision-making & women are often left out. This should be stopped and women should be included in the decision-making when it comes to water policies development.

3.6 Raw water resource availability & quality

a. Raw water resources availability is a highly technical problem. Seawater abstraction should be made from a point where quality is good and steady and in sufficient quantities to satisfy the project requirements. In case of using well water as raw water source for desalination, detailed hydrological study/tests shall be conducted to ensure the draw down in the well and sustainability for the planned capacity throughout the period of operation. For this purpose, a detailed hydro geological study must be carried out to verify that only seawater or brackish water is abstracted from the wells and that the fresh water aquifer upstream are not adversely affected. Raw water quality must be steady within reasonable range so that the pre-treatment process to be selected to be able to treat satisfactorily the water before desalination in all cases and under any conditions.

   Seawater beach wells may be used as a feed water source for seawater systems if there is a good hydro geological connection between the sea and the seashore. In such cases, the wells are quite shallow and can be as regular wells or Ranney wells or as a combination of both. For small desalination plants, regular wells will be satisfactory and much cheaper.

   Open seawater intakes should be located at depths of 10-15 meters water depth, even during low tide with the water level inlet at 6 meters above sea floor to avoid abstraction of seabed load and at least 4 meters below the seawater surface at minimum tide. Abstraction velocities should be very low less than 0.30 m/s to avoid abstraction of fish swimming around the intake.

b. Detailed physical, chemical and biological analyses of raw water at intake are fundamental for the design and operation of desalination systems for determination of the pre-treatment process and to avoid scaling and/or fouling of membranes and evaporators. Water originating from properly designed and operated well field has very low concentration of suspended solids and the treatment process will include only cartridge filters by omitting any media filtration. In case of open seawater intakes, a full pre-treatment process will be required.

3.7 Brine discharge location

Brine discharge (whose salt concentration is much higher than the raw water) would be preferably discharged to the sea but in case this is not feasible, it can be discharged in inland wells or evaporation ponds. In case of discharge to the sea, the location of the discharge point(s) should be positioned at a sufficient distance from the sea intake and at such orientation that the high salinity brine water would not be abstracted by the intake. This will require further consideration of the "excess salinity decaying profile" (excess water salinity is diluted within a distance of 12-15 meters from the point of discharge with a discharge velocity of 6.0 m/sec and concentration of brine 5.8% and seawater 3.5%) and the direction of seawater currents in the discharge location.

Brine discharge to inland is discussed in detail in section 4.8 of this report.

3.8 Pricing structures & financing schemes (Affordability)

a. A successful desalination project in a rural or remote area should manage to recover its running costs & depreciation. This necessitates that the water tariff reflects the real costs of water supply. On the other hand, access to safe drinking should be available & affordable for all.

b. The main challenges facing desalination in rural communities are identified as follow:
   i. The low income dominating in the rural communities.
   ii. Limited capital and financial resources.

    iii. High investment costs required for such projects.

c. In response to these difficulties, a number of support mechanisms that do not distort the market function are possible, such as:
    i. Direct financing of the infrastructure.
    ii. Provision of financial incentives for the operators.
    iii. Enabling private sector involvement.
    iv. Adopting the "life-line rate", where a progressive pricing structure is applied based on the volume of water used in order to assure social justice among the users. Israel reported that "Urban centres subsidize water delivered to rural and remote communities".

Also given the prevailing poverty in rural & remote areas and accepting the principle that access to safe drinking should be available & affordable for all, subsidizing the capital & operational costs of desalination by central government is unavoidable. Based on that, it is suggested that the PCs should consider funding of desalination projects in rural or remote areas, as part of their national strategy on water supplies within their national IWRM framework. It must be emphasized that sustainability of desalination using RES in rural and remote communities should be an integral part of the overall sustainable development plan of the community using a holistic approach and if desalination plant is proofed necessary, this should represent a trigger for further sustainable socio-economic and environmental development to reduce poverty and unemployment while developing markets. Many of the development plans can take stocks from local heritage, history, nature, ecology, indigenous culture, arts, and/or architecture.

Examples from some countries in the Mediterranean area confirm that only central governments can afford construction of desalination projects in rural and remote areas, either by funding them or by undertaking the responsibility through guarantees imposed to the contractors (via BOT/BOOT/PPP contract schemes). In other countries (Israel) the development of IWRM was based on the holistic approach, incorporating the cities, the rural and remote areas, the environment, development, tourism, etc. which contributed to keep the rural population in their area. On the other hand it is true that in some other countries this did not refrained people from rural and remote communities, such is the case in Algeria, from migrating towards urban centres for better quality of life and employment opportunities, which means that the holistic approach must meet the peoples expectations.

3.9 Institutional and regulatory factors

3.9.1 Institutional Factors

The institutional factors that are required for the promotion of the desalination project are the same that promote any water resource structure in the PC's and include the following:

a. **National decision-making level:** This typically includes ministries & other high-level government entities that are involved in setting water policy and planning.

b. **Executive level:** This is usually the role of government departments and organizations that operate under the top-level decision making bodies and they are responsible for the implementation of the decisions taken by the policy makers. The people from this level will be responsible to promote studies, investigations, issue tenders, evaluate tender, award tenders, coordinate execution of the project, commission the project, organize its operation, buy water from desalination project owners and sell desalinated water to the local community.

c. **Stakeholders' level:** This can be the local communities that undertake the actual operation & maintenance of water supply facilities, also being the beneficiaries. Close relationship between the stakeholders and the Executive level responsible for the project implementation and the national decision making organizations (responsible for the projects funding) are very crucial.

3.9.2 Regulatory Factors

The implementation of desalination projects is a vey complex procedure requiring the issue of a number of permits such as water abstraction permit, brine disposal permit, off-shore and on shore works permits, renewable energy installations, all after a thorough Environmental Impact Assessment Study. Following is a description of the EIAS.

3.9.2.1 Environmental Impact Assessment Study

The preparation of an Environmental Impact Assessment Study (EIAS) is a requirement for the promotion of a desalination project. The study will include among others the following.

a) Disturbance on the Marine environment including sand suspension during construction phase taking into account the machinery and methods of construction. The EIAS should include mitigation measures for diminishing or abolishing any adverse effects.

b) Disturbance on the marine environment during the process of abstracting seawater, drifting and sweeping by Suction head or depletion and destruction of brackish and fresh water aquifers during abstraction of brackish water from on land aquifers including impingement of marine life on screens at the intakes. The EIAS should include mitigation measures for diminishing or abolishing any adverse effects.

c) Disturbance to the coastal environment including dust content in the air environment during the construction phase. The EIAS should include mitigation measures for diminishing or abolishing any adverse effects.

d) The impact on the marine environment from the use of chemicals during the pre-treatment, desalination and post treatment processes. The EIAS should include mitigation measures for diminishing or abolishing any adverse effects including the reduction of their amounts in the discharge stream (residual chlorine, iron, trace metals, anti-scalants, anti-foaming agents, thermal discharges, phosphorous, suspended solids and organic compounds), the leakage control and prevention of leakage of chemicals of seawater, brine backwater etc to the land and marine environment. The brine dispersion system should be evaluated and mitigation measure may be proposed for minimizing adverse impacts on the marine environment.

e) The impact to the environment in general (green house emissions to atmosphere) from the energy consumption in case of non-renewable energy and the savings from the use of renewable energy.

f) Disturbance to the environment from disposal of excess excavated materials. These could be used in the construction of roads or embankments etc.

g) Noise and light generation during the construction phase and during the operation phase, disturbance to the environment and measures to reduction of noise and light pollution.

h) General disturbance to the land, air and groundwater, from the materials to be used the emissions and by products during the construction, operation and maintenance of the project.

i) Aesthetics considerations with regard to the appearance of the Facility and vegetation.

j) Any other environmental aspect.

k) MED POL Pollution Monitoring Program for Marine environment affected by the Land based Sources: Since MED-POL Program (the marine pollution assessment and control component of the Mediterranean Action Plan), which is responsible for the follow up work related to the implementation of the Land Based Sources LBS) Protocol, the Protocol for the Protection of the Mediterranean Sea against pollution from LBS and Activities and of the dumping and Hazardous Protocols, MED POL should be requested to assist in the formulation and implementation of a monitoring program of the marine environment affected by the discharge of the brine and other land base sources such as backwash wastewater. Such programs are proposed in the EIAS and the implementation is carried out by the national environmental authorities in cooperation with the polluter.

The EIAS will be carried out according to the national policies and guided by the national legislations and the internationally recognized criteria, principles and procedures. This will be executed for a number of sites and each EAIS shall be examined further during the preparation of the feasibility study, for deciding which is the recommended site from the point of view of techno-economic and environmental impacts.

