

ROADMAP FOR THE DEVELOPMENT OF DESALINATION POWERED BY RENEWABLE ENERGY

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PRODES

PROMOTION OF RENEWABLE ENERGY FOR WATER
PRODUCTION THROUGH DESALINATION

Intelligent Energy  Europe

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EXECUTIVE SUMMARY

**ASSIST IN COORDI-
NATING AND GUIDING
THE RENEWABLE
ENERGY-DESALINA-
TION COMMUNITY**

The world water crisis is one of the largest public health issues of our time. One in eight people (884 million people) lack access to safe drinking water. The lack of clean, safe drinking water is estimated to kill almost 4,000 children per day. Many regions of the world are increasingly turning to desalination of brackish and sea water in their effort to match the increasing demand with the available natural resources. The trend is intensified by climate change, which seems to be already affecting the water cycle resulting in long periods of drought. The desalination industry has responded well to the increasing demand and is constantly evolving by reducing the costs and reliably producing water of very high quality. Most innovations focus on reducing the energy demand, since this is associated with high operating costs. However, desalination processes will always require considerable amounts of energy. If conventional energy sources are used, they contribute to climate change, which, in turn, affects the water cycle and intensifies the original problem that desalination was intending to solve.

For desalination to remain a viable option in a world with a changing climate, renewable energy sources have to be used to meet at least part of its power requirements. The scientific community has been working for decades on optimising technological combinations where the desalination process is powered directly by renewable sources; thermal energy, electricity or shaft power. The industry is also recognising the potential and various companies are active in this field.

This document has been developed within the ProDes project (www.prodes-project.org) with input from various key actors from the industry and academia. This roadmap is intended to assist in coordinating and guiding the renewable energy-desalination community in overcoming the barriers they are currently facing. The main elements of the Roadmap are summarised in a tabular format in the next pages, indicating the main barriers, their effects and the way forward.

BARRIER	EFFECT	STRATEGY
TECHNOLOGICAL		
<p>Most RE-D¹ are not developed as a single system but are combinations of components developed independently</p>	<p>→ Poor reliability → Increased water cost</p>	<ul style="list-style-type: none"> • Promote cooperation between companies from the energy sector, water sector and other specialists to achieve fully functional integrated products • Promote cooperation within the RE-desalination field for achieving R&D results that will benefit the whole sector • Support development of standardized, reliable and robust systems offering competitive performance guarantees
<p>Desalination development focuses on ever larger systems</p>	<p>→ Lack of components appropriate for small scale desalination plants, typical of many RE-D combinations</p>	<ul style="list-style-type: none"> • R&D of components suitable for the smooth and efficient coupling of the existing desalination and renewable energy technologies • Support development of elements that will make RE-desalination robust for long stand-alone operation in harsh environments
<p>Current desalination technology has been designed for use with a constant energy supply, however most RE provide variable energy supply</p>	<p>→ Increased capital and maintenance costs</p>	<ul style="list-style-type: none"> • Support development of components and control systems that allow desalination technologies to deal better with variable energy input, hybrid systems and energy storage to reduce variability • Support development of co-generation systems that produce water and power

RE-D¹ = RENEWABLE ENERGY DRIVEN DESALINATION

BARRIER	EFFECT	STRATEGY
ECONOMICAL		
Lack of comprehensive market analysis as to the size, locations and segments of the market	→ It is difficult to assess the risk and investors are reluctant to invest	<ul style="list-style-type: none"> • Support development of detailed and reliable market analysis
SMEs lack the financial resources and local know-how to enter distant markets	→ Difficulty to access some of the most promising niche markets	<ul style="list-style-type: none"> • Cooperation with agencies from EU countries in the target markets for organising trade missions • Facilitate collection and dissemination of relevant experiences and information in the RE-desalination community
The pricing structures and the subsidies of water supply create unfair competition	→ Investment in RE-D remains unprofitable even where it offers better value than the current solutions	<ul style="list-style-type: none"> • Promote pricing structures and subsidy allocations that let the market choose the most efficient solution and encourage efficiency in the use of the water, while ensuring global access to safe water • Campaign for inclusion of RE for desalination in national schemes that support RE electricity generation
Lack of identified niche markets with the ability to pay for the full cost of the systems, which would demonstrate the technology attracting additional customers	→ No cash is generated that could be used for further product development, reducing the costs and improving the performance	<ul style="list-style-type: none"> • Identify niche markets and use existing support programs in combination with financing schemes to help users that are willing and able to pay for the technology

BARRIER	EFFECT	STRATEGY
INSTITUTIONAL AND SOCIAL		
Negative perception of desalination by the population	→ Opposition of local communities to installation	<ul style="list-style-type: none"> • Support development and implementation of a long-term and consistent communication strategy by the RE-desalination community
RE-D is a new technology and is typically small-scale, suitable for community-led water provision	→ RE-D is not commissioned because water authorities prefer familiar technologies and want to keep centralized control	<ul style="list-style-type: none"> • Facilitate organization of seminars, debates and other events related to RE-desalination involving engineers and decision makers from large institutions responsible for water and energy in the target countries
Bureaucratic structures not tailored for independent water production; separation of energy and water policies	→ The cost and effort required to deal with the bureaucracy does not favor small companies	<ul style="list-style-type: none"> • Promote simpler and straightforward processes to obtain a license for independent water production • Lobby for greater cooperation between the power and water branches in governmental and non-governmental institutions
Lack of training and infrastructure	<ul style="list-style-type: none"> → Reduced plant availability → Lack of personnel for operation and maintenance 	<ul style="list-style-type: none"> • Support education and training at all levels
Cultural gap between project developers and the end-users	→ Projects fail for non-technological reasons like conflict about control	<ul style="list-style-type: none"> • Encourage adequate consideration of socio-cultural factors and establishment of communication channels with the end-users

The main targets, resources and activities require to follow-up the strategies that have been identified. The key recommendation is to formalise the RE-desalination community into a body that will represent the sector and will lobby for its interests. This body is mentioned as the "RE-Desalination Association" in this document and the target is to have it established before 2012 and to include at least 20 members. The other activities identified as priorities can be best carried out through the Association and include:

- Target a 3–5 % share of the new installations in the global desalination market by 2016
- Define the R&D priorities that will benefit the entire sector and promote these priorities to bodies that fund R&D, targeting R&D worth more than 100 million Euro in the period 2014 to 2020
- Support the wider establishment of RE-desalination education and training activities with the aim of reaching 2,000 students and 500 professionals per year within Europe by 2015
- Coordinate the development of a comprehensive market analysis on a country by country basis, covering the four most promising markets by 2014
- Develop and promote appropriate legal structures and policies on a country by country basis, starting with the four most promising markets by 2015
- Raise awareness about the technology and demonstrate its market potential

INTRODUCTION

The world water crisis is one of the largest public health issues of our time. One in eight people (884 million people) lack access to safe drinking water. The lack of clean, safe drinking water is estimated to kill almost 4,000 children per day¹. Part of this problem is caused by drought, which is expected to get worse in the future.

Research and development aiming to increase the energy efficiency of desalination and to power it with renewable energy is achieving important results. The coupling of renewable energy sources with desalination has the potential of providing a sustainable source of potable water, initially for end-users in arid areas with limited alternative solutions. In the long-term, it is aimed to power every new desalination plant with renewable energy sources.

Although interest in RE-desalination has been growing very fast, the applications so far are primarily pilot and demonstration systems. However, the rapid increase in fossil fuel costs and the increased concerns about climate change have intensified the interest in the use of alternative energy sources among the desalination community.

Clearly RE-desalination will be part of the water supply in the near future. The aim of this roadmap is to facilitate the development of the technologies in order to accelerate the transition and make it as smooth and efficient as possible, dealing with all technical, economical, social and environmental issues involved.

The RE-desalination Roadmap contains 5 chapters. Chapter 1 presents the state of the art of RE-desalination. Chapter 2 discusses the potential to gain a share of the water supply market. In chapter 3 the barriers to the development of the technology are outlined, including the technological, economical, institutional and social issues. The fourth chapter proposes strategies to overcome these barriers. Finally chapter 5 specifies the resources and activities needed for the implementation of the proposed strategy.

1. STATUS OF THE RE-DESALINATION TECHNOLOGY

MOST TECHNOLOGIES HAVE ALREADY BEEN TESTED EXTENSIVELY

1.1 INTRODUCTION

There is a wide variety of technological combinations possible between desalination technologies and renewable energy sources. Table 1.1 provides an overview of the possible combinations; however not all of these combination have been tested yet under real conditions.

In this chapter a brief presentation of the most important combinations is given. More detailed information can be found in several other reviews that are evaluating the status of renewable energy driven desalination, like the one by Lourdes², or by Mathioulakis³. One of the most complete overviews published so far, including detailed technical explanations of the main RE-

desalination combinations, can be found in the "Desalination Guide Using Renewable Energies"⁴. Although this publication is now more than 10 years old, it remains relevant and very useful. In particular, pages 34–52 describe the technologies and give guidelines for their selection depending on the size, framework, conditions and purpose of the application.

The ProDes Project, based on the work of the project ADU-RES⁵, updated the information collection on installed RE-desalination plants. In total 131 representative plants have been included, which were installed between 1974 and 2009. Some of them were installed as pilot installations and have been dismantled after some years of operation, but most of the installations are providing drinking water and are used by the local

	SOLAR				WIND		GEOHERMAL		OCEAN POWER		
	THERMAL COLLECTORS	CSP		PV	MECHANICAL	ELECTRICAL	THERMAL	ELECTRICAL	ELECTRICAL	MECHANICAL	THERMAL
		THERMAL	ELECTRICAL								
SD	•										
MEH	•	•					•				•
MD	•	•					•				•
TVC		•					•				•
MSF		•					•				
MED	•	•					•				•
ED			•	•	•			•	•		
MVC			•	•	•	•		•		•	
RO			•	•	•	•		•		•	

↑ TABLE 1.1: POSSIBLE COMBINATIONS OF RENEWABLE ENERGY WITH DESALINATION TECHNOLOGIES

populations. The full list with the plants included in this survey is available at the project website (www.prodes-project.org).

Figure 1.1 shows the technology combinations used in the identified installations, with PV-RO being the most commonly used technology. Solar stills, included under "others", are a simple small-scale technology used broadly worldwide. This technology is not mentioned much in industry reviews or papers and therefore is probably under-represented in this review.

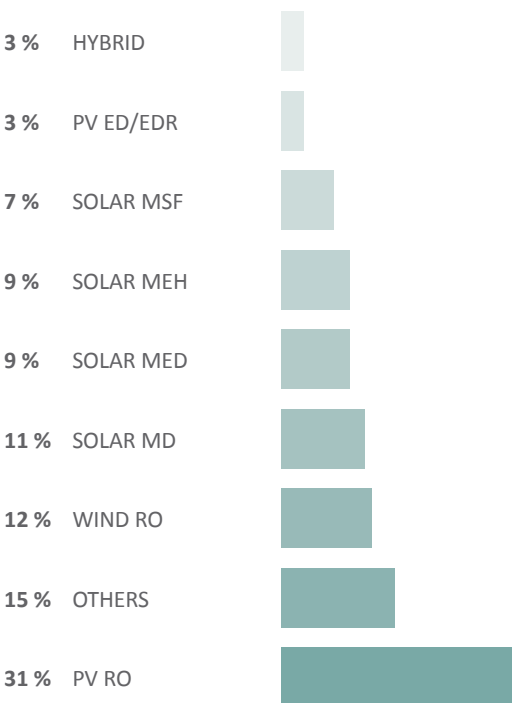


Table 1.2 presents an overview of the most common or promising RE-desalination technologies, including their typical capacities, their energy demand, the estimated water generation cost and the development stage. Most technologies have already been tested extensively and the water generation costs are estimated based on operational experience and real data. However, the practical experience with CSP-MED and Wave-RO is limited; therefore the stated costs reflect technology developers' assessments of the technology when fully developed.

