

# Promotion of Renewable Energies for Water Production through Desalination

Guillermo Zaragoza, Plataforma Solar de Almeria



*Dr. Guillermo Zaragoza is a senior scientist at the Plataforma Solar de Almería (PSA), which is the largest center for research, development, and testing of concentrating solar technologies in Europe and a reference in solar energy for the last 30 years. PSA is a division of the Center for Energy, Environment and Technological Research (CIEMAT), part of the Ministry of Science and Innovation that acts as a public research agency for excellence in the areas of energy, environment, and technology.*

*Dr. Zaragoza has a degree in astrophysics and a PhD in applied physics. He has worked at the Instituto de Astrofísica de Andalucía of the Spanish Research Council and the Atmospheric Physics department of the University of Oxford but with the new millennium moved to sunnier climates to work on solar energy. He has participated in several European R&D projects on solar thermal energy and desalination. His lecturing activities include a master course on solar energy at the University of Almería and an international course on desalination with solar energy organized by the European Desalination Society.*

*One of the projects he has been involved with is ProDes (Promotion of Renewable Energy for Water production through Desalination), which brought together fourteen leading European organizations to support the market development of renewable energy desalination in Southern Europe. The project started on October 1, 2008, and continued for two years, facilitating collaboration between RE-desalination technology providers and SMEs on the local level. It also supported communication between technology providers and investors. It developed courses and a road-map on RE-desalination, and provided recommendations for improving the legislative and institutional conditions in each country. It also provided training for students and professionals. Dr. Zaragoza is a founding member of the RE-desalination working group, which aims to carry on the torch of ProDes project.*

Relevant Paper: Roadmap for the Development of Desalination Powered by Renewable Energy ([http://wri.nmsu.edu/conf/conf11/prodes\\_roadmap\\_online.pdf](http://wri.nmsu.edu/conf/conf11/prodes_roadmap_online.pdf))

PowerPoint Presentation

<http://wri.nmsu.edu/publish/watcon/proc56/Zaragoza.pdf>

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**CIEMAT**

Public Research Organism attached to the Spanish Ministry of Science and Innovation.

R&D activities in the fields of Energy, Environment and Technology, and also in some specific areas of Basic Investigation.

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### PSA R&D INSTALLATIONS

- 1 - Central receiver technology
- 2 - Parabolic-through collector technology
- 3 - DGS Direct steam generation
- 4 - Parabolic dish + Stirling
- 5 - Solar Furnace
- 6 - Water detoxification/disinfection
- 7 - Water desalination

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### CIEMAT SITES

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### CIEMAT RESEARCH PROGRAM

## ENVIRONMENTAL APPLICATIONS OF SOLAR ENERGY

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### PLATAFORMA SOLAR (PSA)

PSA is one of the biggest and most complete existing facilities for research, evaluation and development of solar technologies and applications

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### DETOXIFICATION OF CONTAMINATED WATER

Use of the ultraviolet band of the solar spectrum, not thermal processes.

- > Solar photocatalytic detoxification Projects: SOLARDETOX, LAGAR, ALBAIDA, CADOX, etc.
- > Solar Disinfection Projects: SOLWATER, AQUACAT.....

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### DESINFECCIÓN SOLAR

1 Wash the bottle well the first time you use it

2 Fill the bottle 3/4 full with water

3 Shake the bottle for 20 seconds

4 Now fill up the bottle fully and close the lid

5 Place the bottles on a black area about 1m and 1.5m above the roof

6 Expose the bottles to the sun from morning until evening for at least six hours

The water is now ready for consumption

Fusarium Equiseti

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### AQUASOL PROJECT

AQUASOL project: MED seawater desalination with solar thermal energy

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### SEAWATER DESALINATION

Application of thermal solar energy for desalination covering the most promising technologies with cost reduction as common objective:

Multi Effect Distillation "AQUASOL project"

Thermal Engine + RO "POWERSOL project"

Membrane Distillation "MEDESOL project"

Concentrated Solar Power generation + desalination

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### POWERSOL PROJECT

**Project title:** Mechanical Power Generation Based on Solar Heat Engines

**Participants:** CIEMAT-PSA and ULL (Administrative and Scientific Coordinators) + 11 partners from Spain, Portugal, Switzerland, Algeria, Tunisia and Egypt.

**Budget:** 1.321 k€ [1.050 k€ contribution of the Commission (FP VI - INCO-MED. Priority: B.1.5. Renewable Energy: Cost-effective renewable energies for Mediterranean specific needs) under contract signature process. Contract No. 032344

**Duration:** Three years (project starting: tentatively December 2006)

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### AQUASOL PROJECT

**Project title:** Enhanced Zero Discharge Seawater Desalination Using Hybrid Solar Technology

**Participants:** CIEMAT-PSA (Coordinator) + 8 partners from Spain, Portugal, Greece and France.

**Budget:** 3.250 k€ [1.500 k€ contribution of the Commission (Energy, Environment and Sustainable Development Programme)], Contract No. EVK1-CT-2001-00102

**Duration:** Four years (project starting: March 2002)

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### POWERSOL PROJECT

Main project objective: Technological development of a solar thermal-driven mechanical power generation based on 3 different solar-heated thermodynamic cycles (operating temperatures around 80°C, 100°C-150°C, and 200°C-250°C)

Rankine Organic Cycle development + RO desalination

State of working fluid:  
 - Point 1: Liquid  
 - Point 2: Superheated vapour  
 - Point 3: Saturated vapour  
 - Point 4: Liquid

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### MEDESOL PROJECT

**Project title:** Seawater desalination by innovative solar-powered membrane-distillation system

**Participants:** CIEMAT-PSA (Co-ordinators) + 10 partners from Spain, Portugal, Sweden, Germany and Mexico.

**Budget:** 2,082 k€ [1.385 k€ contribution of the Commission (FP VI – Priority: B.1.6. Sustainable development, global change and ecosystems) under contract signature. Contract No. 036986]

**Duration:** Three years (project starting: 1<sup>st</sup> of October 2006)




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### CSP+D TEST INSTALLATION

PSA-CIEMAT is currently studying the possible configurations for coupling of a MED plant with a solar thermal power plant.