3.10 Desalination Project systems

A desalination project is made usually of the following systems**:**

(a) **Feed raw-water system:** The source may be "well water" either from brackish aquifer or from the sea through an open intake. In case of supply of water from well the feed system provides the wells equipped with pumps and the feed water pipelines for conveyance of the feed water from the wells to the pre-treatment plant. In case the feed water is from the sea through an open intake the system includes the intake heads, the raw seawater marine pipelines from the intake heads to the intake pit, the pumping station in the pit and the on land seawater pipelines from the pit to the pre-treatment plant. The Intake heads should be located at a suitable head for avoiding abstraction of floating or bed load materials thus securing sufficient supplies of seawater.

(b) **Pre-treatment system:** The objective of the pre-treatment is to treat the raw water through filtering to the required quality for passage of water through the desalination system without any problems to the desalination unit. The level of treatment is different for the different technologies (membranes, thermal and others). The concentration of suspended solids in surface water sources is usually much higher than the well water sources. Pre-treatment for surface water source may include a conventional filtration plant or a membrane filtration system.

(c) **Desalination system:** This is the system that removes the salts from the raw water (brackish or seawater). This system may be a 'Membrane system", a "thermal system" or "other system" as given in detail in chapter 2. The selection of the best desalination technology shall depend on the physical, environmental, maturity of the technology, the raw water and product water quality, the availability of the technologies, the energy for operating the plant available (including the renewable energies), the capacity of the operators to operate the specific technology, the costs etc.

(d) **Post Treatment system:** This system provides the treatment of the permeate by the addition of the required minerals and chlorination to make the water suitable for the purpose it will be used.

(e) **Brine discharge system:** The brine is the wastewater from the desalination plant and its concentration in salts is around twice the seawater in case of seawater reverse osmosis technology and other concentrations higher than the raw water depending on the recovery rates.

(f) **Auxiliary systems:** This includes the chemical dosing systems, the Backwash wastewater treatment systems, the electrical supply systems, the Instrumentation and control systems etc.

(g) **Power Supply substation system:** This system secures the power supply to the plant. It can be a substation receiving power from the Grid or from a renewable energy source.

(h) **Power supply system:** This supplies the power to the plant. The source may be a renewable energy supply system (solar, wind power or geothermal) or an Independent power production plant. In all other cases except the Grid supply, the energy source (renewable or independent power production plant or a combination of two) the plant must have its own system for its independent power supply.

3.11 Selection of the site of the desalination plant

It is considered that desalination plants under the Sustainable Water Integrated Management-support mechanism is for desalination processes combined with Renewable Energy Systems. One of the most important parameters apart from the selection of the desalination technology is the selection of the site for the desalination plant. The Project Site is usually made from three sub-areas as follow; (a) the marine works sub-area which will include the seawater open intake and the marine pipelines, (b) the on shore works area which will accommodate the onshore boreholes equipped with boreholes or the intake pit and the intake pumping station and the onshore seawater and brine pipelines (c) the Main Plant area which will accommodate the pre-treatment, the RO process, the Post treatment and all accessories and (d) the Renewable energy plant area.

Desalination Plant Site selection is very vital for the design, financing construction and operation of Desalination Plants. The Site, comprised of inland and offshore parts must fulfil the following requirements.

(i) Must be located in a place where access and interconnections to the power supply grid or to the Independent Power Production or to the renewable energy source and to the water supply networks are technically and economically feasible,

(ii) The area extent and shape (size and geometry) must be the appropriate so that the marine intake head structures, the marine pipelines, the inland pit the seawater pumping station, the inland pipelines, the main facility structures, the post treatment system, the product delivery sub-system, and the power supply system (IPP or national grid substation) are adequately accommodated and optimally located so that civil, electrical, piping interconnections and other works costs are minimized,

(iii) Be suitably located in a marine environment where adequate quantity of feed water with a reasonable good, uniform and steady quality of feed seawater is abstracted at a reasonable cost,

(iv) Be at a location where the brine, backwash wastewater and other wastes are disposed with minimum environmental adverse effects,

(v) The geology and topography are suitable for the construction and erection of the various structures at reasonable costs,

(vi) The environmental, town planning and rural planning regulations, law requirements and restrictions are met,

(vii) The desalination plant is socially accepted by the neighbouring communities and other authorities and,

(viii) The local taxes are not prohibitive and the existing infrastructure shall make easier and cheaper the project implementation.

Usually in the site selection more than one site are selected and after carrying out preliminary layout, design and costing studies together with environmental studies the most appropriate techno-economical site is selected.

3.12 Budgeting and implementation costs including total cost of water

The implementation of desalination projects requires a budget, which is made of the following costs.

a) **Capital costs:** These include all the expenditures associated with the implementation of the project from the time of inception to commissioning. The capital costs are made of two components,

- the development or indirect costs, which are associated with the administrative and financing efforts including engineering, permits issue and to secure the EPC Contractor for the construction and commissioning of the Project during the development and construction phase and to secure the O&M

- contractor for the operation of the project during the Commercial Operation Phase. These costs very from 5% to 30% depending on the size of the project.
- the Construction costs or direct costs or the EPC Price, associated with detailed design, management of the EPC Contractor, procurement of materials, pipes and equipment, Installation of equipment, materials and pipes, civil works execution, Marine works execution, testing and commissioning of the project. The direct cost of the project represents 70-95% of the total capital costs.

The direct costs are calculated using the project design, the construction drawings, the bill of quantities, the construction processes and machinery and the workers hours required to execute the projects and the material costs rates, machinery cost rates and the labour's and technical staff cost rates. Included in the direct cost is a contingency amount, which provides for non-accounted items and risks, involved during construction phase. These direct costs are given as the EPC Costs in monetary units (Euros or US$).

The indirect costs calculations are based on the needs for administrative, legal, financing, engineering and management staff salaries, travelling, accommodation, housing etc for the preparation of the implementation of the project, financing of the project and supervision during the construction phase.

b) **Operation and Maintenance costs:** These include the operation and maintenance cost to be paid to the project operator on a monthly or bimonthly and yearly base and include the management and administration staff cost the labour costs, the chemicals costs, the consumables and replacement parts required in the maintenance of the project. These can be divided into two categories;

- the fixed O&M costs which are independent of the quantities produced i.e. labour and staff cost, insurance costs, environmental monitoring costs permits costs, administrative costs, lighting, air conditioning, cost for equipment maintenance etc and
- The variable O&M costs which are typically proportional to the quantity of desalinated water such as chemicals, replacement of desalination equipment etc. These costs are expressed in monetary units in US$/m3 or US$ per year.

c) **The Energy component cost:** This is the cost of the energy required to operate the desalination plant, to produce steam and power the pumps in thermal desalination units and to operate the pumps in reverse osmosis plants. In both cases, the energy cost is typically proportional to the quantity of desalinated water produced.

d) **Total Cost of desalinated water:** The total cost of the desalinated water is expressed in monetary units US$/$m^3$ or Euros/m^3 and it is equal to the calculation resulting from the sum of the annual capital cost, plus the annual O&M cost, plus the Annual Energy cost all expressed in monetary units per year (US$/year or Euros/year) divided by the volume of desalinated water produced in one year. The annual capital cost is the amortized capital cost over the economic life of the project, using the capital loan rate of interest.

e) **Key factors affecting project costs:** Key factors affecting the various costs components (capital cost, O&M cost and power cost).

- Economy of Scale. The larger the project the smaller the unit cost of water.
- Project Availability coefficient: The larger the project availability coefficient (defined as the percentage of hours of the total annual the project is operational or the percentage of desalinated water produced per year to the average maximum annual production. Obviously in the event of desalination projects combined with renewable energy source (solar without energy storage), the project availability will be very small around 40-45%, which increases the capital cost component. Due to this and in order to reduce the unit capital cost and unit the energy supply could be provided from the renewable energy sources at day time (for solar) and from the grid at night time.

- Product water quality: The higher the quality of desalinated water required the higher the cost. Boron removal further to other parameters requires additional process increasing capital, O&M and energy costs.
- Raw water Quality: The raw water quality has an effect on the desalinated water costs especially when using the Reverse Osmosis technology (TDS, temperature, Organic content, nutrients, boron silica, etc).
- Raw water Intake and Brine water disposal methods: The raw water intake and brine disposal are site dependent and the cost can be decrease by selecting the most suitable site.
- Project risks: There is a number of risks, which are not fully dependent on the project owner but are dependent on others, such as permitting, site availability, power supply risks, construction risks, source water risks, technology risks (associated with the technology maturity), regulatory risks (changes in water quality requirements on power supply tariffs, on wastewater discharge etc), operational risks, desalinated water demand risks and financial risks. All these have to be taken into consideration during preparation of capital costs and operational costs and in formulating the desalinated water price structure.