In this chapter the main technology combinations are briefly presented, grouped under the renewable energy source that drives the process. The desalination processes are explained in the sections where they are first mentioned. Only technologies that have been tested in pilot plants are included here. Other interesting concepts for the future like solar freezing, forward osmosis and vacuum distillation are outside the scope of this document.

← FIGURE 1.1: TECHNOLOGY COMBINATIONS OF 131 RE-DESALINATION PLANTS REVIEWED IN 2009

	TYPICAL CAPACITY	ENERGY DEMAND	WATER GENERATION COST	TECHNICAL DEVELOPMENT STAGE
SOLAR STILL	< 0.1 m ³ /d	solar passive	1–5 €/m ³	applications
SOLAR MEH	1–100 m ³ /d	thermal: 100 kWh/m ³ electrical: 1.5 kWh/m ³	2–5 €/m ³	applications/ advanced R&D
SOLAR MD	0.15–10 m ³ /d	thermal: 150–200 kWh/m ³	8–15 €/m ³	advanced R&D
SOLAR/CSP MED	> 5,000 m ³ /d	thermal: 60–70 kWh/m ³ electrical: 1.5–2 kWh/m ³	1.8–2.2 €/m ³ (prospective cost)	advanced R&D
PV-RO	< 100 m ³ /d	electrical: BW: 0.5–1.5 kWh/m ³ SW: 4–5 kWh/m ³	BW: 5–7 €/m ³ SW: 9–12 €/m ³	applications/ advanced R&D
PV-EDR	< 100 m ³ /d	electrical: only BW: 3–4 kWh/m ³	BW: 8–9 €/m ³	advanced R&D
WIND-RO	50–2,000 m ³ /d	electrical: BW: 0.5–1.5 kWh/m ³ SW: 4–5 kWh/m ³	units under 100 m ³ /d BW: 3–5 €/m ³ SW: 5–7 €/m ³ about 1,000 m ³ /d 1.5–4 €/m ³	applications/ advanced R&D
WIND-MVC	< 100 m ³ /d	electrical: only SW: 11–14 kWh/m ³	4–6 €/m ³	basic research
WAVE-RO	1,000–3,000 m ³ /d	pressurised water: 1.8–2.4 kWh/m ³ electrical: 2.2–2.8 kWh/m ³	0.5–1.0 €/m ³ (prospective cost)	basic research

↑ TABLE 1.2: POSSIBLE COMBINATIONS OF RENEWABLE ENERGY WITH DESALINATION TECHNOLOGIES

SOLAR ENERGY CAN BE USED DIRECTLY ... OR INDIRECTLY

1.2 SOLAR THERMAL ENERGY

Solar energy can be used directly as in the case of the solar still, or indirectly by using solar thermal collectors connected to a desalination plant. There are several possible configurations, which are described in this section depending on the different desalination technologies used.

1.2.1 SOLAR STILL/S/ SOLAR DISTILLATION (SD)

The solar still is a very old concept. Today it is attractive in areas where the land is cheap, because large areas are required to produce relatively small amounts of water. The solar still is basically a low-tech "greenhouse" providing simplicity of construction and maintenance.

The principle of operation is simple, based on the fact that glass or other transparent materials have the property of transmitting incident short-wave solar radiation. The incident solar radiation is transmitted through the transparent cover and is absorbed as heat by a black surface in contact with the salty water to be distilled. The water is thus heated and evaporates partially. The vapour condenses on the glass cover, which is at a lower temperature because it is in contact with the ambient air, and runs down into a groove from where it is collected. Well-designed units can produce 2.5–4 l/m² per day.



↑
TECHNOLOGY: SIMPLE SOLAR STILL
PRODUCT: WATER CONE
ENERGY SOURCE: SOLAR THERMAL ENERGY
DAILY CAPACITY (NOMINAL): 1.5 LITER
YEAR OF INSTALLATION: 2007
TYPE OF INSTALLATION: COMMERCIAL
LOCATION: YEMEN

Beside the simple solar still, alternative systems and configurations have been developed to increase the productivity or simplify the production. Multiple effect basin stills have two or more compartments for recovering part of the condensing heat to warm up the water in an upper compartment. In wick stills the basin is tilted and the salty water is fed into the basin via wicks. Active solar stills are coupled to flat plate solar collectors and can be driven both directly and indirectly and optionally with a heat exchanger.^{6/7/8}

An example is the thermal desalination unit with a heat recovery system from the Solar-Institut Jülich. The energy demand for the production of 1 m³ of fresh water is reduced to approximately 200 kWh due to the use of several stages in which the water is evaporated with the latent heat of each previous stage. About 15 to 18l of distillate can be produced per square meter collector area per day. This technology was developed for capacities between 50 and 5,000 l per day⁹.



↑
TECHNOLOGY: MULTI EFFECT SOLAR BASINS
ENERGY SOURCE: SOLAR THERMAL ENERGY
WATER SOURCE: BRACKISH WATER
DAILY CAPACITY (NOMINAL): 15-18 LITER/M²
YEAR OF INSTALLATION: 2005
TYPE OF INSTALLATION: R&D
LOCATION: GRAN CANARIA
INSTALLED BY: SOLAR-INSTITUT JÜLICH

One of the biggest solar still plants was installed in 1967 on the island of Patmos in Greece. The solar still had an area of 8,640 m² and was desalinating seawater with a production capacity of 26 m³/day. Long lasting solar stills have been built, at current prices, for a unit cost of US\$ 50–150 /m².¹⁰

The main potential for technical improvements is to be found in reducing the cost of materials. Increased reliability and better performing absorber surfaces would slightly increase production per m².

1.2.2 MULTIPLE EFFECT HUMIDIFICATION (MEH)

Multiple Effect Humidification systems use heat from highly efficient solar thermal collectors. They induce multiple evaporation and condensation cycles inside thermally isolated, steam-tight containers and require temperatures of between 70 and 85 °C. By solar thermally driven humidification of air inside the box, water-vapour and concentrated salt solution are separated, because salt and dissolved solids from the fluid are not carried away by vapour. During re-condensation of the generated saturated humid air, most of the energy used before for evaporation is regained and can be used in subsequent cycles of evaporation and condensation, which considerably reduce the thermal energy input required for desalination. The thermal efficiency of the solar collector is much higher

than for solar stills and the specific water production rate is between 20 to 30 litres per m² absorber area per day.



↑
TECHNOLOGY: MULTIPLE EFFECT HUMIDIFICATION
PRODUCT: MIDI-SAL™5000
ENERGY SOURCE: SOLAR THERMAL ENERGY / PV
WATER SOURCE: BRACKISH-WATER
DAILY CAPACITY (NOMINAL): 5000 LITER
YEAR OF INSTALLATION: 2008
TYPE OF INSTALLATION: COMMERCIAL
LOCATION: JEDDAH, SAUDI ARABIA
INSTALLED BY: MAGE WATER MANAGEMENT

1.2.3 MEMBRANE DISTILLATION (MD)

Membrane distillation is a separation technique which joins a thermally driven distillation process with a membrane separation process. The thermal energy is used to increase the vapour pressure on one side of the membrane. The membrane is permeable for vapour but not for water, so it separates the pure distillate from the retained solution. MD offers significant advantages for the construction of stand-alone desalination systems which are driven by solar energy or waste heat. MD is typically ope-

rated at a temperature of 60–80 °C. Due to the nature of the hydrophobic membrane it is less sensitive to biofouling and scaling compared to other thermal desalination technologies. The process itself does not need a constant operation point, as opposed to MED or MSF. This makes it attractive for intermittent energy supplies like the use of solar energy without heat storage.

The Swedish company Scarab Development provides flat plate MD-modules. Production ratios of 12 to 20 kg/h are reported for high temperature gradients across the membrane¹¹. Within the framework of the MEDESOL project the SCARAB module is currently being tested with a solar energy supply¹².

Today's largest MD-system is the MEMSTIL system, developed by TNO in the Netherlands. The MD-modules are of flat plate type. Pilot plants have been installed by the Kepel Seghers Company in Singapore and by Eon in Rotterdam. The design capacities of the waste heat-driven units are 80 and 50 m³/day, respectively¹³. Solar applications of MEMSTIL are not known.

Since 2001, the Fraunhofer Institute for Solar Energy Systems and SolarSpring GmbH have been developing autonomous solar thermally driven Membrane Distillations units for remote areas. Two different system designs (Compact System and Two-Loop System) are available. Nine compact systems for fresh water capacities up to

150 l/day and 2 two-loop systems (1x 1000 and 1x 1600 l/day) with an integrated heat storage system for a 24h-operation have been installed at different test sites. The first system was installed in Gran Canaria, Spain in 2004 and is still in daily operation. In 2010 it is foreseen to install a 100% solar driven system, and also a hybrid system (solar and waste heat) with a capacity of 5 m³/d.



↑
TECHNOLOGY: MEMBRANE DISTILLATION
PRODUCT: ORYX150
ENERGY SOURCE: SOLAR THERMAL ENERGY / PV
WATER SOURCE: SEAWATER (BANK FILTRATE)
DAILY CAPACITY (NOMINAL): 150 LITER
YEAR OF INSTALLATION: 2007
TYPE OF INSTALLATION: COMMERCIAL
LOCATION: TENERIFE, SPAIN
INSTALLED BY: SOLARSPRING GMBH

1.2.4 MULTIPLE EFFECT DISTILLATION (MED)

The MED process has been used since the late 1950s and early 1960s. Multi-effect distillation occurs in a series of vessels (effects) and uses the principles of evaporation and condensation at reduced ambient pressure. In a MED plant, a series of evaporator effects produce water at progressively lower pressures. Water boils at lower temperatures as pressure decreases, so the water vapor of the first vessel or effect serves as the heating medium for the second, and so on. The more vessels or effects there are, the higher the performance ratio. The number of effects is limited to 15–20, however, depending on the process configuration due to practical and economical reasons.

During the 1990's at the Plataforma Solar de Almería (Spain), a parabolic-trough solar field was coupled with a conventional MED seawater distillation unit (14-cell forward-feed vertically-stacked unit with capacity 72 m³/

day), optimizing the overall heat consumption of the system by the incorporation of a double effect absorption (LiBr-H₂O) heat pump. In the context of EU project AQUASOL (2002–2006), the MED plant was connected to a 500 m² stationary CPC (compound parabolic concentrator) solar collector field which supplied heat at medium temperature (60–90 °C) and a new prototype of double-effect absorption heat pump was developed. Operation and maintenance was proven to be highly reliable as no major problem was observed during the tests.



←
TECHNOLOGY: SOLAR MED
ENERGY SOURCE: SOLAR THERMAL ENERGY (CPC COLLECTORS)
DAILY CAPACITY (NOMINAL): 72M³/D
YEAR OF INSTALLATION: 2005
TYPE OF INSTALLATION: R&D
LOCATION: ALMERIA, SPAIN
INSTALLED BY: PLATAFORMA SOLAR DE ALMERIA; AQUASOL PROJECT

THE INTEGRATION OF CSP AND DESALINATION MAKES THE SOLAR POWER CONCEPT FULLY SUSTAINABLE

1.3 CONCENTRATED SOLAR POWER

Megawatt scale solar power generation using Concentrating Solar Power (CSP) technology can be achieved by using any one of the four basic configurations: central receivers, parabolic troughs, parabolic dishes and linear Fresnel systems. All of these configurations are based on glass mirrors that continuously track the position of the sun to attain the desired concentration ratio. The concentrated sunlight is absorbed and the heat is transferred to a power cycle where high-pressure, high temperature steam is generated to drive a turbine in a conventional power cycle.