A specific CSP+D test bed is being built with the elements:

- Parabolic trough field
- Thermal oil storage tank
- MED 14 effects plant
- Double Effect Absorption Heat Pump
- Thermo-compressors
- Vapor generation to simulate extractions from turbines

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### MEDESOL PROJECT

Development of specific multi-effect air-gap membrane distillation concept for brine reduction. 3 different experimental pilot plants will be constructed and tested

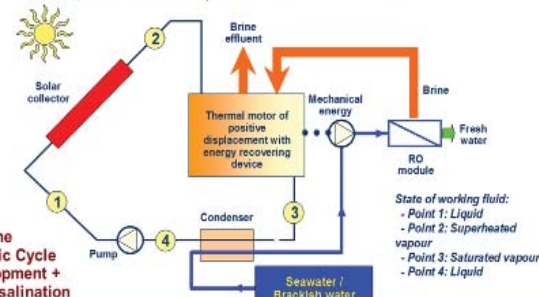




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**Rankine Organic Cycle development + RO desalination**

State of working fluid:

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- Point 4: Liquid

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### MEMBRANE DISTILLATION TEST FACILITY

Collaboration with **Keppel-Seghers** for the evaluation of their Membrane Distillation modules (Memstill consortium) in our installations:

M33 module (1) from Jan. 2009 till Aug. 2009

PT5 modules (3) from Sept. 2009 till Dec. 2009




Conversations with **Fraunhofer Institut** for the evaluation of their modules




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### A World of Salt



Total Global Saltwater and Freshwater Estimates

Category	Percentage	Volume (km³)
Saltwater	97.5%	1 365 000 000
Freshwater	2.5%	35 000 000
- Lakes and river storage	0.3%	
- Groundwater, including soil moisture, swamp water and permafrost	30.8%	
- Glaciers and permanent snow cover	68.8%	

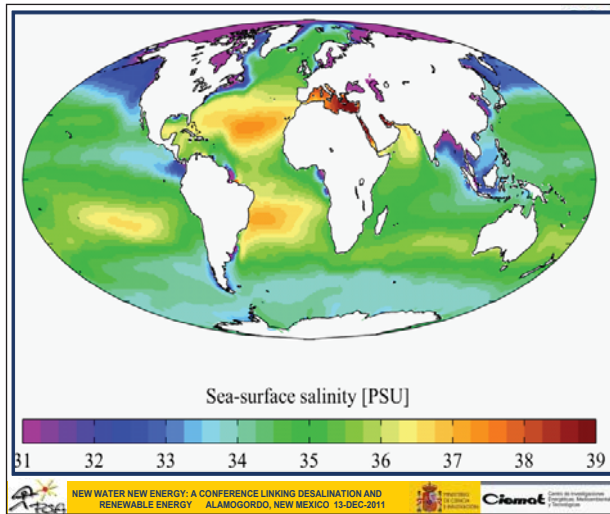
**Types of water according to salinity**

- Freshwaters: up to 1,500 ppm;
- Brackish waters: 3,000-10,000 ppm;
- Seawater: from 10,000 ppm (Baltic Sea) up to 45,000 ppm (Arabian Gulf). The reference average salinity of seawater is 35,000 ppm.

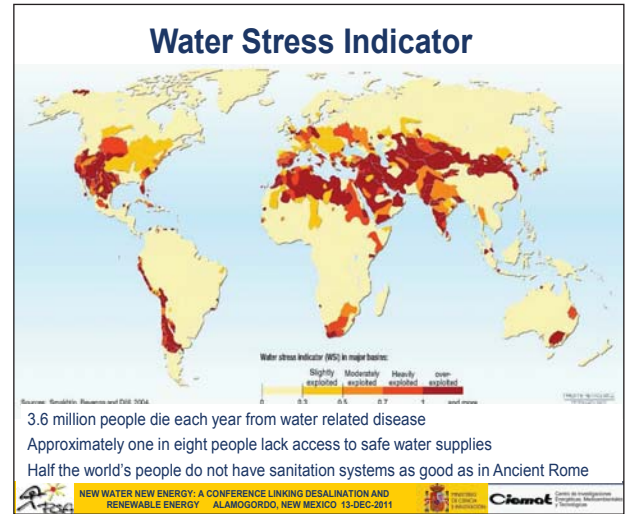
Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational, Scientific and Cultural Organisation (UNESCO, Paris), 1999.