Preliminary capital cost (direct and indirect), which will include contingencies for environmental mitigation measures costs could be made from preliminary drawings for the preparation of the preliminary bill of quantities for each system and using suppliers and contractors cost rates. The O&M costs could be made using the requirements contained in the O&M Manual concerning the operation and maintenance requirements, where the energy cost will be calculated using the specific energy consumption* to be guaranteed by the designer.

* Specific Energy consumption: This is the total energy required by the plant including pumping energy, lighting, heating and air conditioning consumption in the plant for the production of one cubic meter of desalinated water.

f) Calculation of hourly, monthly and annual production of desalination project: For the calculation of the unit cost of desalinated water the total annual cost must be known (calculated as defined above) and the annual water production must be known. The annual desalinated water produced shall be calculated by using the hourly production multiplied by the Plant Availability**.

** Plant Availability is the result of the division of the total number of hours the plant could be operational divided by the total average number of hours available for operation per year. The average plant availability, for a plant supplied with non-renewable energy sources, is around 90 to 95 percent, where plants depending fully of the renewable solar system will have availability around 40-45%

4. Guidelines to screen and assess BAT options for desalination with focus on rural areas

This section aims to present the most important factors that need to be considered for screening and selecting the best technologies for renewable energy desalination for rural and remote communities.

4.1 Evaluation of available water resources and demand characteristics

A rational approach to the process of screening and selecting the best technologies out of the available technology candidates must begin with a comprehensive evaluation of the available water resources, as well as an evaluation of the water demand characteristics at the proposed site. (See previous chapter) This information has a direct influence on the selection of the best technology option to be implemented. Considering the relatively high cost of the desalination option for water supply, a thorough evaluation of the available water resources in terms of quantity and quality, combined with detailed knowledge of water demand, is essential for establishing the *opportunity cost* of the various technology options under consideration. For instance, the availability of brackish water in sufficient quantities at location near the sea makes seawater desalination a less desirable option. Similarly, the lack of conventional water resources or brackish water can make the high cost of seawater desalination justifiable. The knowledge thus gained provides the first major factor for a rational selection process. Furthermore, these two elements – available resources and water demand – are needed to reveal the options available for an integrated water management approach. Besides the obvious implication on required plant size, detailed knowledge of water demand and its variation over time is also essential to understand the likely mismatches between water supply and demand, and between energy source and demand. This will clearly have an impact on design and technology specification, as well as storage requirements. One important class or type of remote location where desalination is commonly applied is the multitude of islands and seaside villages around the Mediterranean, which have significant seasonal influxes of tourists. This is an economically important class of desalination end-user for the respective countries, since they represent an important contribution to the local economy. In general, the seasonal variation of the population at a candidate site and its reflection on the water demand needs to be well understood.

4.2 Evaluation of available renewable energy sources and grid connectivity

The next major step in the process is to carry out an extensive study of the available energy resources, particularly focussing on renewable energy sources, if electric power supply is not available. At this stage, a thorough understanding of the available RESs and their qualitative and quantitative characteristics is required. The intensity and degree of variability of the considered sources needs to be taken into account in order to measure the relative merits of the available options.

Achieving the goal of better environmental sustainability dictates that consideration of the type of renewable energy source available should proceed, and be a driver for, selection of the desalination technology. Low temperature thermal energy sources, for example, favour the selection of thermal desalination processes over RO, even though the energy consumption of SWRO is lower. However, if brackish water is available the cost economics between thermal desalination and RO needs to be studied.

Thus, one might arrive at one conclusion when considering the desalination process in isolation; and arrive at another when one considers the type of energy source available. To give a more concrete example, if it is decided based on studying available water resources and local demand that there is a need for installing a seawater desalination plant, a cost comparison of the competing processes focussing exclusively on the processes might lead to the conclusion that RO is the best option. If, however, there is a low temperature geothermal reservoir available and the site is not connected to the power grid, it may be more desirable to opt for a thermally driven process instead.

A number of different RESs might be available at a given site. It is common in coastal areas on the Mediterranean to have a good amount of sunny days as well as reasonable wind speeds allowing the use of wind turbines for power generation. In such cases, it is necessary to carry out an economic analysis of the available options that takes into account the site-specific characteristics of the sources. That being said, it is also not advisable to select the energy source out of a list of available candidates in isolation of the desalination process either. A preliminary list of possible technology pairs should be compiled for the purpose of comparison. At the very least, one should try at this stage to decide on the broad type of energy source, i.e. whether to provide thermal energy or power. A hybrid approach combining two sources of the same type (e.g. solar PV and wind) can also be adopted as a means of partially overcoming the inherent variability of each single source.

Finally, results of the evaluation of available energy resources may establish the need for a backup power source, such as a diesel generator, to cover periods of low energy availability. The need and type of energy storage is linked closely to the type of process and should therefore be addressed at a later stage, after short-listing the desalination processes.

4.3 Short listing of candidate desalination processes based on available RES

The previous step of identifying, characterizing and selecting the RES should allow the elimination of all desalination processes that are not suited to the type of energy source chosen. The decision to adopt a shaft or electric power RES eliminates thermal processes and shortlists: RO, ED, and MVC. Among these options, RO is the most economical for seawater desalination. The MVC process is has higher power consumption, but is generally more robust than RO, requiring minimal pre-treatment in comparison. RO membranes are prone to fouling and scaling, and are less forgiving of operator errors. For brackish water plants in remote areas, the ED process is very attractive, since it is also more robust than RO, and is well suited to small-scale minimal maintenance plants in remote areas.

If, on the other hand, a low temperature thermal RES is chosen, the previous three processes are no longer relevant, and the potential candidates are MSF, MED, TVC, MD, HDH, and solar stills. The last three processes are generally suited for small-scale systems, up to around $5m^3/d$.

4.4 Maturity and level of deployment of the processes

The maturity of the selected process will reflect on the level of risk associated with project. Novel processes may possess attractive features, open up new possibilities, and occasionally introduce remarkable improvements in performance; but they are particularly difficult to recommend for remote and rural applications. The nature of rural and remote sites preclude easy access to technical support and highly qualified plant supervisors and operators. This factor tends to strongly favour proven and well-tested technologies for reliable solutions to pressing water demands in rural and remote areas. Nevertheless, local governments and decision makers should be aware of potential developments in technology and the possibilities they introduce. It is thus recommended that decision makers adopt a policy of encouraging and allocating funds for pilot testing of promising new technologies to establish their reliability, understand their maintenance requirement, and to gain confidence in their applicability to the local conditions.

In summary, the following factors are to be considered.

- Reliability of a desalination process is of a highest priority even from the total unit cost of the process, when desalination projects aim to provide drinking water.
- Desalination technology is witnessing fast development and it is recommended to keep up with progress on proven state-of-the-art desalination processes.
- A process can be considered matured/proven if it has been commercially operated for ≥ 3 years with success and recommended by water practitioners who used it.
- In all cases and in order to increase reliability of any proven desalination process, a plant should be design with at least two parallel lines, of 50% capacity each, in order to reduce the risk of total plant shutdown.
- Novel processes may possess attractive features, open up new possibilities & occasionally introduce remarkable improvements in performance; but difficult to recommend for rural applications awaiting maturity. In order to forward novel processes, the investment should be contracted as BOT or BOOT, so that the risk is carried by the investor. The investors are more willing to invest in plants serving rural and

remote areas rather than in cities, since the risk in investing in small plants is minimized as opposed to large and mega-plants.

- To reduce the risk of innovative and immature technologies in rural areas, a different mature & tested technology can be considered side-by-side to the new technology. This will reduce the risks of total dependability on the innovative technology. The provider of the new technology will grant the needed guarantees of proper operation & compensation in case of failure.