Recently, direct steam generation in the parabolic troughs has been used for power production. CSP is already in use in countries such as the US and Spain with more than 180 MW production plants currently installed and more than 1500 MW under construction. The overall objective for CSP in MENA (Middle East and North African) countries is to cover 14% of the electricity demand by 2025 and 57% by 2050 at an estimated cost in the range of 8–15 Euro-cent/kWh.

Several configurations are possible for CSP-desalination plants: (i) multi-stage flash (MSF) distillation units opera-

ting with steam extracted from steam turbines or supplied directly from boilers; (ii) low-temperature multi-effect distillation (MED) using steam extracted from a turbine and; (iii) seawater reverse osmosis (RO) desalting units supplied with electricity from a steam power plant or from a combined gas/steam power cycle.

The concept is of special interest for large CSP plants deployed in deserts to generate electricity. By making use of the salt water availability in these regions, the large quantities of fresh water needed for operation can be generated. For a concentrating solar thermal collector array, the land required to desalinate 1 billion m³/year is approximately 10 km x 10 km in the MENA region. This translates to about 27 l/day of desalinated water per square metre of collector area.

CSP plants need large amounts of fresh water for their operation. The integration of CSP and desalination makes the solar power concept fully sustainable, as it can provide fresh water for its own cooling system and the mirror cleaning. One of the most interesting configurations for CSP+D plants is the integration of an MED unit to replace the conventional water cooling system used to condense the exhaust steam. PSA-CIEMAT is currently studying the different configurations possible for coupling an MED plant to a solar thermal power plant. An installation is being built to connect an existing MED with CSP. They plan to have the test bed ready in summer 2010.

1.3.1 MULTI STAGE FLASH (MSF)

The process involves the use of distillation through several (multi-stage) chambers to obtain vapour free of salts. In the MSF process, each successive stage of the plant operates at progressively lower pressures. The feed water is first heated by steam extracted under high pressure from the CSP turbine (max. 120°C). The steam is directed into the first "flash chamber", where the pressure is released, causing the water to boil rapidly resulting in sudden evaporation or "flashing". This "flashing" of a portion of the feed continues in each successive stage, because the pressure at each stage is lower than in the previous stage. The vapour generated by the flashing is converted into fresh water by condensation taking place on the heat exchanger tubing that runs through each stage. The tubes are cooled by the incoming feed water. Generally, only a small percentage of the feed water is converted into vapor and condensed.

Conventional Multi-stage flash distillation plants have been in use since the late 1950s. Some MSF plants contain 15 to 25 stages and have either a "once-through" or "recycled" process. In the "once-through" design, the feed water is passed through the heater and flash chambers just once and disposed of. In the recycled design, the feed water is reused. In the 80's several solar-driven MSF plants have been built for testing purposes.

WATER COST IS DISPROPORTIONALLY HIGHER FOR SYSTEMS WITH CAPACITIES BELOW 5M³/DAY

1.4 SOLAR PHOTOVOLTAIC

1.4.1 PHOTOVOLTAIC-DRIVEN REVERSE OSMOSIS (PV-RO)

The PV-RO system consists of a photovoltaic field that supplies electricity to the desalination unit through a DC/AC converter and a RO membrane for the desalination. During the RO process salt water is pressurized against a membrane. The membrane only allows water to pass, the salt remains on the other side. For stand-alone operation,

a set of batteries is used for storage. As a result, the number of daily operating hours is increased. This technology has been widely tested and also been installed to supply water in rural areas in developing countries, for example, in Tunisia^{14/15}, Morocco and other Mediterranean countries¹⁶.

Investment costs are relatively high, as is the case with most RE-desalination technologies, resulting in specific cost of drinking water in the range of 3.5–7 €/m³ for brackish and 9–12 €/m³ for seawater RO units. The water

cost is disproportionately higher for systems with capacities below 5 m³/day. Despite these high costs compared to conventional large scale desalination plants, this solution is economically feasible in remote locations where the alternatives are limited and also expensive.

Both PV and RO are mature technologies, with a large list of suppliers in many countries. Moreover, there are intensive R&D efforts to increase the PV conversion efficiency and improve the RO process. Also innovative combination topologies of PV-RO have been investigated over the last 3–4 years¹⁷. Therefore, it is expected that costs of PV-RO systems will be reduced significantly in the future.

1.4.2 PHOTOVOLTAIC-DRIVEN ELECTRODIALYSIS (PV-ED/PV-EDR)

Salt water contains ions. These ions are attracted to either positive or negative charges. This fact is utilized for the electro dialysis (ED) process. A series of membranes are installed in a unit. These membranes are selective in that either only anions or cations are allowed to pass through them. The two types of different membranes are installed alternately. One side of the unit is connected to a positive pole and the other to a negative pole. As water streams through the channels created by the membranes, the anions are attracted by the positive pole and pass through the anion selective membrane. The cation

selective membrane, however, serves as a barrier and the anions remain in the channel they are in. The process is the same for the cations but towards the negative pole. In all, two types of channels are formed: one type with cations and anions and one type with fresh water. Electro dialysis Reversed (EDR) operates with the same principle as ED except for the fact that the polarity of the poles is reversed several times an hour. The reversal is useful in breaking up and flushing out scales, slimes and other deposits. The advantage of combining ED with PV, compared to RO with PV, is that no inverter is needed, because ED works with direct current.

Little experience exists using these kinds of systems with renewable energy (RE). Only a few pilot units for R&D purposes are in operation. 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.



↑
TECHNOLOGY: PV-RO
ENERGY SOURCE: SOLAR PHOTOVOLTAIC
WATER SOURCE: BRACKISH WATER
HOURLY CAPACITY (NOMINAL): 2.100 LITER
YEAR OF INSTALLATION: 2006
TYPE OF INSTALLATION: COMMERCIAL
LOCATION: KSAR GHILÈNE, TUNISIA
INSTALLED BY: CANARY ISLANDS INSTITUTE OF TECHNOLOGY (ITC)

AUTONOMOUS WIND-DRIVEN DESALINATION SYSTEMS ARE PARTICULARLY INTERESTING IN REMOTE WINDY AREAS AND ESPECIALLY ON SMALL ISLANDS

1.5 WIND ENERGY

Wind energy technology can be scaled-up easier than PV so many options can be considered. There is not so much experience in off-grid wind systems coupled to a desalination unit, since it is much easier and more economical to connect both the desalination plant and the wind farm to the grid. Nevertheless, autonomous wind-driven desalination systems are particularly interesting in remote win-

dy areas and especially on small islands, where the wind power penetration to the grid is limited by the stability criteria of the electricity grid.

1.5.1 WIND-DRIVEN REVERSE OSMOSIS (WIND-RO)

Wind energy has been used as power supply for desalination systems, mostly for reverse osmosis systems.

In this case a wind generator is coupled to a RO plant with a buffer and batteries as a back-up.

The highly fluctuating wind power requires a control system which fits the available wind to the energy requirements and restricts or dumps the surplus wind energy accordingly in order to achieve a stable operation. The experience with a 2 x 230 kW off-grid wind farm connected to 8 x 25 m³/day SWRO units, tested within the framework of an EU project (JOULE III program) serves as one example. The wind system included a 100 kVA synchronous machine – flywheel to power the isolated grid and to stabilize the frequency and a 7.5 kW UPS. A double



control system (wind generators and loads) was used to continuously balance the instantaneous power¹⁸.

Cost of water produced by wind-powered RO systems ranges from 3–7 €/m³ for small RO plants (less than 100 m³/day), and is estimated at 1.50–4 €/m³ for medium capacity RO units (1,000–2,500 m³/day).

1.5.2 WIND-DRIVEN MECHANICAL VAPOUR COMPRESSION (WIND-MVC)

Vapour compression (VC) units have been built in a variety of configurations. Usually, a mechanical compressor is used to compress vapour, which generates heat. This heat is used for evaporation. Mechanical vapour compression (MVC) coupled to wind systems have also been analysed, but further development is needed. VC has to operate at certain temperatures: 100°C for atmospheric pressure or 60°C at 80% of vacuum (0.2 bar). Thus, the system requires a minimum amount of time to achieve operating conditions, as well as to continuously maintain those conditions. Fast scaling generation was detected during frequent stops, which is a usual situation under the variable power supply of an autonomous wind system¹⁹.

←
TECHNOLOGY: REVERSE OSMOSIS
ENERGY SOURCE: 2 STAND ALONE WIND TURBINES
WATER SOURCE: SEAWATER
HOURLY CAPACITY (NOMINAL): 8 M³
INSTALLED BY: CANARY ISLANDS INSTITUTE OF TECHNOLOGY (ITC)

**THERMAL DISTILLATION
TECHNIQUES BASED
ON DIRECT HEATING ...
WILL BE THE METHOD
OF CHOICE IN MOST
GEOHERMAL
DESALINATION PLANTS**

1.6 GEOTHERMAL

Different types of geothermal energy sources exist. These are classified in terms of the measured temperature as follows: 1) low ($< 100^{\circ}\text{C}$), 2) medium (100°C – 150°C) and 3) high temperature ($> 150^{\circ}\text{C}$). Geothermal energy can be directly used in combination with MED, MEH, TVC and MD (low temperature) or with MSF (medium temperature). Moreover, thermal energy conversion into shaft power or electricity would permit the coupling with other desalination systems like RO, ED and MVC.

The first desalination plant powered by geothermal energy was constructed in Holtville, USA in 1972 by the United States Department of the Interior, Bureau of Reclamation. Two more geothermal powered distillation plants have been installed in France and in southern Tunisia. Both of them use evaporators and condensers of polypropylene with operation temperature range of 60°C – 90°C .²⁰

During the 1990s a research project in the Milos Island in Greece demonstrated that it is technically feasible to utilize low enthalpy geothermal energy for electricity generation and seawater desalination. In 2000, a pilot geothermal MED plant producing $80\text{ m}^3/\text{day}$ was installed in Kimolos Island by CRES. It operates at 61°C with a 2-stage MED unit.

At sites where drinking water is scarce and geothermal sources with temperatures of 80 – 100°C exist, such systems

can be developed at acceptable costs ($< 7.5\text{ €/GJ}$ and $< 2.2\text{ €/m}^3$), and one can consider the option of geothermal desalination. For reservoirs with higher temperatures, there is also the option to generate power for use in a desalination plant.

It is recognized that there is significant potential to improve desalination systems based on geothermal energy. Thermal distillation techniques based on direct heating from geothermal energy will be the method of choice in most geothermal desalination plants.²¹

BASED ON THE DIRECT PRESSURISATION OF SEA WATER

1.7 OCEAN POWER

1.7.1 WAVE ENERGY DRIVEN RO AND MVC

Wave energy, in general, and wave-powered desalination technologies, in particular, are still in the prototype stages. One of the most obvious combinations for RE-desalination is wave power coupled with desalination because, in most cases, the two main components of (wave) energy and (sea) water are available in abundance and at the same location.

All of the wave-powered desalination plants built as prototypes up to now use reverse osmosis for the desalination process²². The reverse osmosis plants are powered either by electricity generated by a wave energy plant or directly

by using sea-water pressurised by the action of the waves. A plant using mechanical vapour compression (MVC) has also been proposed, but no prototype has yet been built.

The current wave-powered desalination technologies are based on modifications of wave energy technologies designed for electricity production. Therefore, they are typically relatively large with unit capacities in the range of 500–5,000 m³/day. Thus, the primary target of wave-powered desalination plants is municipal-scale water production. The co-generation of fresh water and electricity by wave power is also being actively developed. While smaller desalination units (less than 500 m³/day) are technically feasible, the development effort for the smaller capacity units is modest at present.