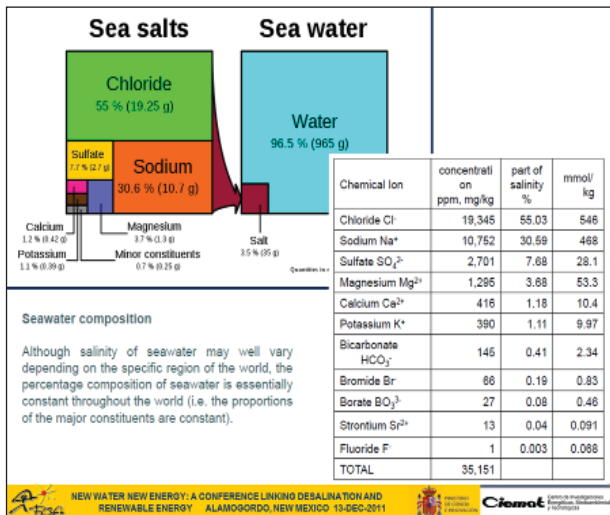
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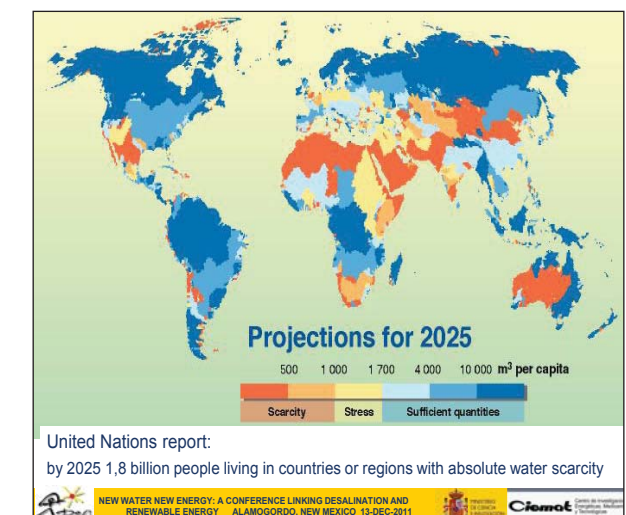
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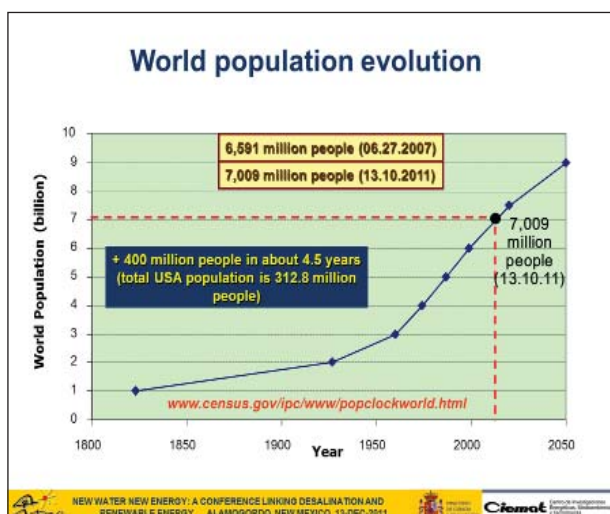
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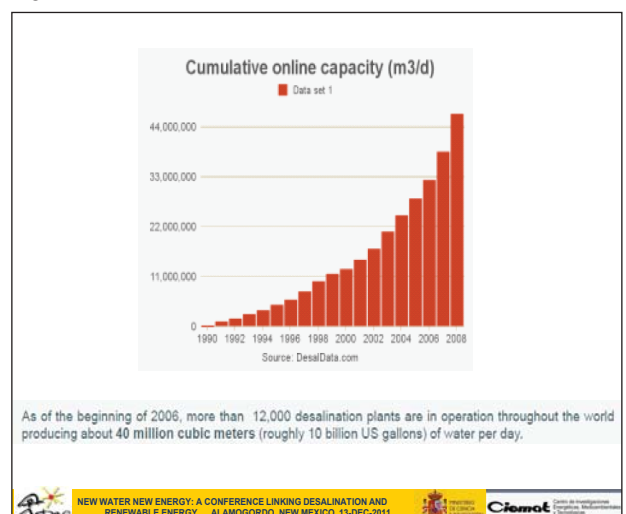
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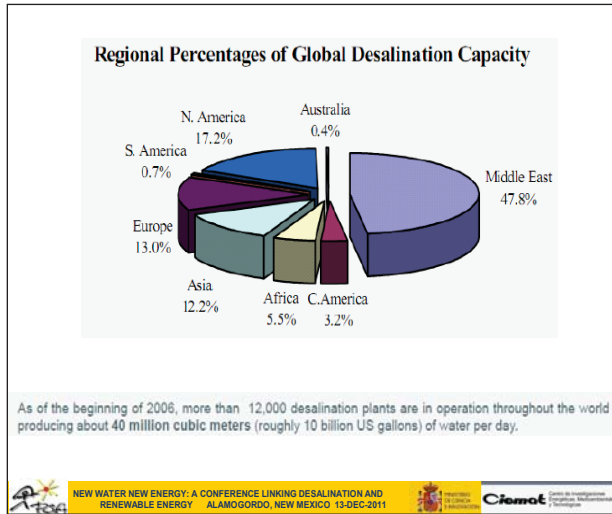
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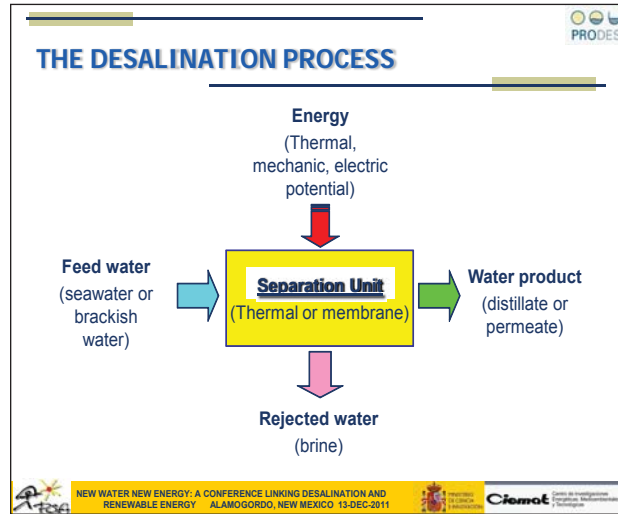