4.5 Pre-treatment requirements

Desalination processes differ in the level of feed pre-treatment they require for stable operation and long plant life. Membrane processes are generally more sensitive than thermal processes, and among the membrane processes, RO tends to be the most sensitive to feed quality specifically with respect to iron, silica, Fluoride, organics, etc. in feed water. RO plants drawing their feed from open intakes require thorough pre-treatment systems, typically consisting of chemical dosing and filtration. In addition, periodic cleaning of the membranes is required based on observed plant performance, as well as frequent backwashing of the filters and intermittent disinfection of the intake system. It is clear that a good degree of skill is required for trouble-free operation of RO plants. When the local geology of the site permits the use of beach wells as the intake system of a SWRO plant, the pre-treatment requirements can be significantly less demanding, and this option is preferable whenever possible. Recent experience at several SWRO plants operated or supervised by WESCO in Saudi Arabia has shown that often much of the chemical dosing, including coagulants, chlorination and acid dosing, can be reduced or eliminated without any negative effect on the RO plant, while reducing the impact on the environment and lowering operating costs. This of course can only be established on a case-by-case basis, and the possibility needs to be investigated at each plant. High recovery brackish plants are often designed to exceed the solubility limits of some of the sparingly soluble salts present in the feed water, and in such cases the use of an anti-scalant is likely to be a mandatory requirement. Recent technological innovations include SWRO or Brackish RO plants without any chemical in the pre-treatment process, which is both environmentally, and economically friendly ad must easier to operate.

The ED process is generally more robust than RO, requiring less stringent feed pre-treatment. This makes it an attractive option for brackish plants in remote and rural areas with little access to technical support or skilled operators. Membrane distillation, due to the hydrophobic nature of its membranes is quite resistant to fouling compared to RO, and thus has very little pre-treatment requirements; however, more care is required during the start-up of the plant.

The Volume of product water and the availability of the renewable energy sources are the most important factors in the selection of the combination of the desalination technology and the renewable energy source. The volume of product water defines the size of the desalination plant and the power required. Obviously, for large desalination plants the energy requirements are very large, which make the marriage of the desalination plant with renewable energy sources (since both the desalination plant and renewable energy source plant will be very large) not economically feasible. For limiting the size of the desalination plant and that of the renewable energy plant use of energy from the grid at night could be made.

4.6 Operational skill level required

A related issue to technology maturity & pre-treatment requirements that is important factor in selecting & recommending a technology is the relative ease of plant operation compared to the level of skill available in rural communities. However, since the desalination plants in rural and remote areas are usually selected to be small and simple to operate the need for sophisticated technical capacity to operate such small plants is minimum.

Nevertheless, appropriate training of the local community can be given from the commissioning stage (even from the design of the plant if possible) and at regular periods after the plant start-up, in managing, operating and routine maintenance. This capacity development should be on the job with familiarization on the design and concepts of the desalination technology and associated RES. Furthermore, support from the service provider and/or designer should be assured especially for irregular conditions (e.g. break down of high-pressure piping or pumps etc). Alternatively, efficient support for irregular and major failures could be provided by a more centralized technical centres that can be called in whenever needs arise.

The minimum suggested staff in such projects to assure efficient and uninterrupted operation of the plants should include

- Plant Operator, with the minimum training for the day-to-day operation of the plant
- Maintenance experts (small team of 1-2 persons at central level to operate on call for a number of DES plants)
- Specialized experts at Central level including, High Pressure Pumps Expert, IT expert for automations, Chemist and Material Science Expert.

It was also suggested in case of lack of competence of the local people a PPP scheme could be chosen to operate the desalination plant and eventually increase the capacity of locals.

4.7 Energy storage vs Water storage options

Desalination plants are almost invariably designed to operate at fixed or slowly (seasonally) changing operating points, drawing fixed energy input at fixed rates. This contrasts sharply with the nature of many RESs, such as solar and wind, which are marked by instantaneous, diurnal, and seasonal variation. This introduces the need for energy storage and buffering. Energy buffering refers to a small amount of energy storage intended to smooth and filter out instantaneous and short-lived variations in the energy source. Longer interruptions in energy, such as the absence of solar energy during the night, cannot be handled by buffering and require a larger scale of storage. The evaluation of available RESs, mentioned above, should establish a clear picture of the degree of variability of the proposed sources over various time scales. Long and frequent short-term intermittencies in the rate of energy supply from the RES increase the buffer storage requirements.

Since the storage of electricity is not practical based on current technology, while water storage during the RES occurrence can be more effective especially at rural or remote areas where the water supplies are rather small and thus the water storage requirements entail low investment costs On the other hand since the storage of thermal energy, is more economical, this will tip the balance towards favouring a thermal energy type of RES and a thermal process combination.

Notably, geothermal energy supplies energy at virtually constant rate and operating conditions, which has the advantage of eliminating energy storage.

Taking into account the total cost of the desalination plant and the RES plant for operation only during RES availability it can be said that both will be double or more than the required daily capacity. The Plant capacity and the RES plant sizes can be reduced tremendously if a hybrid power supply is possible by utilizing RES during their intense occurrence (e.g. solar power during the day) and fuel (diesel) power or grid power (if available) as a substitute during their low occurrence. This solution must be fully analyzed to prove that it is more cost effective.

4.8 Brine disposal

4.8.1 Brine Disposal methods and comparison

In coastal areas, brine can be disposed by dispersing it in to the sea. Brine disposal is a critical and utmost important factor, particularly for inland brackish water desalination plant, that needs to be considered while deciding the location for the plant and the desalination technology. The desalination technology that enables very low recovery will result in comparatively large volume of brine to be disposed. RO scores over ED, MSF and MED processes when brine disposal is a problem. In inland desalination plants, brine can be disposed by any one of the following techniques:

- Zero Liquid discharge techniques by Thermal Method.
- VSEP Treatment.
- Brine injection.
- Evaporation pond.
- Using brine to produce agriculture and aquaculture products
- Evaporation pond using enhanced Evaporation Mechanisms.

a. Brine Concentrators (Disposal of Brine Water Using Zero Liquid discharge techniques by Thermal Method):

The generated brine from the desalination plant can be further concentrated using brine concentrators or evaporators to produce almost a zero discharge. Though this option would be ideal for brine disposal, this option has not been recommended due to very huge investment, associated high O&M cost and need for skilled staff.

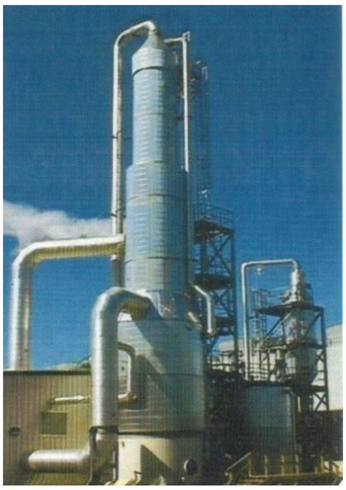

Figure 24**:** Ionics` brine concentrator & crystallizer at the AES Ironwood power plant

b. Brine Concentrators (Disposal of Brine Water by VSEP Treatment):

New Logic Research, Emeryville California has developed a new proprietary vibrating membrane filtration system that is not limited by solubility of sparingly soluble salts unlike conventional reverse osmosis membrane technology and is capable of extremely high recoveries of treated water from brine. The process is called Vibration Shear Enhanced Process (VSEP). VSEP employs torsional vibration of the membrane surface, which creates high shear energy at the surface of the membrane. The result is that colloidal fouling and polarization of the membrane due to concentration of brine are greatly reduced. In addition through put rates of VSEP are 5 to 15 times higher in terms of GFD (gallons per square foot area of membrane surface) when compared other conventional RO membranes. The sinusoidal shear waves propagating from the membrane surface act to hold suspended particles above membrane surface allowing free transportation of liquid media through the membrane.

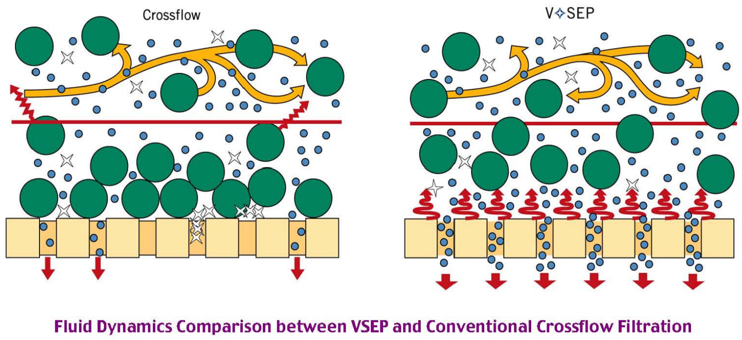

Figure 25: VSEP Fluid Dynamics Comparison   Figure 26: VSEP Module

New Logic has conducted pilot testing of several projects and supplied few commercial VSEP plants where the objective was to reduce the volume of reject from RO membrane system. The results have shown that it is possible to recover 99% from brine leaving behind 1% for disposal. However, for a 99% recovery a two-stage VSEP system will be required which is very expensive. VSEP system is not recommended for rural desalination plant brine disposal, as this calls for huge investment, associated O&M cost and skilled staff.

c. Brine injection:

Brine disposal by injection in to wells is one of the possible methods of brine disposal at cheaper cost. However, brine disposal by injection into aquifer has been cautioned to be risky by the hydro geologist as the Injection of brine may destroy the aquifer in which is being pumped and may prevent its exploitation forever. Risk of contaminating the over lying aquifer in future will always be there since prevention of leakage cannot be guaranteed due to many reasons, one of which is the fractures that could be developed by tectonic activities. Decision on brine disposal by injection well needs to be taken after detailed hydro-geological investigation.

d. Disposal of Brine Water in Evaporation pond:

Solar evaporation is a well-established method for removing water from brine water. Evaporation ponds for brine wastewater disposal are used all over world especially in regions having a relatively warm, dry climate with high evaporation rates, level terrain, and low land costs. Solar evaporation ponds are being used in big desalination plants (Salbook & Bouyeb) of 60,000 m^3/day capacity in the Riyadh region (KSA).