↑
TECHNOLOGY: REVERSE OSMOSIS
PRODUCT: OYSTER
ENERGY SOURCE: WAVE POWER
WATER SOURCE: SEAWATER
DAILY CAPACITY (NOMINAL): 3000M³
YEAR OF INSTALLATION: -
TYPE OF INSTALLATION: R&D

Developers of wave-powered desalination technology currently include:

- Aquamarine Power Ltd - Oyster® desalinator technology
- Carnegie Corporation Ltd – CETO desalinator technology
- Oceanlinx Ltd – OWC desalinator technology

All three of these technologies are based on the direct pressurisation of sea water (avoiding the generation of electricity) that is then fed into a reverse osmosis desalination plant to produce fresh water. The DUCK plant, in development by

the University of Edinburgh, uses MVC to produce fresh water. At present, there is no commercial development of this technology.

1.7.2 OCEAN THERMAL ENERGY CONVERSION (OTEC)

Another source of ocean power is called Ocean Thermal Energy Conversion (OTEC). It makes use of the temperature difference between the water surface and deep sea layers. OTEC is a low grade thermal source of energy and so most suited to distillation processes. A prototype of an OTEC desalination plant has been built in India, but it is no longer in operation due to failure of the pipe accessing the deep sea-layers. Research in OTEC-desalination continues in Japan, India and Mexico.

The final major source of ocean energy is tidal energy, which can be extracted using tidal barrages or tidal turbines. Currently, no consideration has been given to coupling this technology with desalination technologies. It is expected to face similar challenges as wind-powered desalination since in both cases the generating mechanism is a rotating shaft.

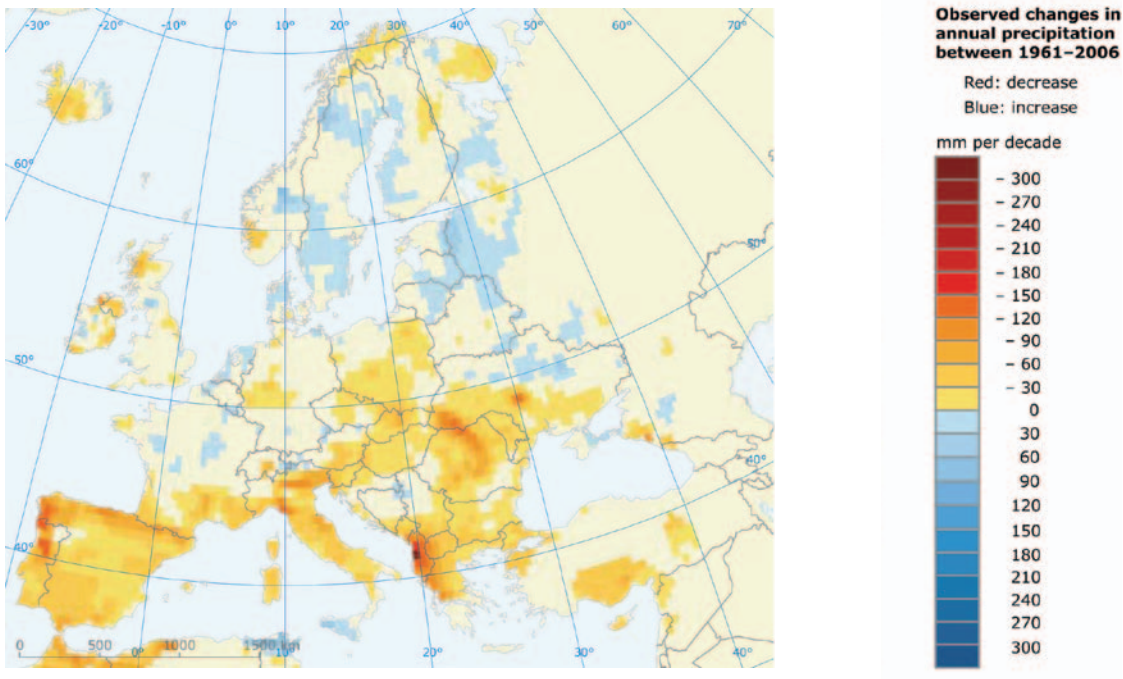
2. PERSPECTIVES OF RE-DESALINATION

**BALANCE BETWEEN
WATER DEMAND AND
AVAILABILITY HAS
REACHED A CRITICAL
LEVEL**

2.1 WATER CRISIS

The balance between water demand and availability has reached a critical level in many areas of Europe and throughout the world in general. This is the result of over-abstraction and prolonged periods of low rainfall or drought in combination with ever increasing demand. Where the water resources have already diminished, a deterioration of the water quality has normally followed since there has been increasingly less water to dilute pollutants. In addition, seawater often intrudes into "over-pumped" coastal aquifers.

Climate change will exacerbate these adverse impacts in the future, with more frequent and severe droughts expected across southern Europe²⁴. For the years between 1961 and 2006, these effects are already apparent as shown in figure 2.1. The trend of reduced precipitation in the Mediterranean is clearly shown. Climate models predict a future increase in precipitation in northern Europe and a decrease in southern Europe, with particularly dry summers.



↑
FIGURE 2.1: CHANGES IN ANNUAL PRECIPITATION 1961–2006²³

IT IS FORECASTED THAT THIS CAPACITY WILL MORE THAN DOUBLE BY 2016

2.2 THE GLOBAL DESALINATION MARKET

The Mediterranean region, affected by the water crisis described in section 2.1, is currently one of the fastest growing desalination markets. Spain is the largest user of desalination technologies in the western world. Globally, it ranks fourth behind Saudi Arabia, the United Arab Emirates and Kuwait. It ranks first in the use of desalinated water for agriculture. Its 700 plants produce some 1.6 million m³/day, enough for 8 million people²⁵. Other Mediterranean countries also rely increasingly on desalinated water as an additional resource for public water supply and to support holiday resorts in arid areas. Malta, for example, relies on desalination for 57% of its water supply. Desalination also started appearing in regions not normally regarded as arid; London's water utility Thames Water is currently investing €300 million to build the region's first desalination plant. Several market studies for desalination have already been

made. The GWI for example has currently made a report on the water sector of 49 countries including desalination: "The Global Water Market 2011 – Meeting the world's water and wastewater needs until 2016."

According to Global Water Intelligence²⁶, the capacity of operating plants around the world was estimated at 52 million m³/d in 2008. It is forecasted that this capacity will more than double by 2016 reaching 107 million m³/d. The expected growth over that 8 year period is estimated to be worth \$64 billion.

The commercial water supply is not the only market for desalination technologies. Purified water is also needed for boilers used in industrial processes. The water is often produced on-site through desalination technologies, which can be partially powered from the heat of the boiler in a semi-closed loop. Also increasingly more food and drink processing plants are using desalinated water (RO) to get a consistent water quality.

WATER COSTS TYPICALLY INCREASE WITH DECREASING PRODUCTION CAPACITY

2.3 THE STATUS OF RE-DESALINATION

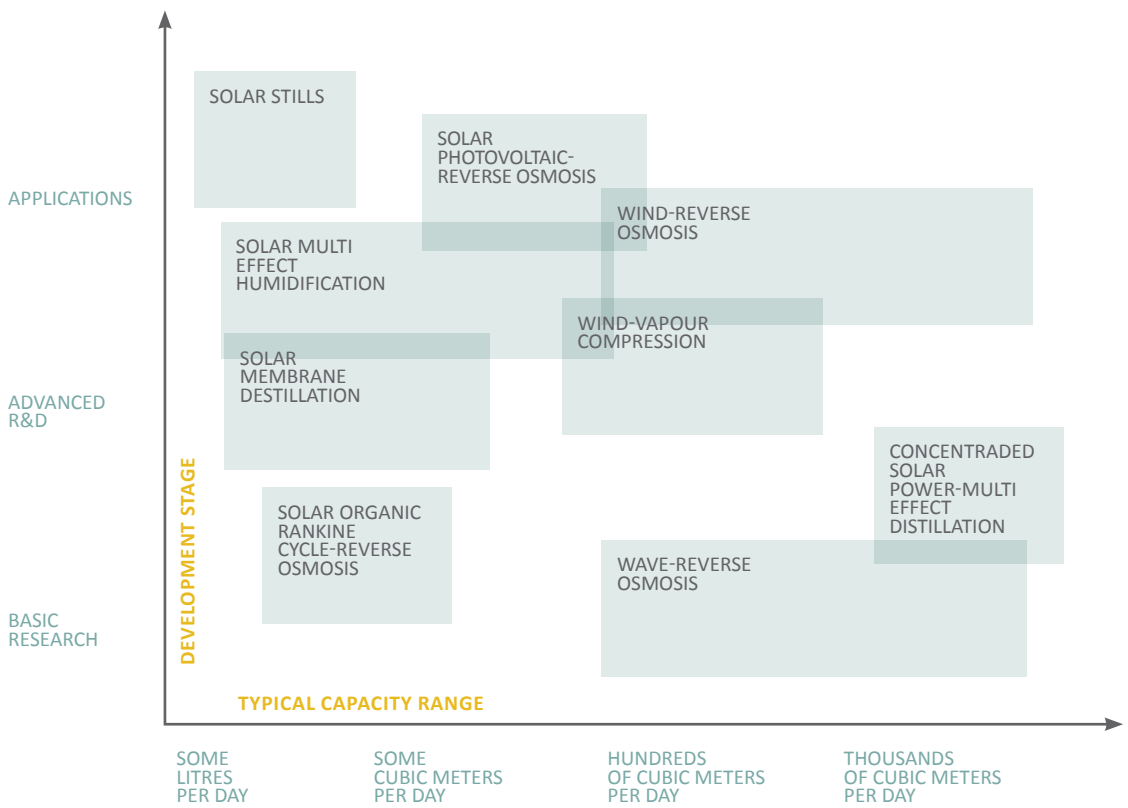
Desalination powered by renewable energy is a very wide field that includes many technologies at various stages of technological development, each addressing different market segments. In chapter 1 the different technologies were presented. Figure 2.2 illustrates the development stage and the typical capacity range of some common RE-desalination technology combinations.

The figure does not reflect the cost of the technologies. It does show how much research has been performed and the improvement potential of the technologies. Furthermore, it gives an overview about the typical capacity range rather than the technically possible capacity range.

The difference in technological maturity compared to conventional desalination is reflected by the cost of the pro-

duced water. Typical costs for conventional technologies are about 1 €/m³ depending on the plant size, technology and raw water quality. However, water costs typically increase with decreasing production capacity. The cost of water from RE-desalination ranges from 1.5 €/m³ to more than 30 €/m³, depending on the technology used, the salinity of the feed water and several other site specific factors like the renewable energy potential.

In the literature, several different figures are given for the cost of each technological combination. These are calculated from pilot or demonstration systems. However, the costs of these installations are greatly affected by the size and the local conditions. Also, the methodologies used to calculate these costs and the assumptions made vary considerably. Therefore, these figures are not directly comparable.



↑ FIGURE 2.2: DEVELOPMENT STAGE AND CAPACITY RANGE OF THE MAIN RE-DESALINATION TECHNOLOGIES

The following table shows the results of a recent theoretical calculation²⁷ and gives an idea about the average costs of

some technological combinations. All calculations have been made with a lifetime of 20 years and an interest rate of 7%.