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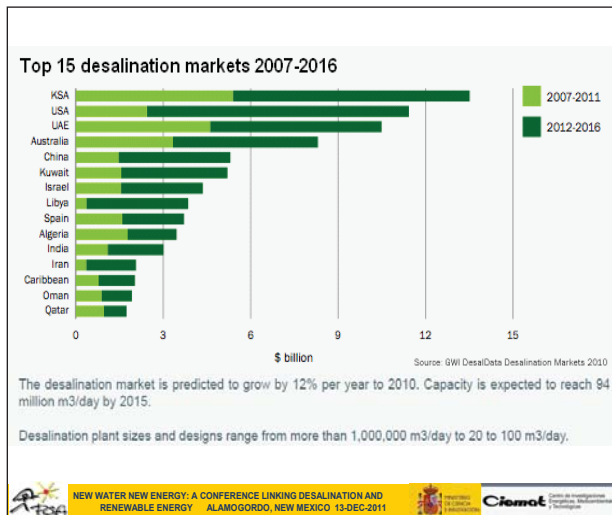
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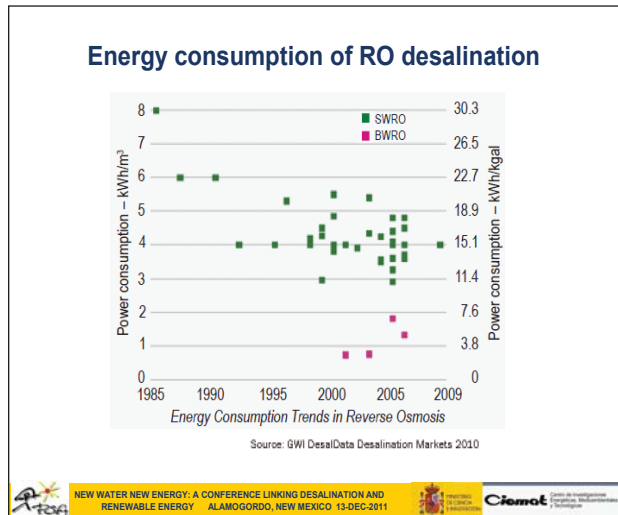
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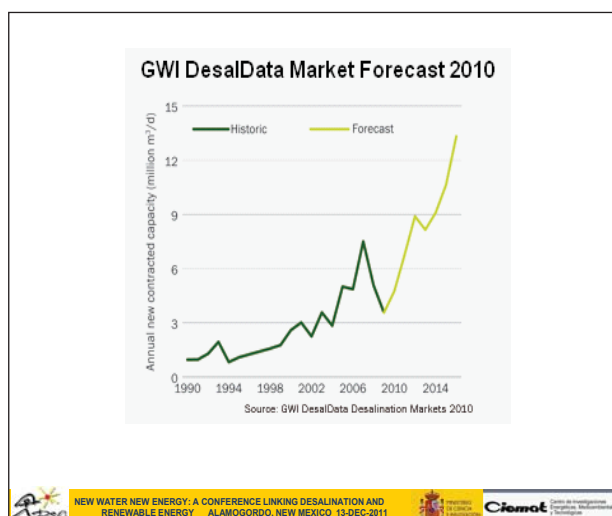
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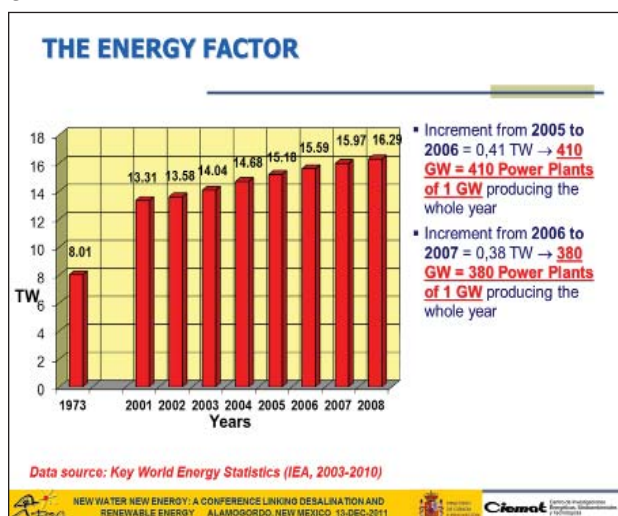
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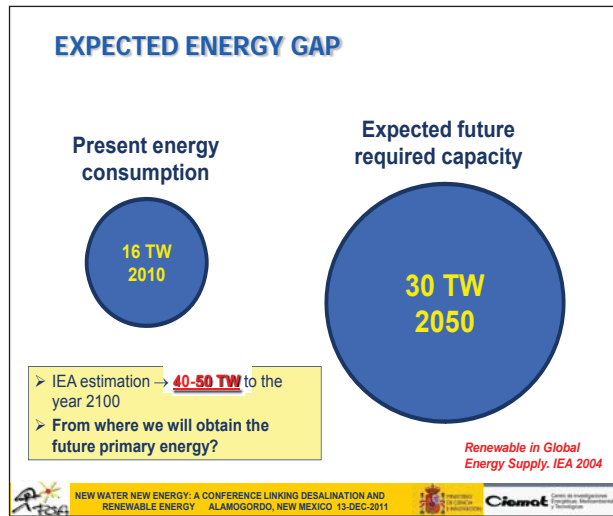
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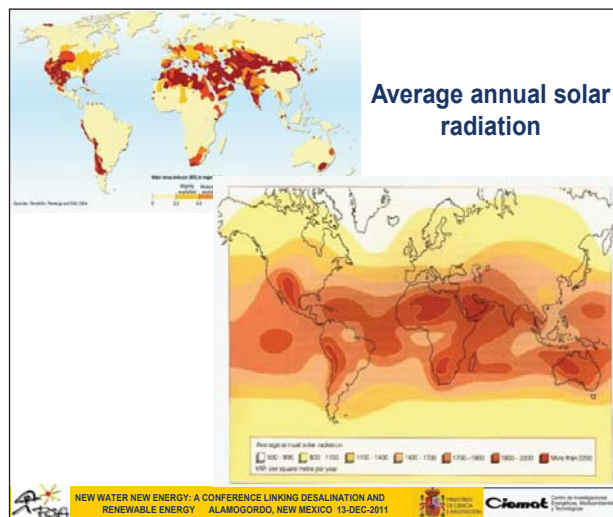