Hence, for rural desalination where access to dispose brine to sea is not there, evaporation ponds are more suitable due to following reasons:

- They are relatively easy and straightforward to construct.

- Properly constructed evaporation ponds are of low maintenance and require little operator attention compared to mechanical equipment.
- Except for pumps to convey the brine wastewater to the pond, no mechanical equipment is required.
- For smaller volume flows, evaporation ponds are frequently the least costly means of disposal, especially in areas with high evaporation rates and low land costs.

Figure 27: Evaporation pond with double synthetic liner and leak detection system in New Mexico.

Despite the inherent advantages of evaporation ponds, they are not without disadvantages that can limit their application, as described in the following list:

- They can require large tracts of land if they are located where the evaporation rate is low or the disposal rate is high.
- Requirement of impervious liners of clay or synthetic liners such as PVC or HDPE substantially increases the costs of evaporation ponds.
- Seepage from poorly constructed evaporation ponds can contaminate underlying potable water aquifers.
- There is little economy of scale for this land-intensive disposal option.

e. Using brine to produce agriculture and aquaculture products:

One of the alternatives for disposing brine is utilizing it for agriculture or aqua culture purposes. This technique involves addition of downstream facilities, which can be considered as a separate project of the main plant itself. This option, if implemented properly, will generate more job opportunities to the local people, business and profits opportunity to the potential investors and will serve as a good model for brine disposal of inland desalination plants.

The technique involves either some or all of the following:

- Construction of an algae farm
- Construction of a fish farm
- Plantation of halophytes such as blue panic

Ideally, the brine from the desalination plant should be first routed to an algae farm, where good quality algae can be produced and harvested on daily basis. The algae can be used as feed for fishes, animals or can be used to produce green urea. The overflow of water from the algae farm can then flow to a fish farm, where variety of fish such as Tilapia could be grown. Finally, the enriched brine from the fish farm could be used to irrigate salt tolerant plants (halophytes) such as blue panic. It is estimated that harvesting could be done frequently several time a year. These blue panic plants can be used as forage and has good proteins. Seepage from farms/ponds can contaminate underlying potable water aquifers.

However, a separate detailed feasibility study needs to be carried out on this.

f. Disposal of Brine Water in Evaporation pond using enhanced Evaporation Mechanisms:

Size of the evaporation pond is a function of the rate at which reject brine is evaporated from it. If it were possible to increase/enhance the natural evaporation rate, it would be possible to reduce the size of evaporation ponds. Such a reduction would result in substantial savings in the construction costs of ponds.

Methods to enhance natural evaporation from evaporation ponds include:

- spray evaporation
- creating turbulence in the pond;
- allowing brine to pass over inclined rough surfaces;
- creating an air flow over the pond

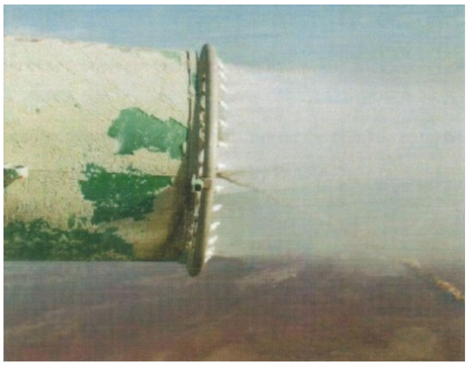

Figure 28 & Figure 29 Turbo-Mist evaporator in operation

Spray evaporation has been found to be effective in reducing the evaporation pond size to one sixth. However, this technique requires power for continuous operation of the turbo-mist evaporator and is suitable where the land is high. Also the carryover of spay due to wind may result in salt deposit in areas around the evaporation pond causing a potential environmental concern.

g. Comparison table for brine disposal in inland plants: The table below shows the available options for brine disposal.

Description	Capital cost	O&M cost	O&M Skill requirement	Environmental impact	Preference
Zero Liquid discharge (Thermal)	V.High	V.High	High	Moderate	Sixth
VSEP Treatment	High	High	High	V.Less	Fifth
Brine injection	Less	less	Nil	Less/Moderate	Second
Evaporation pond	Less	less	Nil	V.Less	First
Produce agriculture and	Moderate	Moderate	Moderate	HIgh	Third

aquaculture products					
Evaporation pond using enhanced EvaporationMechanisms	Moderate	Moderate	Less	Less	Fourth

4.8.2 General on Brine disposal

From experience, the most appropriate method for brine disposal from desalination plants operating in rural and remote inland areas is the use of evaporation ponds, due to the limited brine production (this was based on the assumption that in most rural and remote areas, desalination is produced from brackish water, which has a recovery of up to 90% of the volume of feed water. Therefore, only 10% of the feed water is lost as brine. The relatively ease in land availability in rural and remote areas and the low investment cost compared to the other disposal methods tends to make this option the most feasible one.

Brine injection although technically feasible and cost effective in areas with limited area for ponds it requires extensive hydro geological investigations and studies to prove that the brine will be confined and will not cause any damage to the freshwater aquifers. In view of the high level of hydro geological studies required and the high risk of polluting fresh water aquifers the brine injection should be considered after all other methods are ruled out and the risk of fresh water aquifers is very small or non existing.

Another brine disposal approach that could be considered for local community development is the reuse of brine in agricultural and aquaculture. A big disadvantage of this is the fact that the use of brine in agriculture would degrade the quality of the soil and it would need 3-4 times the volume of brine for washing the soil from salts.

In the coastal areas, the most cost efficient method of brine disposal is the discharge to the sea using carefully designed outfalls equipped with diffusers to help in the dispersion of brine in the near shore marine environment with minimum environmental impacts. In the design of the brine discharge systems the MED-POL program requirements must be taken into account, through an Environmental Impact Assessment Study. The MEDPOL programme (the marine pollution assessment and control component of MAP) is responsible for the follow up of work related to the implementation of the Land Base Sources Protocol, the Protocol for the protection of the Mediterranean Sea against Pollution from Land Based Sources and activities (1980, as amended in 1996) and of the dumping and hazardous waste protocols. MED-POL assists Mediterranean countries in the formulation and implementation of pollution monitoring programmes, including pollution control measures and the drafting of action plans aiming to eliminate pollution from land based sources.

According to the MED-POL representative, many countries refused to ratify the new Protocol. On the other hand, the international experts explained that the discharge of brine to the sea (from seawater desalination) affects only the near shore marine environment within a radius of approx. 100 m from the diffusers. Brine discharge of carefully situated and designed seawater desalination plants will have limited environmental impacts on the near-shore marine environment. According to the CDG, discharge of brine (particularly when mixed with cooling waters) through outfalls extended to the open sea where eddy currents disperse and dilute the brine to the open sea were found to be of very limited environmental impacts.

A solid recommendation culminated from the CDG discussions indicated that once it is decided to implement a desalination project, its environmental impacts should be assessed in accordance to the national EIA policies and guided by the internationally recognized criteria & methodologies (see section 3.9.2.1)

4.9. Other practical site characteristics

In addition to the above factors, a number of additional factors relating to the characteristics of the proposed site will also have a bearing on technology selection. Factors such as land topography and access, the availability and quality of roads and transportation considerations, and other infrastructure are all factors that need to be considered during the planning and screening stage to ensure adequacy for the proposed technologies. For more details on the criteria for selecting the site for the desalination plant are given in section 3.11.