COMBINATION	COST (€/m ³)	ASSUMPTIONS
Off-grid wind powered-seawater RO systems	1.07	<ul style="list-style-type: none"> Nominal capacity: 1,000 m³/d Number of annual operation hours: 5,200 Specific energy consumption: 3.3 kWh/m³
Seawater PV-OR	11.81	<ul style="list-style-type: none"> Nominal capacity: 100 m³/d Number of annual operation hours: 3,000 Specific energy consumption: 6 kWh/m³
Brackish water PV-RO	8.29	<ul style="list-style-type: none"> Nominal capacity: 100 m³/d Number of annual operation hours: 3,000 Specific energy consumption: 1.6 kWh/m³
Brackish water PV-EDR	8.47	<ul style="list-style-type: none"> Nominal capacity: 100 m³/d Number of annual operation hours: 3,000 Energy consumption: 3.31–3.65 kWh/m³ (depending)
MED + solar pond	1.44	<ul style="list-style-type: none"> Nominal capacity: 6,000 m³/d Number of annual operation hours: 8,320* Electric consumption: 2.25 kWh/m³
CP solar collectors + biomass-MED	4.84	<ul style="list-style-type: none"> Nominal capacity: 6,000 m³/d Number of annual operation hours: 8,320* Electric consumption: 2.25 kWh/m³

↑ TABLE 2.1: AVERAGE COSTS OF SOME TECHNOLOGICAL COMBINATIONS

(*) MED ANNUAL OPERATION AVAILABILITY 95%, BY INCLUDING EXTERNAL ENERGY SUPPORT

THE MARKET IS LARGE

2.4 THE PERSPECTIVES OF RE-DESALINATION

The desalination market is growing very fast with the demand increasing in all continents. The installed capacity is expected to double within a period of 8 years as explained in section 2.2. This growth will create important additional energy requirements which are associated with environmental and socio-economic issues, currently high in the political agenda. As a result the RE-desalination option has started attracting the interest of politicians and other stakeholders. Already in 2004, Spain's Minister for the Environment, Cristina Narbona, stated that her government will support renewable energy powered desalination technologies²⁸.

At present, the RE-desalination community has a unique opportunity to capitalize on the potential for political and social support.

In principle any desalination plant can be operated by renewable energy. However, the first steps of the technology in the market will be at the lower capacity systems, where several RE-desalination technologies have been developed and tested because of their suitability for remote areas where few alternatives exist. At the same time the first large-scale desalination systems are being installed in areas countries that source large shares of their total water supply through desalination and the energy issues becomes critical. This is the case for example in the Canary Islands and

in Australia that have introduced regulations supporting the use of renewable energy for powering desalination plants.

To better identify markets and applications of RE-D, four different capacity ranges are defined for the purpose of this Road-Map:

- Very small scale: < 1 m³/d
- Small-scale: < 10 m³/d
- Medium scale: 10–1,000 m³/d
- Large scale: > 1,000 m³/d

The number of people that can be served from a plant of a certain capacity depends on the intended use of the water. If the water is only needed for drinking purposes 3–5 litres per person per day (l/p/d) are enough. To cover other needs as well UNICEF and the WHO define 20 l/p/d as the minimum water requirement. In Europe the average water consumption is about 150 l/p/d. If the desalinated water is also used for irrigation even more water is needed per person and day.

It is important though when sizing a plant to take into account the average daily production expected and not the nominal, especially in the case of RE-desalination that produces water only when the energy is available. According to that, also appropriate water storage facilities have to be provided, to ensure water supply for periods of reduced production.

Very small scale (< 1 m³/d) plants are targeted directly to the end-user. Typically a single user like a household would install such a desalination plant in remote areas where electricity and water supply are non-existent or unreliable. Currently the alternatives used are bottled water, or water delivered by boats and trucks. There are several well-established RE-Desalination technologies that are addressing this market, like solar stills, solar membrane distillation (MD) and solar multiple effect humidification (MEH).

The market is large, including for example families living in isolated houses, remote holiday homes, military personnel like border guards, small health centres etc. There are suitable locations in Europe, like the small islands in the Mediterranean, but there is also a huge potential worldwide in areas like Northern Africa, Oceania etc, offering good export potential for European companies.

Small scale RE-D (< 10 m³/d) plants are targeting users very similar to the "very small scale" plants. The main difference is that they can cover the daily water needs of more than 100 people and thus they do not target single users, but small groups. For example, a "very small scale" plant would be used by a single holiday home, while a "small scale" plant would be used by a group of 10 to 20 holiday homes, or by a small hotel. The main technology in that range is PV-RO but all RE-desalination technologies from the "very small scale" applications are modular and could be used in the "small scale" range as well.

Also this market segment is very large including for example small villages, holiday resorts, isolated tourist attractions, isolated industrial sites etc. There are hundreds of islands in Europe and several thousands worldwide with less than 100 inhabitants, water supply problems and plenty of sunshine. Another example of possible applications are the autarkic apartments built in North Africa, Mexico and in the Caribbean for workers or tourists.

Medium scale RE-D (10 – 1,000 m³/d) can be used for water supply of villages, or other large users like hotels. The alternative solutions used currently are water transportation or conventional desalination, since in that range the users tend to have access to electricity. However, in the case of islands or other isolated areas the cost of electricity generation can be high and the local grid can be unstable. A large load like a desalination plant might further destabilise the electricity network especially in periods of high water and electricity demand. This problem is addressed when powering desalination directly by renewable energy, like in the case of wind-RO or wind-MVC, the most common technologies in that range.

The market is huge, since it can address any area facing water shortage with a permanent or seasonal population from 500 up to 50,000 people, including towns like in the Middle East region, islands, golf resorts etc. The only limitation when using wind energy is that the selected site needs an attractive wind profile, which is more re-

strictive than the solar powered technologies that can operate practically anywhere where water is needed.

Large scale RE-D (> 1,000 m³/d) can be used for municipal water supply and any other application where conventional desalination is also used. Currently the direct competition with conventional desalination is feasible mainly in cases where there is political support, like in some States in Australia where desalination developers are obliged to generate from renewable sources electricity equal to the desalination plant consumption. Mostly this is applied in the form of large grid connected reverse osmosis plants for the municipal water supply of cities and wind parks in other locations to offset the energy requirements of the desalination plants. This kind of applications are expected to be more widely used, especially at the range up to 10,000 m³/d, that are common in Southern Europe where supporting framework conditions exist for renewable energy, if the support schemes are suitably adapted.

There is large potential though for the future, with innovative technologies coupling water and electricity production, through Concentrated Solar Power and MED plants. The CSP plant generates electricity. During this process waste heat is also generated which can be used to power the thermal desalination process. With the CSP market growing very fast, the CSP-MED combination has great potential, especially for the Mediterranean Solar Plan.

3. BARRIERS

LACK OF TECHNOLOGIES APPROPRIATE FOR SMALL-SCALE APPLICATIONS

In this chapter the barriers to the development of RE-desalination are identified and categorised. These barriers relate to the development of RE-desalination technology only and do not include barriers associated with the

renewable energy or desalination technologies independently. Each section starts with the main points summarized in a table.

3.1 TECHNOLOGICAL BARRIERS

Most RE-D are not developed as single system but are combinations of components developed independently

- Poor reliability
- Increased water cost

Desalination development focuses on ever larger systems

- Lack of components appropriate for small scale desalination plants, typical of many RE-D combinations

Current desalination technology has been designed for constant energy supply, whilst most RE provide variable energy supply

- Increased capital and maintenance costs

3.1.1 SYSTEM RELIABILITY AND COST OF WATER

For the most part, renewable energy technologies and desalination technologies have developed along independent paths with no consideration as to how the two technologies may work together. For the efficient coupling of the two technologies in RE-D plants, dedicated technologies have to be developed. Depending on the particular RE-D technology, this can manifest itself in a range of different plant aspects.

For many desalination technologies, the focus has been on the development of relatively large plants. This has resulted in a lack of technologies appropriate for small-scale applications, which is a promising market for RE-desalination plants. Technologies requiring more development for small-scale applications include small capacity pumps and system control algorithms for decentralized desalination systems, suitable pre and post treatments of the water, suitable energy recovery technologies, energy storage and methods for safe and efficient disposal of the brine in inland plants. Furthermore, the inclusion of complementary equipment, for the autonomous operation requires the installation of additional elements (e.g. batteries, converters, control system ...) and thus a consequent increment in the specific cost.

3.1.2 VARIABILITY OF ENERGY SUPPLY FROM RENEWABLE SOURCES

The majority of renewable energy sources supply a variable amount of energy depending on such factors as the wind speed, solar radiation intensity, etc. The designs of conventional desalination plants, however, are based on a constant supply of energy so there is typically a mismatch between energy supply and demand.

If the energy supply and demand are mismatched, either the renewable energy or desalination plant is under-utilised. Operation under variable conditions could also lead to increased maintenance requirements, for example, more frequent replacement of the membranes. Under-utilization and increased maintenance requirements lead to higher specific costs of water making the RE-desalination plant less commercially attractive.

Fluctuations in the energy supply can have other negative effects on desalination plants, like microbial and other biological contamination in unheated parts of solar thermal systems or pressure fluctuations and variable salinity of the product water in PV-RO systems without batteries.

To reduce or avoid fluctuations, energy storage could be used, which, however, has several limitations. For electricity, the only commercially available option is batteries, which have limited storage capacity and a relatively short

operational life. For heat storage, the main option today is heat storage in a tank of a thermal fluid (like water or oil), which has short storage time.

**INVESTORS ARE
GENERALLY RELUCTANT
TO INVEST IN
RE-DESALINATION
TECHNOLOGIES**

3.2 ECONOMIC BARRIERS

Lack of comprehensive market analysis as to the size, locations and segments of the market

→ It is difficult to assess the risk and investors are reluctant to invest

SMEs lack the financial resources and local know-how to enter distant markets

→ Difficulty to access some of the most promising niche markets

The pricing structures and the subsidies of water supply create unfair competition

→ Investment in RE desalination remains unprofitable even where they offer better value than the current solutions

Lack of identified niche markets with the ability to pay for the full cost of the systems, which would demonstrate the technology attracting additional customers

→ No cash is generated that could be used for further product development, reducing the costs and improving the performance

3.2.1 MARKET AND RISK UNCERTAINTY LIMIT INVESTMENT

Commercialization of RE-D is a relatively new area and little is known about the size of the potential market and the types of RE-D plants that are most suitable for different parts of the market. Without a comprehensive market analysis, it is difficult to determine where and how to enter the market, how long it may take to receive a return on investments, how large the return on investment may be and therefore the magnitude of risk associated with investment in the technology.

The primary consequence of this uncertainty is that investors are generally reluctant to invest in RE-desalination technologies, and when they do invest, they desire high rates of return on their investment to compensate for the higher perceived risks. Although there are a number of authoritative studies that show that the need for desalination technologies is growing, together with public and governmental support for renewable energy technologies, this is inadequate to define the market for RE-desalination. The need of RE-desalination is not congruent with the demand. The range of RE-desalination technologies is large, and each technology has particular characteristics which need to be matched to a market analysis to enable investment decisions to be made. This level of detailed analysis is currently missing.

Obtaining investment for RE-desalination is also hampered because the majority of the technology developers are small companies that lack clear commercial direction in product development and exploitation. Such companies do not have the resources to address the main target markets, because typically the markets are relatively remote with difficult access, currency risks and high political risks. Further, different cultures in business and utility services are involved. This is compounded by the lack of market analysis so that the investors have limited confidence in the commercial potential for the technology. Without external investors these small companies do not have the resources to address the main target markets which are often geographically distant creating difficulties for access. Moreover, fluctuating exchange rates coupled with political instability in some target countries as well as differences in business and political culture mean that the difficulties in penetrating the markets are significantly increased.

In a number of countries and regions where RE-desalination is expected to have a substantial market, the market may be significantly influenced by the supply of development funding. Furthermore, the role of NGOs in project implementation may be important. Small RE-desalination technology companies do not have the resources to interact effectively with large organizations, such as the United Nations Development Program (UNDP), because of the large bureaucratic structures that such organizations

have. This again reduces the attractiveness for investors because of the uncertainties involved. Moreover, large companies buy proven technologies to ensure that the water supply will be secured. As a result, new and potentially better technologies have little chance to develop.

3.2.2 PRICING STRUCTURES

Access to safe drinking water is generally considered a fundamental human right. Consequently the cost of water production, either by desalination or otherwise, is often only very loosely linked to the price that consumers pay for their water. In many cases the price paid is much less than the cost of the water production due to subsidies provided by the central government or local authorities. This is further complicated because the costs of water distribution are also generally difficult to isolate. This limits the development of commercial RE-desalination plants because relative to the subsidized public resources the water from RE-desalination plants is too expensive and the plants unprofitable.