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PRODES Promotion of Renewable Energy for Water production through Desalination

Intelligent Energy Europe

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### Targets and main steps

- ProDes aims to support the market development for RE-desalination, through the following strategy:
  - ✓ Bring together the European players and coordinating their activities
  - ✓ Develop training tools
  - ✓ Identify key players on the local level and connect them with technology providers
  - ✓ Connecting with investors to facilitate product and project development
  - ✓ Working with policy makers to outline a support mechanism
  - ✓ Making the general public aware of the technology

Intelligent Energy Europe

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### ProDes: Main facts

- Co-financed through the “Intelligent Energy for Europe” programme

Intelligent Energy Europe

- > **Contract number:** IEE/07/781/SI2.499059
- > **Starting date:** 1 October 2008
- > **Closing date:** 30 September 2010
- > 14 partners with a focus on Southern Europe

[www.prodes-project.org](http://www.prodes-project.org)

Intelligent Energy Europe

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### Expected results

- A working group will be established within EDS coordinating the RE-desalination community activities
- Training courses will be established enriching the pool of experts on a European level
- The companies will build a network for promoting their products to the niche markets of remote areas in Southern Europe
- The framework conditions in each country will be improved
- The general public will become familiar with the technology

Intelligent Energy Europe

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## Specific objectives of PRODES

- Develop & communicate a road-map on RE-desalination
- Develop courses and provide training for students and professionals
- Facilitate collaboration between RE-desalination technology providers & SMEs on the local level
- Support communication and understanding between technology providers & investors
- Provide recommendations for the improvement of the legislative & institutional conditions

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## PRODES Introducing RE-desal to higher education

RE-desalination introduced in the **higher education** system of relevant countries in order to fill the knowledge gap and help produce the missing specialists that will work with entrepreneurs active in this fast emerging market.

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## Workpackages of PRODES

- Transfer of research results to the market
- Introducing RE-desalination to higher education
- Creating the link with the market
- Mobilizing investment
- Legislative and Institutional Issues

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## PRODES Introducing RE-desal to higher education

THEORY CONTENT (themes are presented with their relative contribution to the total)

1. Introduction: Basics and principles of salt water chemistry. Definition and fundamentals of desalination. Historical overview. [5%]
2. Conventional desalination processes and technologies: State of the art of desalination industry. Current technologies, their evolution and perspectives. [15%]
3. Renewable energies in relation to desalination: State of the art of renewable energy generation technologies and their application to desalination processes. [7.5%]
4. Technologies for desalination powered by renewable energy: Description of the basics of the technology and the development of the engineering of several desalination processes powered by solar energy.
  - 4.1. Solar thermal energy and desalination:
    - 4.1.1. Solar stills: Simple distillation systems based on the passive evaporation of saline water in greenhouse-type devices. [5%]
    - 4.1.2. High capacity solar thermal distillation: Advanced systems of thermal distillation using active solar heating, as multi-effect distillation (MED) and multi-stage flash distillation (MSF). [5%]
    - 4.1.3. Solar thermal membrane distillation: Thermally-driven systems based on hydrophobic micro-porous membranes to separate vapour from a salt water stream through the establishment of a vapour-liquid interface between both sides of the membrane. [7.5%]
    - 4.1.4. Solar thermal humidification/dehumidification: Technologies that replicate the natural cycle of water, with evaporation of saline water and condensation at atmospheric pressure. [5%]
  - 4.1.5. Solar ponds: Thermal desalination processes coupled with salinity-gradient solar ponds as a source of thermal energy. [5%]
  - 4.2. Solar photovoltaic and desalination: Combination of electricity produced by solar photovoltaic energy and desalination using techniques of reverse osmosis and electroanalysis reversal. [10%]
  - 4.3. Wind energy and desalination: Combination of electricity produced by wind energy and desalination using techniques of reverse osmosis and electroanalysis reversal. [10%]
  - 4.4. Other renewable energy sources and desalination: Other processes which associate wave, tidal or geothermal energy generation with desalination. [5%]
5. Design and operation of desalination plants powered by renewable energy: Operation and management of industrial plants. Control and remote monitoring systems. Handling of detrimental effects as scaling, corrosion and fouling. Necessary pre-treatments and post-treatments to guarantee successful plant operation. Optimization of energy consumption and water cost. [10%]
6. Environmental issues on desalination powered by renewable energy: Environmental implications of desalination technologies and their association with renewable energies. [5%]
7. Economic and sustainability issues of desalination powered by renewable energy: Basic economics of the described technologies, costs of operation and maintenance, desalinated water tariff, etc. Sustainability also entails other aspects of society, as the policies of desalination and the involvement of the local community. [5%]

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## PRODES Transfer of research results to the market

Identify the research needs of the industry for developing competitive products ready for the market.

Find know-how pools within the academic community or other research performing entities.

A large number of relevant stakeholders consulted during that process

**RE Desalination Roadmap**  
presented and discussed in a dedicated event within a conference organised by the European Desalination Society (Baden Baden 2009).

**RE Desalination Working Group** which will operate independently from the project to be established and integrated in the structures of the European Desalination Society.

The main task of this group is to update the road-map and follow-up its implementation after the completion of ProDes.