4.10 Capital and operating costs of the total proposed solution (See also section 3.12)

After all other factors are duly considered and appropriately weighed-in, the ultimate deciding factor for selecting the best solution out of a number of equally acceptable technical solutions is the total cost. This ordering emphasizes that cost alone cannot be the deciding factor when considering the provision of a precious life-sustaining resource such as water to remote or disadvantaged local communities, and a number of important particularities of such cases need to be considered. After ensuring the relevant particularities are taken into consideration and have appropriately guided the selection process, it is then fair and reasonable to base the final selection among the remaining candidate technologies on the basis of total life cycle cost. Details on classification of costs and budgeting of costs are contained in section 3.12. Social and environmental cost to the community (ies) affected must also accounted.

5. Modality for assessing community needs

5.1 Geographical considerations

The comprehensive geographic profile of a proposed site plays a central role in setting and modifying the requirements and local community needs for BAT in desalination. Such factors include the physical geography of the location which influences the type of soil and terrain, earthquakes and volcanic activity, surface topography, geothermal reservoir activity, and other geologic factors. These factors will have an immediate influence on site construction practices and civil engineering, including relevant construction codes and standards. In addition, the surface topography will have a significant influence on the quality of renewable energy resources available, or the ability to extract it efficiently.

Another critical aspect of the total geographic profile of a particular community is the local hydrology of the site. This includes the movement, distribution and quality of water at the location, and the portfolio of water resources available such as rivers and lakes (fresh water bodies) in addition to groundwater aquifers, sustainable extraction rates, drainage basins and flood plains, and other aspects of the total hydrological profile.

Establishment of the water balance of the region, with its three main components: precipitation, runoff, and evapo-transpiration, allows better management of water resources and a clear understanding of shortages, as well as the time-scales associated with various components of the water balance. Collectively, the various aspects of the hydrological profile of a location or region can be thought of as the inherent “supply-side” characteristics of water supply at the location. The “demand-side” characteristics are the subject of the next section. The mismatch in quantity, time, or location between the supply and demand gives shape and definition to the problem that the BAT desalination solution seeks to fully or partially alleviate.

Another aspect of the geographical profile of a community that must be taken into consideration is the possible historical and archaeological heritage of a site. Care must be taken to preserve such heritage from possible damage caused by digging and site construction and other civil works. Care must also be taken to protect heritage sites from the much more subtle aesthetical damage that can be caused by unsightly plant installations. To cite an example, some societies and individuals find the sight of wind turbines and wind farms to be objectionable. Thus the perceived visual impact of the technology on a site is important consideration, especially so for historical sites. Care shall also be taken to avoid the locations of wildlife habitat to protect them.

5.2 The human factor: demographic and socio-cultural considerations

It cannot be overstressed how important social, cultural, and demographic factors are to the success of a remote or rural desalination project. Basic statistics need to be gathered and analysed at the level of the community or village, as well as at a regional level. These include percentage of rural versus urban population in a region, the population density, average income per family, level of literacy and education and percentage grid connectivity. In addition, qualitative assessments of cultural perspectives and social aspects related to water usage and consumption need to be carried out. Social aspects often do not receive the attention they require and deserve in project planning. The ADIRA project [28] outlines a number of basic principles related to the social aspects of an autonomous desalination project. These are listed below with some slight adaptation:

1. **The Socio-technical approach**
   This principle emphasizes the interdependency and interaction between three elements: people, technologies, and organizations. This interdependency must be fully understood and accounted for in order to improve the chances of success of a project.
2. **Focus on people**
   The people affected by the project must be included in all stages, and their input must be taken into account. In addition, their values and cultural perspective need to be recognized and respected.
3. **Learning**
   The target group, particularly in rural communities, need to learn in order to maximize their benefit from a new project. Opportunities for learning, raising awareness, and training need to be provided from the earliest stages of a project.
4. **Independence and autonomy**
   The willingness of community members and target groups to participate and engage with a project depends largely on the level of independence and autonomy they are afforded. This means that community members need to be able to make their own decisions about proposed actions that will potentially affect their lives. Technological solutions, however cleaver and innovative they might be in the eyes of the designers or the decision-makers, must not be imposed on a community that finds them objectionable.
5. **Flexibility and Process orientation**
   The general conditions and circumstances for water supply in rural areas can change relatively quickly, and are generally very site-specific. This dictates the adoption of a flexible process-oriented approach to projects that is able to easily react and adapt to changes. Inflexible approaches or fixed solution templates are inadequate for handling the large degree of variation between different projects, and even within a single project over time.
6. **Sustainability**
   In this context, sustainability refers to the continuous support of the project by the authorities and other stakeholders after its completion, and the continuous service and operation of the installed systems. Even though sustainability, by this meaning, can only be verified over relatively long stretches of time, many of

the factors that influence sustainability can be identified from the earliest stages of a project. Sustainability criteria need to be compiled and documented during the planning stages to provide a reference and guide for later project activities, in the interest of improving the chances of achieving sustainability. Average income per family, poverty levels, affordability, willingness to pay for the water produced by the desalination plant and government subsidies, play a major role in sustainability.

7. **Realism**
   Project plans, objectives and expectations must be realistic and feasible. Unrealistic or excessively demanding plans are bound to result in disappointment and/or failure. A good assessment and understanding of the real environmental context and particularities of a project is essential for insuring that project plans are feasible and firmly grounded in reality, rather than being driven solely by desires.

Cultural, religious and gender related issues

All too frequently, socio-cultural and religious causes are found to lie at the heart of failed community water projects[14]. Cultural and religious nuances vary widely between cultures and communities, and therefore a conscious and organized effort to understand such aspects needs to be made from outset. In this regards social science methods are the most appropriate means[28]. Often a new technology introduced into a community for the first time is perceived as an alien intrusion that is incompatible with long-standing traditions, social structures and responsibilities of the community[14].

In most societies and cultures, the responsibility for water management, sanitation and health at the household level lies with women[29].While this role has allowed women to acquire much wisdom on matters of hygiene, sanitation and water management, often they are exposed to vulnerabilities associated with walking long distances to fetch water, such as harassment, and inability to attend school. To cite an example:

> "In *Morocco*, the Rural Water Supply and Sanitation Project of the World Bank aimed to reduce the burden of girls "who were traditionally involved in fetching water", in order to improve their school attendance. In the six provinces where the project is based, it was found that girls' school attendance increased by 20 % in four years, attributed in part to the fact that girls spent less time fetching water. It was also found that convenient access to safe water reduced the time spent fetching water by women and young girls by 50 to 90 %."[29]

Despite the important role women play in management and preservation of household water resources, in many societies, men take charge of decision-making and political issues and women are often left out. Women often end up having very little say in determining the kind of services and support they need to facilitate their roles.

> "Gender considerations are at the heart of providing, managing and conserving our finite water resources and safeguarding health through proper sanitation and hygiene. The importance of involving both women and men in the management of water and sanitation has been recognized at the global level, at least since the 1977 United Nations Water Conference at Mardel Plata and during the International Drinking Water Supply and Sanitation Decade, 1981-1990. The Dublin principles, endorsed at the International Conference on Water and the Environment in 1992, recognized that "Women play a central part in the provision, management and safeguarding of water." The statement called for recognition of the contributions of women as providers and users of water and guardians of the living environment in institutional arrangements for the development and management of water resources." [29]

Capacity building

Successful project planning, implementation and sustainability require comprehensive and carefully planned capacity building. Ideally, this should target all the various stakeholders in a project, including consumers, technicians, decision makers, designers, contractors and suppliers. The most important of these groups are consumers and technicians at the village or site level, and the decision makers. Training programs need to be designed and delivered to develop the necessary human resources in the PCs in the following areas:

- Water supply management, technology evaluation, and flexible project planning. This aspect mainly targets planners and decision-makers in the PCs.
- Design of BAT desalination systems using RES in rural and remote areas. This can be introduced into the national engineering curricula of the PCs or offered as intensive training programs to practicing engineers.
- Installation and commissioning of relevant technologies. This should target local engineering and contracting companies and can be done in partnership with the technology manufacturers and system integrators.
- Operation and maintenance: In addition to engineering and contracting companies, this element should focus on training the local workforce available at the village or remote location in order to achieve the skill level required for the continued sustainability of the project. This can be viewed as being complimentary to the rational selection of the technologies that are suitable for the available operators. One aspect does not eliminate the need for the other. Technology selection must reasonably match the available skill level, while training must still be provided to ensure that the skill level is adequate for the technologies adopted.

5.3 Water resource availability

As mentioned previously, an extensive survey of the water resources in the vicinity of the proposed site needs to be carried out. The total quantity and quality water needs to be determined, in addition to analyses of well and/or seawater. Detailed water chemical analyses of raw water sample are required for the design of desalination systems to avoid scaling and/or fouling. In case of using well water as raw water source for desalination, detailed hydrological study/tests shall be conducted to ensure the draw down in the well, sustainability of the well for the current capacity plant throughout the period of operation of desalination plant. Aquifer recharging also needs to be considered, if study reveals that it is essential for the capacity of the plant considered. Another important aspect is the degree of proximity of the water sources to proposed site, which can have an impact on the water cost.