Even in cases where the water from RE-desalination has lower costs than the other alternatives, RE-desalination might not seem so attractive because of the cash-flow characteristics. The high initial investment costs of RE-technology and the subsequently low operational costs dissuade smaller users with limited capacity to motivate

the required funds. For example, a family might not have enough saved money to buy a RE-desalination plant, but they may earn enough to buy bottled water, which in the long run is much more expensive than producing desalinated water from an own plant.

Although in many countries financial support is available for electricity produced by renewable energy sources, this support does not currently transfer to electricity displaced by the use of renewable energy in a desalination plant. This lack of financial support that is available for many other renewable energy technologies means that RE-desalination plants remain unprofitable even in places where the production of renewable energy itself is highly valued.

3.2.3 LACK OF FUNDING FOR DEMONSTRATION PLANTS

In the early development stages of a technology, additional funding is typically obtained from sales in niche markets. Early investors are prepared to take the risk with a new technology because the potential benefits are sufficiently large. In general, RE-desalination technology developers have not yet identified and penetrated these markets, therefore not enabling these areas to demonstrate and further develop their technologies. Moreover, the potential for the exploitation of niche markets has not been adequately demonstrated to

investors so that the required investment funding is generally not available. Unfortunately, there is circularity in obtaining funding for new technologies, including RE-desalination. To obtain funding it is necessary to demonstrate the technology is promising, yet funding is required in order to make this first demonstration.

An additional difficulty is that the niche markets are often small communities without the knowledge and abilities to help access the funding required for a new plant. Thus, there is a mismatch between investment ability and demand for RE-desalination plants.

**LIMITED SUPPORT
FROM INSTITUTIONS,
POLITICIANS AND
LOCAL COMMUNITIES
BECAUSE OF THE
PERCEIVED RATHER
THAN ACTUAL
DEFICIENCIES**

3.3 INSTITUTIONAL AND SOCIAL BARRIERS

Negative perception of desalination by the population → Opposition of local communities to installation

RE-D is a new technology and is typically small-scale, suitable for community-led water provision → RE-D is not commissioned because water authorities prefer familiar technologies and centralized control

Bureaucratic structures not tailored for independent water production; separation of energy and water policies → The cost and effort required to deal with the bureaucracy does not favor small companies

Lack of training and infrastructure → Reduced plant availability
→ Lack of personnel for operation and maintenance

Cultural gap between project developers and the end-users → Projects fail for non-technological reasons like conflict about control

3.3.1 PREVALENCE OF NEGATIVE PERCEPTIONS

Although there is support for renewable energy and desalination these technologies are not universally accepted as desirable because they are perceived to be uneconomic, unreliable, environmentally damaging and/or aesthetically displeasing. These perceptions are not necessarily consistent but remain problematic for the introduction of RE-desalination plants. For example, water obtained by desalination may be considered energy intensive thus environmentally damaging, which can limit the introduction of RE-desalination plants even though the energy is "clean". Another perception is that desalinated water is not suitable for human consumption, either because of individual prejudice or cultural issues.

Moreover the taste of desalinated water is often different from the locally perceived "normal taste", especially for water from distillation plants.

Some of these negative perceptions arose due to past failures of prototype plants and some due to a misunderstanding of the technologies. Whatever the source of the information, the consequence is that RE-desalination plants often have limited support from institutions, politicians and local communities because of the perceived rather than actual deficiencies.

3.3.2 PREVALENT CULTURE IN INSTITUTIONS AND SOCIETY

In general, water authorities have been found to be reluctant to commission RE-desalination technologies because of their lack of confidence with conventional desalination technologies and a culture of risk avoidance. Such technological conservatism is common in large hierarchical corporations, where there is little incentive for suggesting new technologies that offer potential benefits but are risky because the technology is unproven. Most RE-desalination technologies fall into this category. This attitude towards RE-desalination technologies is perpetuated within the water authorities and other large-scale suppliers of water because of the lack of knowledge and experience with RE-D technologies so that they are not able to make well informed decisions about the suitability of RE-D plants.

In addition, the provision of non-indigenous water supply has typically been provided using a centralized approach, where water supply and quality can most easily be controlled. Many RE-desalination technologies are appropriate for small-scale deployment in rural locations, but adoption of these technologies would result in a perceived loss of control by the water providers. This perceived loss of control typically runs against the prevalent culture within water providers making it unlikely to be adopted. This reluctance of the water providers to exploit local water sources using RE-desalination may be supported by local rural communities that do not trust new fresh water supplies powered by

renewable energy and would in some cases prefer to rely on traditional fresh water supplied even in cases where the supply is of a low quality and high cost.

3.3.3 SEPARATION OF ENERGY AND WATER POLICIES

In many countries the management of energy is totally separated from the management of water so that coordinated organization and provision of these two fundamental services is not possible. Electricity generated by renewable energy sources is subsidized when fed into the grid while the fresh water produced through renewable energy driven desalination is not. However, the separation of the management of energy and water means that the benefits of RE-desalination are not always fully recognized because decision-makers focus independently on either the supply of water or the supply of energy. Without the full benefits of a coordinated provision of energy and water the probability of RE-desalination plants being commissioned is reduced.

3.3.4 LEGAL STRUCTURES

The provision of non-indigenous water supplies has typically been highly centralized and the legal structures required to ensure specific water quality standards have generally matched this concept of centralised provision. Consequently, the legal structures are often highly

bureaucratic and not tailored for small-scale independent water production (incl. permissions for feed-water consumption and brine discharge). For each water supply source, they require a large investment of time and effort. The situation is further complicated with the installation of a renewable energy system if permissions are required from the authorities dealing with energy issues. Many RE-D plants are developed by independent water suppliers who have only a small capacity, and thus the legal overhead is relatively large making the installation potentially uneconomical.

3.3.5 LACK OF TRAINING AND INFRASTRUCTURE

The installation of RE-desalination plants remains uncommon and there is only a limited amount of practical experience in working with these technologies. Consequently, there is little access to trained personnel capable of operation and maintaining the RE-desalination plants. Moreover, there is a limited distribution network for the supply of consumables and spare parts so that RE-desalination plants may have a reduced availability due to non-technical difficulties with maintenance.

These maintenance difficulties are compounded because in many cases the RE-desalination plant is not currently available as an integrated product and there are no guarantees and service contracts.

3.3.6 RELIGION, GENDER AND THE ENABLING ENVIRONMENT

The last thirty years of community water projects around the world have shown that the failure rate of such projects is discouragingly high. A closer look at the reasons reveals a multitude of complex socio-cultural and religious causes that differ vastly among cultures and locations. Introduced to the community for the first time, the new technology is often perceived as an alien intrusion disrupting existing traditions, responsibilities and structures. In some cultures for example men take charge of political issues and are influential in decision making processes, while women are responsible for household and community management. Introduction of a new RE-D technology often becomes a matter of conflict as it is perceived by men as being part of the political arena promising status and influence, while women traditionally have been in charge of water management.

Sometimes the nature of the project itself is the reason for failure. Usually community water projects installed by outsiders in rural areas of developing countries fail shortly after the end of the project, as soon as outside funding dries up and outside conflict resolution, motivation or enforcement stop. This alone shows that such projects have not been fully integrated into the community and a true sense of ownership and responsibility did not develop. The well meant technology may even be perceived as a means of outside control and loss of independence.

4. STRATEGY FOR PROMOTION OF RE-DESALINATION

COMMON EFFORTS BY THE RE-DESALINATION DEVELOPERS ARE NEEDED

Following the structure of the barriers identified in chapter 3, a strategy for overcoming them is outlined here. Each section starts with the main points summarized in green.

4.1 TECHNOLOGICAL STRATEGIES

- Promote cooperation between companies from the energy sector, water sector and other specialists to achieve fully functional integrated products
- Promote cooperation within the RE-desalination field for achieving R&D results that will benefit the whole sector
- Support development of standardized, reliable and robust systems offering competitive performance guarantees
- R&D of components suitable for the smooth and efficient coupling of the existing desalination and renewable energy technologies
- Support development of elements that will make RE-desalination robust for long stand-alone operation in harsh environments
- Support development of components and control systems that allow desalination technologies to deal better with variable energy input, hybrid systems and energy storage to reduce variability
- Support development of co-generation systems that produce water and power

4.1.1 IMPROVING THE RELIABILITY AND REDUCING THE COSTS

The various small developers of RE-desalination should come together and cooperate for the development of the components that can be used by all of them. This will show to the industry that there is large market potential and will help motivate them to develop products specifically for RE-desalination.

Focused R&D efforts are needed to develop the components necessary for the smooth and efficient coupling of the existing desalination and renewable energy technologies. Other R&D priorities include the elements that will make RE-desalination robust for long stand-alone operation in harsh environments. Some issues that RE-desalination developers have to deal with are listed below:

- Adaptation of pumps and energy recovery systems for efficient operation in small-scale plants
- Use of seawater-resistant materials
- Automated and environmental friendly pre- and post-treatment technologies
- Control systems that optimise the performance and minimise the maintenance requirements
- Obtain certification for food safe systems for materials that are in contact with the water

These common needs should be jointly promoted to organisations that fund R&D, like the European Commission and the national governments, to include the RE-desalination needs in their programmes and priorities.

The target should be the development of standardized, reliable and robust systems integrating the renewable energy with the desalination unit offered to the end user with comprehensive performance guarantees.

4.1.2 DEALING WITH THE VARIABILITY OF ENERGY SUPPLY

RE-driven desalination systems need to be able to handle the variable and intermittent energy supply from renewable energies. There are a number of alternative approaches to handle this mismatch.

One approach is to provide additional sources of energy for the desalination plant, either conventional or renewable, so that the supply of energy is more constant. For example, this could be achieved by combining a wind turbine with a photovoltaic panel. Hybridization with the electricity grid, together with tailor made control systems can guarantee continuous operation. Conventional energy suppliers like gas turbines that can vary their load have to be integrated in grids with a high percentage of renewable energy to stabilize the production. This could be a good solution for small inland grids that are harder to stabilize than large grids and for countries with

a feed-in tariff that, because of this support system, have a large share of renewables.

An alternative approach is the co-generation of electricity and/or heat with the desalination of water. The management of the energy system would allow an optimal utilization of the desalination plant. The management of the available energy between electricity/heat and water production would depend on the needs and on the tariff structures of both commodities in the area of operation.

The improvement of the thermal and electrical storage technologies is considered to be one of the main approaches to reduce the intermittent nature of the energy supply. This is currently achieved by the use of batteries or a thermal heat storage system. Alternative storage for both electricity and heat should be developed.

In the case of heat storage, one of the solutions is the utilization of latent-heat storage materials like melting salts or paraffin. Electrochemical storage is also under consideration. In the case of electricity, flywheels are one example. As opposed to batteries, they are not affected by temperature change, do not have a memory effect and are environmentally friendly. Compressed air and hydrogen are also promising technologies for electricity storage.

A salinity gradient unit powered by reverse electrodialysis could be also a very suitable electricity storage solution for desalination plants²⁹. This technology uses the difference in salinity to produce electricity. During desalination, brine water with a high salinity is produced. This product, combined

with sea or brackish water through a salinity gradient power unit, can produce electricity when required. This has also the advantage that the salinity of the rejected brine is lowered, which makes the process environmentally friendlier.