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## PRODES Introducing RE-desal to higher education

PRACTICAL CONTENT (themes are presented with their relative contribution to the total)

1. Practical assessment of solar energy resource: Basics of solar radiation measurement equipment and procedures. Available meteorological data suitable for solar radiation assessment. Characterization of solar radiation resources from in-situ measurements or meteorological data series. [15%]
2. Practical assessment of wind energy resource: Basics of wind energy resource measurement equipment and procedures. Available meteorological data suitable for wind energy assessment. Characterization of wind power resources from in-situ measurements or meteorological data series. [15%]
3. Mass and energy balances in thermal desalination processes, with basic concepts of design: Addressing the physics and chemistry basics of the desalination processes, and how they reflect on the design of the processes and technologies. [10%]
4. Design of low temperature (T < 80°C) solar thermal fields to be coupled to a membrane distillation / humidification-dehumidification desalination system: Optical and thermal characterization of stationary solar collectors. Technical description of solar plant components and configuration. Solar plant dimensioning for prescribed thermal load and solar resources. [10%]
5. Design of intermediate (80°C - T < 200°C) solar thermal fields to be coupled to a multi-effect distillation (MED) plant: Optical and thermal characterization of tracking solar collectors. Technical description of solar plant components and configuration. Solar plant dimensioning for prescribed thermal load and solar resources. [10%]
6. Process design of a conventional membrane desalination process: Major components, process steps and configuration of membrane desalination plants. Optimization of power consumption and water cost. [10%]
7. Design of a solar photovoltaic field to be coupled to a reverse osmosis desalination plant: Photovoltaic panel characterization parameters. Technical description of solar photovoltaic plant components and configuration. Dimensioning for prescribed energy requirements. [10%]
8. Design of a wind energy field to be coupled to a reverse osmosis desalination plant: Wind energy turbine characterization parameters. Technical description of wind energy plant components and configuration. Dimensioning for prescribed energy requirements. [10%]
9. Overview of demonstration installations: Assessment and discussion of real plants, with thorough examination of experiences gained regarding performance, technical issues of operation, main problems encountered and cost analysis. [10%]

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**PRODES**  
**Introducing RE-desal to higher education**

RE-desalination introduced in the **higher education** system of relevant countries in order to fill the knowledge gap and help produce the missing specialists that will work with entrepreneurs active in this fast emerging market.

Separate **courses for professionals** to deliver faster results by training the people that are already active in the market.

The course adapted and offered as an **e-learning course**, which will reach a much wider audience than the specific courses.

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A course on **desalination with solar energy** is offered yearly by EDS (in collaboration with scientists from Plataforma Solar de Almería).

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**PRODES**  
**Introducing RE-desal to higher education**

The course (<http://agora.cognosfera.org/>) is developed into 10 chapters (9 theoretical + 1 practical case) with several intermediate questionnaires for the evaluation.

1. Basic concepts on Desalination and Renewable Energies.
2. Desalination I. Membrane Processes (EDR, RO).
3. Desalination II. Distillation Processes (MED, MSF, H/D, MD).
4. Solar thermal energy and MED.
5. Solar thermal energy coupled with H/D or MD.
6. Solar photovoltaic energy powered RO systems.
7. Wind energy powered RO systems.
8. Other technologies.
9. Non-technical aspects.
10. Practical case (four different cases but only one is mandatory):
  - Case 1. PV - RO system
  - Case 2. Solar - MEH system
  - Case 3. Solar - MD system
  - Case 4. WIND - RO system

e-learning course  
[prodeslearning.com](http://prodeslearning.com)

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**PRODES**  
**Introducing RE-desal to higher education**

**Desalination with Solar Energy**

A 3-day intensive course

Lecturers: Julián Blanco, Diego-César Alarcón Padilla, Guillermo Zaragoza

**April 18-20, 2012, Almería, Spain**

**REGISTER NOW**

Special Offer: Both Barcelona Conference 2012 and Course

	Till March 20	After March 20
EDS Members Course only	€ 2150	
Non-members Course only	€ 2350	
Special Offer - EDS	€ 2400	€ 2700
Special Offer - Non-members	€ 2700	€ 3000

The fee includes 4 nights accommodation, lunches, coffee, dinners, course Workbook and CD.

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**PRODES**  
**Introducing RE-desal to higher education**

E-LEARNING COURSE ON INTRODUCTION TO DESALINATION BY RENEWABLE ENERGIES

HOME VideoTutorials Course About Contact Testimonials Press Statistics

E-LEARNING COURSE ON INTRODUCTION TO DESALINATION BY RENEWABLE ENERGIES

**This** training action is the first online course focused on the topic "desalination by renewable energies".

**The** course summarizes the main relevant aspects of desalination (membrane and distillation processes) and the application of renewable energy technologies for autonomous operation.

**This** e-learning course is based on an interactive and friendly use philosophy and is developed into ten chapters with several intermediate questionnaires for the evaluation. Glossaries, videos, games, and other elements complete the training process. The student will know his/her progress in any moment.

**The** purpose is that the on-line student is the main leader of his/her own training process in a flexible way: the students with high time restrictions will be able to complete it with a minimum dedication of ten hours; on the other hand, the course will offer several complementary training options for the students with more time or specific interest.

The **E-LEARNING COURSE ON INTRODUCTION TO DESALINATION BY RENEWABLE ENERGIES** is organized by the Canary Islands Institute of Technology (IITC) with a long history (since 1990) in testing autonomous desalination units driven by renewable energies. This training activity is developed under the framework of the **PRODES project**, an EU co-financed project within the **Intelligent Energy for Europe Program**.

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**PRODES**  
**Creating the link with the market**

Facilitate collaboration between technology providers and key actors in local markets (municipalities, utilities or small enterprises supplying water treatment or renewable energy equipment and services).

- Municipalities or local utilities gain access to the new technology enabling them to solve their water supply problems.
- Local entrepreneurs generate new business
- Technology providers find markets for their products
- Local companies develop partnerships with technology providers promoting the products in the regions they are active, offering installation, operation and maintenance services.