5.4 Pricing structures and financing schemes

A successful desalination project in rural or remote area should at least manage to recover its running costs and its depreciation [28]. This necessitates that the water pricing reflects the real costs of water supply. On the other hand, access to safe drinking water is a basic right for all humans, and consequently the basic human requirements for water should be available and affordable for all. Subsidies are usually needed to ensure water supply in rural communities. However, subsidies applied to conventional water resources distort the market and make alternative resources such as desalination and RES less attractive. Therefore subsidies need to be applied in a consistent way that allows the market to select the most efficient water supply method [14].

The main difficulties facing the implementation of desalination by RES in rural communities are:

1. The low income of the rural population.
2. Limited financial resources within rural communities.

3. High investment costs required for such projects.

In response to these difficulties, a number of support mechanisms that do not distort the market function are possible, such as[28][14]:

- Direct financing of the infrastructure.
- Providing financial incentives for the operators.
- Encouraging private sector involvement.
- Adopting the “life-line rate”, where a variable pricing structure is applied based on the volume of water used. The first tier of consumption, representing essential human needs, would be affordable to all, while the following tiers of consumption are priced at increasingly higher rates.

The life-line rate scheme has a number of advantages: 1) the minimum water requirement is affordable to all; 2) the average price of the consumption tiers can be set to reflect the actual cost; and 3) there is an incentive for users to conserve water.

The main financing models possible, in the order of increasing capital investment by the system provider and decreasing investment by the end-users, are listed below:

- Cash sales: Users buy and own the complete system upfront. The end-user thus owns the system from the outset and is responsible for operation and maintenance.
- Consumer credits: Users buy the system from the manufacturer or system provider in instalments, where the credit is granted by the system provider.
- Credit institutions: Users buy the system in instalments, where credit is provided by a third party credit institution.
- Lease: The User does not buy the system, but rather leases it from the company or financial intermediary, with the option of buying it after the end of the lease period. In this case, the ownership of the system is retained by the system provider or the financial intermediary, and is usually responsible for maintenance and repair.
- Fee for service: A company or public water supplier owns the system and sells the product (water) to the end users. The company is responsible for operation, maintenance and repairs.

5.5 Institutional and regulatory factors

The distribution of responsibilities in the water sector can generally be divided into three levels [28], [30]:

1. **Decision making level**

This typically includes ministries and other high-level government entities that are involved in setting water policy and planning. The main responsibility usually lies within one ministry that has the overall control over the water sector. However, there are typically other ministries that are also involved in water policy to various degrees, such as Environment, Agriculture, Development, Finance and other ministries.

2. **Executive level**

This is usually the role of government organizations that operate under the top-level decision making bodies.

3. **User level**

This can be either government or non-governmental organizations (NGOs) that undertake the actual operation and maintenance of water supply facilities. The user level is usually different for urban and rural areas. While cities have many favourable features such as large demand and high geographic concentration that allow economies of scale, rural areas present various economic and technical challenges. This often means that subsidies are required to enable the provision of essential water resources to rural communities.

While there are no specific regulations directly targeted at desalination projects, a host of licenses are likely to be required for desalination projects in rural and remote areas. The specific licenses required are specific to each country, but generally the following items can be expected[28]:

- Borehole drilling and seawater withdrawal.
- Brine disposal (often in the form of liquid waste disposal regulations).
- Coastal zone construction.
- Drinking water quality.
- Renewable energy installations or electric power supply approval.

5.6 Additional Guidelines to Screen and assessment of Desalination BAT using RES

This section contains in brief some additional guidelines in screening and assessing the Best Available Technology using RES. This section contains the recommendations of the international and national experts as agreed during the Athens meeting 11 & 12 of June 12. The guidelines are given as steps 1 to 4 as follow.

Step 1: Evaluation of available water resources & demand characteristics: The international and national experts agreed to the need for a comprehensive evaluation of the available water resources, as well as an evaluation of the water demand characteristics at the proposed site to be the first step, with a purpose to ensure that all options are exhausted prior to deciding on desalination.

In order to evaluate and establish the needs of a rural or remote community for desalination projects, the real need for the community has to be examined within an overall assessment of water resources available to the community. Introduction of desalination, if decided, into a community should be within an IWRM context and should be considered by central and local authorities as a first milestone towards the overall sustainable development of the community. Accordingly, a detailed opportunity cost analysis should be elaborated before deciding on desalination. Factors to be taken into consideration in the opportunity cost analysis should include but not limited to alternative water resources, reuse of wastewater, production cost of desalination at the point of use, environmental externalities, savings from reduction of non revenue water (minimisation of leakages and illegal withdrawals), reallocation of water from irrigation with its socio-economic impacts, re-evaluation of crop development in agriculture policies etc.

A capacity development workshops need to be planned to train water officials on the principles of opportunity cost analysis for desalination shall be considered within the capacity building WP of SWIM program. It will be implemented “parallel but separate” to the tasks of SWIM-SM.

The recommended activities need to be implemented in synergy with other EU or Mediterranean projects such as NED-POL and H2020; donors and stakeholders to avoid duplication and to pool resources.

Step 2: Evaluation of available RES & grid connectivity: According to the experts, the next major step in the process is to carry out an extensive study of the available energy resources, with a particular focus on renewable energy sources, in case electric power grid or supply is not available. A thorough understanding of the available

RESs, their qualitative & quantitative characteristics are required. At this point, it was suggested that a Risk Analysis of the RES availability should be considered when evaluating desalination projects.

In addition to that, a capacity development programme is considered necessary to orient water policy makers in SWIM countries of the new developments and state-of-the-art aspects (technical, advantages, economics, limitations, etc.) of RES compatible with small-scale desalination.

Step 3: Short listing of candidate desalination processes based on available RES: The previous steps of identifying, characterizing and selecting the RES should allow the elimination of all desalination processes that are not suited to the type of energy source chosen within the socio-economic, environmental and cultural specificities of the community in need for desalination.

Step 4: Environmental Impact Assessment of DES-BAT & RES projects: Once the implementation of a desalination plant is decided based on exhaustive elimination of alternatives using opportunity cost analysis tools, an EIA has to be under taken to identify, avoid and/or mitigate any potential environmental impacts according to national EIA policies. The cumulative environmental impacts (primarily from the discharge of brine to the sea or its reuse in agriculture) resulting from the operation of the desalination plant will be given adequate weight in the EIA studies.

Based on the CDG discussions with the national consultants, they agreed to the following:

1. SWIM-SM should consider the development of a comprehensive tool-box (guidelines) to support policy makers decide on desalination after exhausting all other options. The tool box should follow a logic sequence, simple and friendly to use. The tool-box shall include the economic and environmental instruments needed to decide on desalination while avoiding its environmental impacts.
2. SWIM to ensure the incorporation of EIA as a fundamental step in the structure and context of the proposed DES-BAT & RES guidelines.
3. A succinct plan for the development of the proposed guidelines (tool-box) need to be developed & discussed with the CDG, electronically shared with PCs, developed, electronically shared & then discussed in an enlarged regional consultative meeting with the involvement of national water & environment experts from PCs in collaboration with UNEP-MAP.

6. Recommendation of integration into National IWRM plans

Water was recognized since the antiquities as the "blood of the Earth", as the perquisite for life in our planet and as one of the most vulnerable and scarce natural resources. Growing water-stress in south Mediterranean countries poses threat to the economic development and human live hoods, mainly among the poor and most vulnerable populations living in arid rural areas. Agriculture uses 70 to 85% [35] of the renewable water resources. Irrigation systems are often scattered across vast rural areas, with poor efficiency and lack of managerial control. UN Secretary General pointed out in the Millennium Conference (2000): "We need a Blue Revolution in agriculture that focuses on increasing productivity per unit of water – more crops per drop. Urbanisation, pollution, over-exploitation of natural resources pressures Mediterranean aquatic ecosystem biodiversity. The region has lost more than 50% of its wetlands.

The need for careful and wise management of water resources was recognized in Stockholm, in 1972. Increasing demands in water, deterioration of water quality and quantity and mismanagement of natural resources make water an even vulnerable and finite resource. The latter is more evident in the Mediterranean region where the sectoral approaches in water management are still prevailing in many countries [35] and cannot meet the contemporary needs for a sustainable resources management.