Another approach would be to minimize the impact of a variable energy supply on the desalination plant operation. The fundamental desalination plant design and components should be re-thought so that they operate optimally under a variable energy supply. The development of RO membranes which are less sensitive to variable pressure and flow could achieve this goal. The membrane industry has the capacity to manufacture such membranes, if they are convinced that the market for this product is sufficiently large. Also, new control software is required to ensure that the available energy is optimally used and that the system is protected from fluctuations. Therefore contributions from experts who specialize in control algorithms are necessary. For example, ENERCON seawater desalination systems have no fixed operating point. By adjusting the piston speed, the water production can range between 12.5% and 100% of the nominal capacity, therefore making operation with a fluctuating energy supply possible. The output can be adjusted flexibly to meet the water demand without shutting down the plant.³⁰

All of the options mentioned for dealing with the intermittency of the energy source require more R&D activities. Again, common efforts by the RE-desalination developers are needed to motivate interest from the industry and secure support for R&D programs.

ESTABLISH A FAIR SUPPORT SYSTEM FOR RE-DESALINATION

4.2 ECONOMIC STRATEGIES

- Support development of detailed and reliable market analysis
- Cooperation with agencies from EU countries in the target markets for organising trade missions
- Facilitate collection and dissemination of relevant experiences and information in the RE-desalination community
- Promote pricing structures and subsidy allocations that let the market choose the most efficient solution and encourage efficiency in the use of the water, while ensuring global access to safe water
- Campaign for inclusion of RE for desalination in national schemes that support RE electricity generation

- Identify niche markets and use existing support programs in combination with financing schemes to help users that are willing and able to pay for the technology

4.2.1 DEVELOPING A GOOD MARKET UNDERSTANDING

The lack of reliable and detailed analysis of the markets for RE-desalination has been identified as one important barrier for small companies active in the field. Studies have already been carried out, each one of them facing different limitations. The work carried out up to now should be used as a basis, and now a comprehensive study, guided by industry, needs to be developed. The study is to include:

- Identification and detailed analysis of the main target groups for each available RE-desalination combination

- Quantification of demand by these groups into geographical location, their willingness and ability to pay at the alternative solutions they offer
- Prioritisation of the target markets taking into account the demand, institutional framework and socio-economic conditions

The product developers, who on basis of such an analysis decide to enter promising markets away from their native country, will still need support, especially if they are small entities. To enter the market, they will need to deal with the local legal system, currency risk and political developments. They will also need to establish a local presence with sales, marketing and technical staff, maybe through collaboration with a local company.

One way to obtain this kind of support for interested European companies is through contacts with local agencies in the native country or through the EC, which can also organise trade missions in the most promising markets. As an additional measure, the RE-desalination community can get organised, collect relevant information and make it available to its members to help them expand to new markets.

4.2.2 DEVELOPING SUITABLE PRICING STRUCTURES

Introducing water pricing across all sectors, representative of the real water costs is critical for achieving sustainable water use. This can provide incentives to use water resources efficiently and recover the full cost of water services, including supply, maintenance, new infrastructure, environmental and resource costs. As such, it reflects the, 'water user pays' principle. Effective water pricing needs to be based, at least in part, on the volume of water used, rather than adopting a flat-rate approach. To this end, water metering plays a key role and must be implemented across all sectors. Successful water pricing will require a good understanding of the relationship between tariff and the use of water for each sector and needs to take into account local conditions.

On the other hand, the water pricing should not make anyone compromise their personal hygiene and health because they cannot pay their water bill. Access to safe drinking water is a fundamental human right and consequently has to be available and affordable for everybody.

The challenge is to define pricing that reflects the costs but allows global access to safe water. Traditionally public subsidies have been used to achieve this. In many cases this will still be the case in the future, especially where real water costs are high relative to the income of the local people. However, the structure and mechanism of the

subsidies has to be incorporated in a pricing system that allows the market to choose the most efficient water supply solution, while encouraging efficiency in the use of the water at the same time.

A possible pricing solution is the life-line rate³¹. With this pricing system the first necessary unit of water is cheap. The price of the following water units increases in blocks. This pricing structure is similar to the increasing block structure and presents three advantages: The average water price reflects the real cost; users have an incentive to rationalize their water consumption and third everyone can afford the minimum needed amount of water.

The use of renewable energy for the energy requirements of water infrastructure should be incorporated in the support schemes available in many countries for electricity generated by renewable energy and exported to the grid.

For the authorities to establish a fair support system for RE-desalination, the water generation cost from these technologies has to be transparent. Currently, every technology developer or researcher who installs demonstration plants publishes water cost figures which are not comparable. A comprehensive methodology for the water calculation cost has to be developed. It must take into account the capital costs and the operation and maintenance costs for the, average framework conditions prescribed in a well-defined manner. The calculation shall be performed

according to basic modern financial principles, incorporating market rates for the interest as well as reasonable technical assumptions for the product lifetime. The RE-desalination community has to develop this methodology for the different technologies and oversee its application.

4.2.3 MOBILISING INVESTMENT FUNDING

The market analysis mentioned in section 4.2.1 will identify the niche markets for each technological combination showing the highest potential. These markets should be targeted directly by the product developers, aiming at raising the initial revenues and demonstrating the good performance of their systems.

However, in many cases there might not be any users willing or able to pay the full price of the first RE-desalination systems, when the costs are still relatively high. Many alternatives are available e.g. by using public support, incentives or innovative financing schemes. Particularly for developing countries, programmes offered by NGO's and international development aid organizations need to be identified and used.

Many individuals, or groups of people not served from centralized services, currently buy bottled water or water delivered by trucks, which costs more than the average cost of water generated by RE-desalination. In principle,

they could afford the technology, however, they might not be able to pay up-front the whole capital cost in order to benefit over the years by the lower daily cost of the water supply. Therefore, suitable financing schemes should be developed to help them pay the investment cost of a desalination plant over 10 or more years. Several micro-financing schemes have been successfully demonstrated for different technologies.

However, the institutions that provide the financing will need to be sufficiently confident that the plant will operate without problems for 10 or more years. It is up to the technology developer to provide comprehensive guarantees as outlined in section 4.1.1.

AWARENESS ABOUT RE-DESALINATION AND ITS BENEFITS HAS TO BE INCREASED

4.3 INSTITUTIONAL AND SOCIAL STRATEGIES

- Support development and implementation of a long-term and consistent communication strategy by the RE-desalination community
- Facilitate organization of seminars, debates and other events related to RE-desalination involving engineers and decision makers of the large institutions responsible for water and energy in the target countries
- Promote simpler and straightforward processes to obtain a license for independent water production
- Lobby for greater cooperation between the power and water sectors in governmental and non-governmental institutions
- Support education and training at all levels
- Encourage adequate consideration of socio-cultural factors and establishment of communication channels with the end-users

4.3.1 IMPROVE THE PUBLIC PERCEPTION OF THE TECHNOLOGY

To overcome possible negative perceptions, the awareness about RE-desalination and its benefits has to be increased among the general population and target groups. More information about the progress, potential and especially about successful projects should be made available to the general public and targeted audiences. For this, a long-term and consistent communication strategy has to be developed. Of course, product developers manage their own promotional campaigns, but the RE-desalination community should come together in order to address a much broader audience. Contacts have to be developed and maintained in specialised publications and in the mass media of the most relevant countries. They will regularly provide coverage of the progress in the field and will promote the success stories of RE-desalination installations.

One of the most important issues for improving the public acceptance of the technology is to adapt the taste of the desalinated water, specific to each culture. Especially for distillation technologies, the produced water might have no taste, although it is of very high quality. This fact is difficult to accept for populations that are used to consuming, for example, brackish water. All RE-D systems would profit from a universal solution to the taste problem. A simple mechanism that can be applied to small decentralised systems and adapts the taste to the local preferences has to be developed.

4.3.2 CHANGE THE PREVALENT CULTURE IN INSTITUTIONS

Within large public or private institutions, opinions are slow to change. However, as structures are gradually changing due to the privatisation of the energy and water market and as new young employees are hired, the opportunity arises to promote new ideas and approaches, like the decentralisation of the water supply and the adoption of innovative technologies like RE-desalination.

If RE-desalination is included in the curricula of higher education young scientists and engineers, who eventually will be working for large institutions, will become familiar with the technology at an early stage. The RE-desalination community should build on the existing efforts of education and training in the sector by supporting the update and wide use of the materials.

Organising seminars, debates and other activities specifically directed towards the engineers and decision makers of large water and energy institutions in selected countries, will help make them more familiar and comfortable with this technology, understanding its benefits and applicability.

4.3.3 PROMOTE COORDINATION OF ENERGY AND WATER POLICIES

In most countries the management structures of energy and water are totally separated, as analysed in chapter 3. A stronger cooperation between both sectors should be encouraged and supported in governmental and non-governmental institutions. Special emphasis should be given to establishing and maintaining communication channels between the decision makers of the two sectors. In addition, independent monitoring should ensure that their policies are coordinated and consistent. There are a lot of synergies and common issues between the two sectors that remain unexploited.

The RE-desalination community should work together with the other relevant interest groups to promote this cooperation between energy and water policies. Such interest groups are the hydroenergy plant owners and operators, power plant operators that need fresh water for cooling etc. The International Energy Agency, recognising the need of closer cooperation between the energy and the water sectors, organised in March 2009 the "Workshop on Renewable Energy and Water" bringing together key stakeholders from both fields.

4.3.4 REDUCE THE BUREAUCRACY

All stakeholders that are interested in promoting small independent production of water production plants should work

together to promote simpler and more straightforward legal processes. The RE-desalination community can learn from the solar energy sector. In many countries by forming pressure groups, PV associations have succeeded in simplifying the procedures for domestic production of electricity and sale of surplus energy to the grid, allowing any individual to become an independent power producer.

In all countries the RE-desalination community has to work with the authorities to identify and remove the bottlenecks in the licensing process. Many of these issues are the result of limited cooperation between the energy and water authorities. As a result, many small producers having to visit many different organisations that deal with water, energy and the environment to secure all of the permits required to construct and operate a RE-desalination plant.

4.3.5 TRAINING AND INFRASTRUCTURE

Education and training on all levels is necessary, covering technological, economical, social and institutional aspects of RE-desalination. Many universities already teach RE-desalination as part of their curriculum. Nevertheless, much more must be done to include RE-desalination in a large number of relevant universities and technical schools in order to cover the technology in more detail. Relevant education should be provided especially in those countries where the technologies are most suited. Cooperation between the

universities on national and international levels should be promoted to facilitate the exchange of teaching materials, lecturers and researchers specialised on RE-desalination.

The networks for the distribution of spare parts and the availability of maintenance personnel will only be developed together with the market. Existing networks of relevant technologies should be exploited, to facilitate the process. Also the use of planning and other support tools that have been developed in EU co-funded projects^{32/33}, should be promoted.

4.3.6 FACTORING IN RELIGION AND GENDER ISSUES

Appropriate technology must consider socio-cultural and religious factors in order to be sustainable. It is not helpful to install technologies such as modern RE based desalination systems as part of aid projects without ensuring proper adoption by the local community. A basic principle should be a combination of local community partnerships involving the key players and identifying and eventually addressing the key conflicts. Often it is an influential individual or a group within the community who openly - or secretly - oppose a project for entirely unexpected reasons. A strategy respecting values and traditions, involving participatory community partnerships and, whenever possible, public-private partnerships may alleviate the known problems surrounding the introduction

of new methods and technologies in rural regions of developing countries.

Aid projects almost always bring a plethora of external methods and methodologies, values, expectations and targets to the recipient community. At the same time, the local culture often has a long tradition and deeply engraved values related to water and water management. It is therefore essential to take those traditions and value seriously and integrate them into any strategy aimed at strengthening the enabling environment and resolving allocation conflicts.

Conflicts of interests leading to manipulation and corruption must also be explored as part of pre-project analysis. For example, it would be difficult to install a renewable energy based desalination plant with a bottling facility, if the village mayor owns the local bottled water import company.