**Networking** events organized in each country to facilitate contacts between local enterprises and international technology providers.

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### PRODES Mobilizing investment

Crucial for RE-desalination technology developers to improve their products and compete equally with conventional water supply solutions in isolated, water-scarce areas.

Support technology providers in plans to investors for raising capital by:

- conducting a **survey** among technology developers to analyze the nature and size of resources required and the methods they use to raise funds
- approaching potential investors to collect their **feedback** on the fund raising methods followed by the companies and Research Institutes
- developing **guidelines** for technology developers with recommendations on fund-raising strategies and instructions for developing a business plan
- identifying the most promising **niche markets** and concrete **project opportunities** in the involved countries
- identifying opportunities for European companies to **export** innovative desalination systems powered by renewable energies

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### RE Desalination Roadmap

**Objective:**

Outline the vision, barriers and strategies to accelerate the development of RE desalination so that it can become a significant part of the unconventional water supply market

**Structure:**

- **Current status** of the technology
- **Perspectives** of RE desalination
- **Barriers** that hinder the development of the technology
- Outline of the **strategy** to overcome the barriers
- Resources needed for the **implementation** of the technology

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### PRODES Legislative and Institutional Issues

Collaborate with key-decision makers to improve framework conditions for promotion of water production by RE-desalination and ensure adequate legal protection of the consumers and the environment.

An assessment on how the **framework conditions** in the target countries can affect the implementation of RE-desalination.

Concrete **recommendations** for improvements developed and communicated to **key decision-makers** like public authorities and policy makers through an event in each country.

Realistic **targets** defined for the future regarding the share of water produced by RE-desalination on the overall desalinated water produced.

Concrete **suggestions** made for **local, regional or national schemes** to promote the more efficient use of current public spending to support sustainable solutions in line with the social and environmental policies.

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### Current status of the RE-desalination technology

Technology	Percentage
PV RO	31%
OTHERS	15%
WIND RO	12%
SOLAR MD	11%
SOLAR MED	9%
SOLAR MEH	9%
SOLAR MSF	7%
PV ED/EDR	3%
HYBRID	3%

Technology combination of the 131 RE-desalination plants reviewed in 2009

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### RE Desalination Roadmap

The Roadmap for RE-desalination is one of the main project results.

Developed with input from all target groups and extensive review of existing work, carried out by the ProDes consortium.

Final document widely distributed and a working group established which will lead the implementation of the strategy outlined in the Roadmap.

[www.prodes-project.org](http://www.prodes-project.org)

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### Current status of the RE-desalination technology

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

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

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### Main barriers of the RE-desalination technology

Barrier	Effect	Strategy
<b>Technological</b>		
Most RE-D <sup>1</sup> are not developed as a single system but are combinations of components developed independently	<ul style="list-style-type: none"> <li>→ Poor reliability</li> <li>→ increased water cost</li> </ul>	

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### Main barriers of the RE-desalination technology

Barrier	Effect	Strategy
<b>Technological</b>		
Desalination development focuses on ever larger systems	→ Lack of components appropriate for small scale desalination plants, typical of many RE-D combinations	

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### Main barriers of the RE-desalination technology

Barrier	Effect	Strategy
<b>Economical</b>		
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	

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### Main barriers of the RE-desalination technology

Barrier	Effect	Strategy
<b>Economical</b>		
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	

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### Main barriers of the RE-desalination technology

Barrier	Effect	Strategy
Institutional and Social		
Negative perception of desalination by the population	→ Opposition of local communities to installation	

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### R&D priorities for the RE-desalination technology

- Components suitable for specific 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 optimize performance and minimize maintenance
  - Obtain certification for food proofed systems for materials that are in contact with the water
- Components suitable for the smooth and efficient coupling of the existing desalination with renewable energy technologies

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### Main barriers of the RE-desalination technology

Barrier	Effect	Strategy
Institutional and Social		
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"> <li>Promote simpler and straightforward processes to obtain a license for independent water production</li> <li>Lobby for greater cooperation between the power and water branches in governmental and non-governmental institutions</li> </ul>
Lack of training and infrastructure	<ul style="list-style-type: none"> <li>→ Reduced plant availability</li> <li>→ Lack of personnel for operation and maintenance</li> </ul>	<ul style="list-style-type: none"> <li>Support education and training at all levels</li> </ul>
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"> <li>Encourage adequate consideration of socio-cultural factors and establishment of communication channels with the end-users</li> </ul>

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### R&D priorities for the RE-desalination technology

- Development of elements that will make RE -desalination robust for long **stand-alone operation** in harsh environments
- Development of components and control systems that allow desalination technologies to deal better with **variable energy input**
  - Hybrid systems
  - Energy storage
  - Salinity gradient systems
- Development of **co-generation** systems that produce water and power

The fact that RE-Desalination belongs to both water and energy sectors, has been a barrier for securing R&D funding since neither sector felt totally responsible for this area

- reverse this situation and use it as an opportunity to include RE-D priorities in both.

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### Targets for the RE-desalination technology

New desalination plants to be constructed up to 2016 are expected to be worth, in total, over \$64 billion.

RE -desalination community 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.

- Plants with capacities below 1,000 m<sup>3</sup>/day: 15 to 20% of the market share aimed by RE -desalination, using existing technologies like wind-RO, wind-MVC, solar MD, solar MEH and PV-RO.
- 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.

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### Legislative and institutional issues

**Greece:**

Development of a specific framework for the desalination of brackish and seawater

Priority should be given to implementation of small autonomous RE Desalination units in remote areas (small islands).

- new RES Law 3851/2010, already provides priority on the licenses authorization for the implementation of RE desalination projects.