Over the past few decades there has been an increasing and recurring realization on one hand of the vital role that water plays for sustainable development, and on the other hand of the interdependence and competing demands of the various water use sectors on this finite resource. This has led to a new paradigm in the management and planning of water resources that is collectively called Integrated Water Resources Management (IWRM). The Global Water Partnership (GWP) defines IWRM as 'a process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital eco-systems'.

Water cycle is the "integrated water resources model" of nature. A sustainable management practice of water resources must not only take into account but also respect the fragile balance between the components of the water cycle. Rainwater, terrestrial water (lakes, rivers, etc.), coastal and marine water, wetlands: all must be managed in a holistic manner that is based on their particularities and implications, using all the available tools and methods. A modified water cycle recommended is illustrated below.

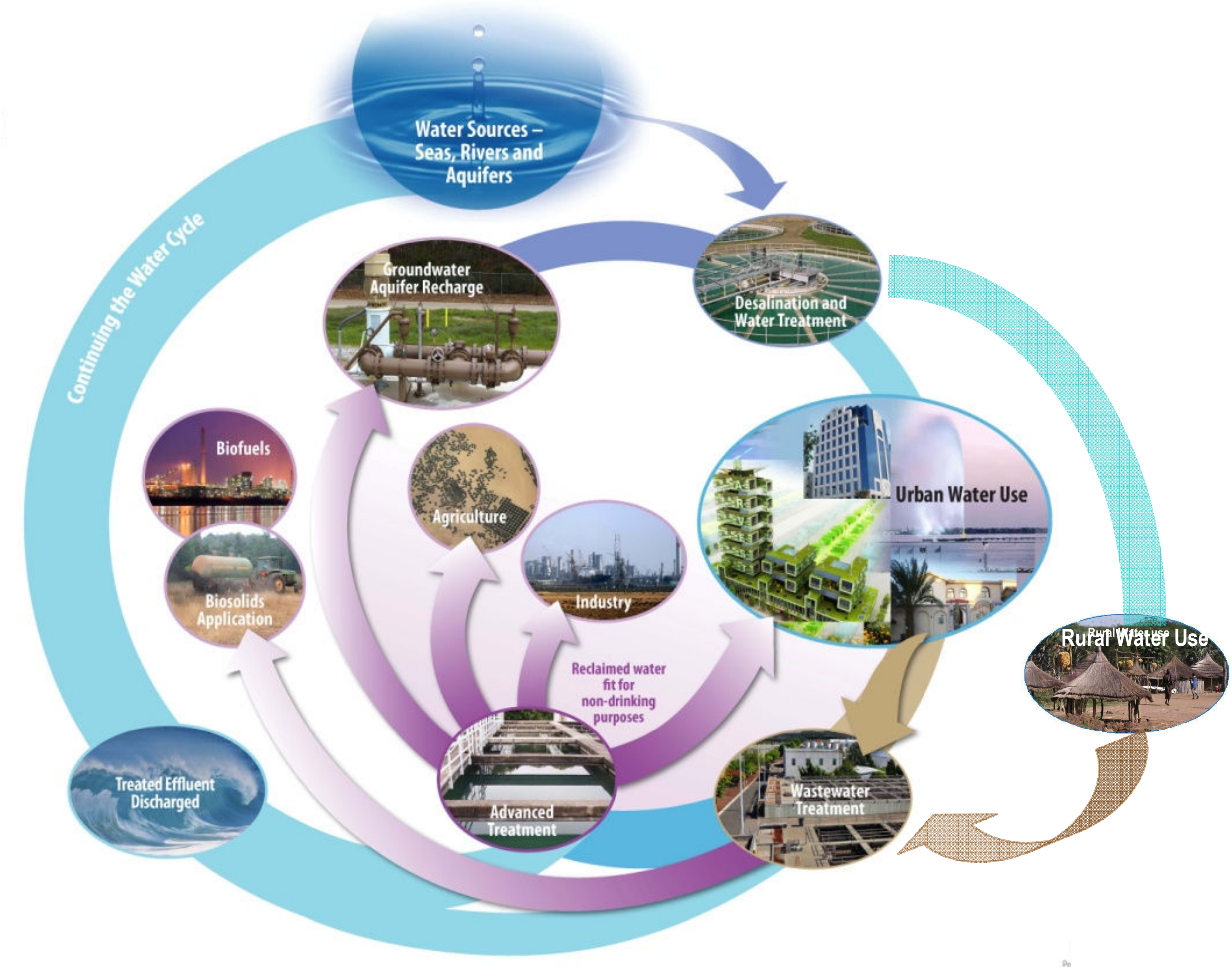

Figure 30: Recommended water cycle

The application of IWRM requires:

1. An enabling environment of appropriate policies and laws, where the governing authority acts as an enabler rather than a top-down manager.
2. Institutional roles and frame work, represented by all organizations and agencies across water-use sectors. It is essential of these institutional roles to discuss, plan, and act in coordination, realizing the participatory nature of the IWRM paradigm.
3. A set of management instruments, which are the practical tools through which the IWRM plans can be implemented. These include water resource assessments, development of River Basin Organisations (RBOs), incorporation of the stakeholders in decision-making, communication and information dissemination, ensuring financial sustainability, resource allocation and conflict resolution, regulatory instruments, and technology.

With this brief background in mind, while planning desalination projects for rural areas the following are to be considered.

- Desalination being a fairly costly source of fresh water, it is clear that consideration of desalination as an alternative source of water supply from the outset should be part of a comprehensive National IWRM plan. Desalination should only be considered after ensuring that good water management practices are followed on a national level, and properly managed conventional water resources are found to be insufficient. Contemplating construction of desalination plant to supply drinking water to a remote community that is exhausting its fresh groundwater resources on irrigation with low economic return shall be seriously reviewed with respect reallocation. Having said that, it is not uncommon in the case of arid rural and remote areas for the cost of water supply and transportation from conventional resources to be more expensive than desalination [14].
- Rational selection of desalination technology, whose operation during its life time is sustainable.
- While computing the life cycle fresh water production cost from desalination plants, other than desalination plant installation, operation and maintenance costs, the cost associated with raw water supply, pre-treatment, post treatment, brine disposal meeting Environmental Mitigation Plan (EMP) shall be taken in to account.
- Evaluation of the feasibility for rural and remote area desalination shall constitute a part of an integral approach that considers the specifics of each region and location in order to recommend the optimal approach or combination of approaches for each case. Thus, the opportunity cost of any proposed solution must be well understood and considered before a decision is made one way or the other. Moreover, the high cost involved in producing desalinated water, should encourage society and decision-makers to view the resulting wastewater as a valuable resource that should be recovered and re-used wherever possible.
- Water transportation is another area that should be carefully considered along with desalination, particularly if points of use are at higher altitude compared to points of production. Authorities need to consider the pumping cost.
- Thorough and rigorous EIAs are likely to prescribe several measures for mitigation of environmental impacts of desalination, such as a longer intake pipeline route with very low inlet velocity at the intake head and longer brine discharge pipeline route along with dilution and dispersion of brine in sea, chosen to avoid damage to a sensitive marine eco-system, to cite few examples. Potential environmental impacts are present in every phase of a desalination project [31]. Notably, the practice of IWRM offers the right opportunity and context for national and regional scale EIAs associated with increased desalination
- Considering the rapid pace of technology development, decision makers should also frequently perform updated evaluations and appraisals of the technologies that aim to extract value from desalination brine

streams. These include the extraction of valuable minerals, salt and the generation of power through electrochemical means or through available osmotic pressure differential.

- Though not specific only to desalinated water supply, priority to be given to arrest network leakages to conserve the water loss and make true assessment of available resources.

An ideal IWRM water policy should exhaust all opportunities to rearrange the bundles of water endowments among different users to attain **“win-win”** outcomes. For instance, a policy of re-cycling wastewater for irrigation could potentially leave both farmers and households better off and allow adequate water for the local wetlands and thus, be a "win-win" policy. Integrated water management can also open up possibilities for positive synergies between desalination and wastewater treatment. A good example of this is the Japanese *Water Plaza* project[32], which combines tertiary treated wastewater streams with SWRO feed to reduce the RO feed salinity, thereby reducing the energy required, as well as taking advantage of the availability of treated wastewater to reduce the size of the required SWRO pre-treatment system. A 30% improvement in energy efficiency is reported to have been achieved by this approach.

Finally, it should be highlighted that although the concept and principles of integrated water management are common, the strategies and tools may vary widely, even within the South Mediterranean region, according to the diverse socio-cultural, economic and environmental conditions of the involved countries.

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