5. RESOURCES AND ACTIVITIES

RE-DESALINATION COMMUNITY IS TARGETING A 3–5% SHARE OF THAT MARKET

5.1 TARGETS AND TIME FRAME

The RE-desalination strategy in chapter 4 outlines the main points of focus in order to overcome the barriers the technology is facing. To successfully implement the strategy, all actors must collaborate to bring together the necessary resources and implement specific activities that will deliver concrete results. For encouraging action and defining a benchmark against which the progress can be monitored, specific targets with associated time frames are set here.

As mentioned in section 2.2, new desalination plants to be constructed up to 2016 are expected to be worth, in total, over \$64 billion. The RE-desalination community in that initial stage of development is targeting a 3–5% share of that market, worth \$2–3 billion over the next 7 years. This is a market large enough to attract the interest of major players who will catalyse fast developments. The largest part is expected to be among the plants with capacities below 1,000 m³/day where on a global scale in the next decade 15 to 20% of the market share is aimed by RE-desalination,

using existing technologies like wind-RO, wind-MVC, solar MD, solar MEH and PV-RO. For larger plants, just below 2% of the market could be reached when in addition to the very large wind powered RO systems, CSP-MED and wave-RO plants start being implemented.

The "RE-desalination Association" described in paragraph 5.2 should be established before 2012 and [include initially more than 20 members](#), with at least 75% of them being commercial companies.

The 8th Framework Programme of the European Commission is the main target and will cover the R&D activities from 2014 for a period of seven years presumably. Several topics relevant to RE-desalination are planned for that programme. As a result, the number of co-financed projects related to RE-D over that period will increase to over 50. This represents [R&D worth more than 100 million Euro](#).

The education and training activities should expand continuously to more universities and institutes in Europe and throughout neighbouring regions. The target is that by 2015 at least 2,000 students per year in Europe have [a subject within their curriculum relevant to RE-desalination](#). And by 2015, more than 500 professionals per year should be trained in RE-desalination.

The market studies analysed in section 5.5 should be made as soon as possible. The target set here is to complete mar-

ket studies for at least four countries, preferably Greece, Spain, Morocco and Tunisia by 2014. More countries are to be included in the next few years. The country specific [studies of the legal framework conditions](#) should follow, with the first four countries to be covered before 2015.

POWER AND RESOURCES TO REPRESENT THE RE-DESALINATION INDUSTRY

5.2 ESTABLISHING THE RE-DESALINATION ASSOCIATION

In the description of the strategy in chapter four it has been indicated in several points that joint action by the RE-desalination community is required. For that purpose, the first action necessary for the implementation of the strategy is to formalise the community in an organisation that is widely accepted and has the power and resources to represent the RE-desalination industry and promote its interests on every level. This organization will be called here the "RE-Desalination Association".

The Association should build on the achievements of other groups or initiatives with similar interests, benefit from their experience and work closely together with them where their

objectives are common. The following are some key groups doing relevant work and who have expressed interest in RE-desalination. They could facilitate the establishment of the RE-Desalination Association:

European Desalination Society: EDS³⁴ is the association of desalination related industries. It organizes every year at least one major conference and several training courses. Both the conferences and the courses are increasingly including RE-desalination related topics.

European Renewable Energy Council: EREC³⁵ is the umbrella organisation of the European renewable energy industry, trade and research associations active in the sectors of bioenergy, geothermal, ocean, small hydropower, solar and wind energy.

Solar Thermal Desalination Workgroup of the European Solar Thermal Technology Platform³⁶: The workgroup is dedicated to the support of solar thermal powered desalination.

Task on "Solar water & energy processes and applications" of the SolarPACES initiative³⁷: It operates under the umbrella of the International Energy Agency, bringing together teams of international experts focusing on the development of large combined solar power and desalination plants, medium scale solar thermal desalination and stand-alone small solar desalination systems.

The working group established by ProDes on RE-desalination is to follow-up on the implementation of the roadmap and lead the efforts for the establishment of the RE-Desalination Association. Together with the groups defined above and other relevant organisations the general framework for the new organisation will be defined. A first meeting will be organised parallel to a major event of the sector to launch the group. Subsequently periodic meetings open to all the members of the RE-Desalination Association will prioritise and organise its activities.

The RE-Desalination Association will need initially one or two full time employees and funds to cover basic office and promotion requirements. These basic expenses should be funded by fees from its members. Additional funding for concrete activities can be secured by members who have a

particular interest or by public funding that will have to be secured. The activities of the RE-Desalination Association will include:

- Define the R&D priorities that will benefit the entire sector and coordinate activities in this direction
- Support the wider establishment of RE-desalination education and training activities
- Supervise and coordinate a comprehensive market analysis
- Develop and promote appropriate legal structures and policies
- Raise awareness about the technology and demonstrate its market potential

Each one of these points is further discussed in the following paragraphs.

SUPPORT THE DEVELOPMENT OF THE SECTOR

5.3 R&D PRIORITIES

In section 4.1, a number of R&D priorities that are relevant for the whole RE-desalination sector have been defined. A list according to the latest technological developments in the sector should be updated regularly. The update will be made after a regular consultation process and a review of the R&D progress by a scientific committee.

Links with programmes that are funding R&D activities should be developed, like national research programmes or the Framework Programme of the European Commission. The identified R&D priorities should be promoted for inclusion as priorities through these channels to support the development of the sector.

In the past, the fact that RE-D belongs to both the water and the energy sectors, has been a barrier for securing R&D funding since neither sector felt totally responsible for this area. It should be worked to reverse this situation and use it as an opportunity to include RE-desalination priorities in both.

The R&D priorities are:

- R&D of components suitable for RE-D
 - Adaptation of pumps and energy recovery systems for efficient operation in small-scale plants
 - Development of seawater-resistant materials (e.g. pumps)
 - Automated and environmental friendly pre- and post- treatment technologies

- Control systems that optimise the performance and minimise the maintenance requirements
- Obtain certification for food proofed systems for materials that are in contact with the water
- R&D of components suitable for the smooth and efficient coupling of the existing desalination and renewable energy technologies
- Support development of elements that will make RE-desalination robust for long stand-alone operation in harsh environments
- Support development of components and control systems that allow desalination technologies to deal better with variable energy input
 - Hybrid systems
 - Energy storage
 - Salinity gradient systems
- Support development of co-generation systems that produce water and power

ACTIVITIES ARE DRIVEN BY THE MARKET DEMAND

5.4 EDUCATION AND TRAINING

In the strategy outlined in chapter 4, educational and training activities have been identified as a major tool for overcoming all kind of barriers: technical, economical and social/institutional.

The training field is growing very fast. Various activities are being organised. These usually take the form of seminars for professionals which are organized e.g. by the ProDes project or by EDS, and last from one to five days. Such training activities are driven by the market demand and are expected to continue requiring specific support.

The training activities have to be monitored, promoted, and it has to be assured that they do not overlap and maximise the synergies. The quality assurance of the training and

the accreditation of the courses is also important. Finally, the wider implementation of the training activities has to be promoted, especially in regions where the application is suitable but the industry in the sector or the means to cover the full cost of the training are lacking.

Regarding the inclusion of RE-D in the educational system, a beginning has already been made. Especially the ProDes project has developed and implemented courses for students that have been incorporated in the curriculum of universities in Spain, Portugal, Greece and Italy. Established classes at the universities should be continued and expanded. The material developed in the ProDes project is openly available through the project's website³⁸. It should be ensured that this information is widely disseminated to other interested parties.

FIRST STEP TOWARDS BRINGING NEW TECHNOLOGIES TO THE MARKET

5.5 MARKET STUDY

A comprehensive market study normally is part of any business plan, and is the first step towards bringing new technologies to the market. As such, it is the responsibility of the technology developers to carry out market studies focusing on the specific characteristics of their products. However, as analysed in section 4.2.1 this is not always easy and external support or cooperation between the companies of the sector would be beneficial.

The market studies should be prioritised by country, starting from the most promising ones and gradually including more. In each country, the following elements should be analysed:

- Who are the main stakeholders in the water supply market?
- Outline of the institutional and legal framework, with particular focus on independent water production
- Current status of the desalination market and experiences with RE-desalination
- Current status of the renewable energy market and the relevant legal framework
- Identification and prioritisation of the most suitable regions for RE-desalination

- Initial profiling of the target groups for each RE-desalination segment in the most promising target areas, including their average water demand, willingness and ability to pay for water and alternative water supply options

The quality and detail of the market study depend on the availability of resources. For the result to be of any use to the industry, a group of experts has to be formed that have good understanding of both the technical and business perspectives and experience in market studies. This group has to be enriched with selected experts from each target country. It is estimated that for every country, 12 to 18 person-months will be necessary. The funds to finance this are substantial and have to be mainly taken from the industry that will benefit from the results. Co-funding from European or other public sources could then be sought.

The ProDes project and other initiatives have done important work already analysing the situation in selected countries and developing suggestions for a possible RE-desalination support scheme. This valuable experience can be incorporated in the studies. There are also commercial studies for sale in the market like the GWI survey of the water sector of 49 countries including desalination: *The Global Water Market 2011 – Meeting the world's water and wastewater needs until 2016*. This study can build the base for a market study for RE-D.

LEGAL AND POLICY ISSUES ARE IMPEDING THE APPLICATION OF RE-DESALINATION TECHNOLOGIES

5.6 LEGAL AND POLICY ISSUES

There are several legal and policy issues as highlighted in section 4.3 that are impeding the application of RE-desalination technologies. Studies should be carried out in each selected country, identifying the bottlenecks in the legal system for independent water producers and the difficulties faced by RE-D developers because the legal framework was designed before they even entered the picture. Aspects of cooperation between the governmental departments and non-governmental institutions in charge of water and energy should be analysed. Finally, the study should focus on the mechanisms and perspectives of the existing subsidies for water and renewable energy.

The study should conclude with recommendations for

enhancing cooperation in the energy and water sectors, improving the legal framework and adapting the subsidy systems for giving a fair chance to RE-desalination.

The quality and detail of the studies depend on the availability of resources. A group comprised of experts from various fields has to be formed, which as a whole understands the legal situation and the economy in each country as well as the technology. It is estimated that at least 12 person-months will be necessary to carry out this study. Again the funds have to be taken mainly from the industry benefiting from the results together with possible co-funding from European or other public sources. There are synergies with the market studies presented in the previous paragraph. If both are organised together for every country economies of scale can be exploited, with common experts assisting in both groups.

LONG-TERM AND CONSISTENT COMMUNICATION STRATEGY

5.7 RAISING AWARENESS

A long-term and consistent communication strategy to raise awareness has to be developed professionally through newsletters, press releases and journalists. Information about the technologies and successful installations should be directed to the general public.

Key stakeholders should be targeted, like professionals from the water and energy sectors. To that end, the organization of seminars, debates and other events related to RE-desalination should be encouraged and facilitated in the target countries.

Finally the affiliated industries should be addressed. Direct meetings or other means of communication should be used

to demonstrate to the industry that the RE-desalination market is large enough to justify development and production and to motivate them to develop equipment and production in this area.

LIST OF ABBREVIATIONS

BW	brackish water
BWRO	brackish water reverse osmosis
CRES	Centre for Renewable Energy Sources
CSP	concentrating solar power
ED	electrodialysis
EDR	Electrodialysis Reversed
ITC	Canary Islands Institute of Technology
MD	membrane distillation
MED	multiple effect desalination
MEH	multiple effect humidification
MSF	multi stage flash
MVC	mechanical vapour compression
OTEC	ocean thermal energy conversion
PV	photovoltaic
RE	renewable energy
RE-D	renewable energy driven desalination
RO	reverse osmosis
SGP-RE	salinity gradient powered by reverse electrodialysis
SD	solar distillation
SWRO	sea water reverse osmosis
TVC	thermal vapour compression
VC	vapour compression
VMD	vacuum membrane distillation
Brine	water that is saturated or nearly saturated with salts. It is produced as a waste product during desalination

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