Public or private projects and activities categorized according to their impacts on the environment. Desalination units >100 m<sup>3</sup>/day: serious risks for the environment, <100 m<sup>3</sup>/day: subject to general specifications, terms and restrictions for reasons of environmental protection.

- proposed: <50 m<sup>3</sup>/day to belong at Category C (insignificant risk or nuisance or degradation to the environment).
- <10 m<sup>3</sup>/day for Municipal Use, exempted from the licenses procedures

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### Legislative and institutional issues

**Spain:**

RE is a key and powerful industrial sector in Spain with a very significant contribution to electricity generation: 24.7 % of electricity in 2009 and very promising role for the next decade (42.3% in 2020).

The subsidy strategy (Feed-in tariffs) has allowed this high development of the RE sector.

Initiatives on subsidies, as the one, focused on desalination in the Canary Islands, addressed to reduce water prices in the region, which are higher than the average price in the country.

→ proposed: specific subsidy to desalinated water produced by RE resources.

Desalination included in the new Plan for Renewable Energy in Spain (2011-2020).

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### Activities of the RE-desalination Working Group

- Define the R&D priorities that will benefit the entire sector and coordinate activities in this direction
  - R&D worth more than 100 M€ in the period 2014 to 2020
- Support the wider establishment of RE-desalination education and training activities
  - 2,000 students and 500 professionals yearly within Europe by 2015
- Supervise and coordinate a comprehensive market analysis
- Develop and promote appropriate legal structures and policies
  - both on a country by country basis
- Raise awareness about the technology and demonstrate its market potential

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### RE-desalination Working Group

**Working group on Renewable Energy Desalination** to promote the use of desalination powered by renewable energy as an environmentally friendly and decentralized solution for sustainable water supply.

Work of the group guided from the Road Map.

Participation open to stakeholders → register in [www.prodes-project.org](http://www.prodes-project.org)

There are already more than 100 registered members that will be meeting annually in events coordinated with the conferences organized by the European Desalination Society.

Next meeting to take place parallel to the "Desalination for the Environment, Clean Water and Energy" conference in 23-26 April 2012 in Barcelona (Spain).

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### RE-desalination Working Group

[www.prodes-project.org](http://www.prodes-project.org)

working group

**RE Desalination Working Group Registration**

The ProDes project ([www.prodes-project.org](http://www.prodes-project.org)) has initiated the working group on Renewable Energy Desalination. The main mission is to help the market development of the technology and its application in different parts of the world. The ProDes roadmap outlines a strategy for the sector, which is guiding the activities of the working group.

You are invited to become a member of the group and contribute to its exciting work. Please fill in the form and submit it to become a member and receive information about the upcoming meetings.

**1. Please provide your contact information below so that we can contact you with updates on the working group**

Create your [prodes@prodes-project.org](mailto:prodes@prodes-project.org) with EnergyMailing, the world's leading questionnaire tool.

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**Desalination** *Meeting Online*

- Abstract submission
- Call for Papers
- Pre-Conference Event
- Post-Conference Events
- Registration
- Visas
- Exhibits
- Sponsorship
- How to Reach
- Accommodations
- Contact
- Join EDS

**Pre-Conference Event**  
April 18-20, 2012, Almeria, Spain  
3-day course on Desalination with Solar Energy

**The 3rd Osmosis Membrane Summit**  
Barcelona - April 19-21, 2012

**AEDyR**  
ASOCIACIÓN ESPAÑOLA DE DESALINACIÓN Y REUTILIZACIÓN

**Conference and Exhibition on DESALINATION FOR THE ENVIRONMENT CLEAN WATER AND ENERGY**

April 23-26, 2012  
Barcelona, Spain

**DEADLINES**

Notification of acceptance: 15 December 2011  
Papers 29 February 2012

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### Renewable Energy

Renewable energy resource: ilimitably available and not generate pollution

```

    graph TD
        Light --> PV[Conversion to electricity by photovoltaic cells]
        Light --> PS[Plants produce food for photosynthesis]
        Heat --> DUC[Direct use of heat for heating and cooking by using solar heaters and solar cookers]
        Heat --> WT[Causes winds, tides, ocean waves]
        Heat --> RHF[Rain and hence rivers, water falls etc]
        
        PS --> AN[Animals]
        PS --> FC[Forest fossilized to coal]
        PS --> MA[Marine animals fossilized to crude oil, gas]
        
        AN --> AD[Animal dung used for producing gober gas]
        
        WT --> WE[Source of wind energy, and ocean energy]
        RHF --> HE[Source of hydroelectricity]
    
```

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### Renewable Energy

Limitations:

- Intermittent, difficult to predict and fluctuant
- Occupy large areas
- Adverse impact on the environment:
  - visual impact
  - noise
  - influence marine and aerial life
- Size of RE power plants is limited (few MW)
  - despite being one of the most used, hydropower is not considered because it is associated to high availability of water (desalination not necessary)

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### Renewable Energy

**Power oriented RE technologies are based on three major resources:**

- Solar radiation;
- Wind;
- Waves.

Solar fotovoltaic / thermal



Wind



Waves



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### Renewable Energy for Desalination

A number of different technologies allow the exploitation of renewable energy resources, providing energy as heat, power or even a combination of both energy forms

heat production RE technologies

- Solar thermal
- Biomass
- Geothermal


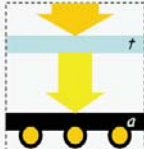
power production RE technologies

- Solar Thermal electricity
- Wind Power
- Wave Power
- Solar Photovoltaic

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### Solar thermal energy

**Main elements of a solar collector**

- Cover (t)
- Absorber (a)
- Reflector (r)

Optical and thermal features determine the collector efficiency ( $\eta$ ).

$$\eta = \frac{\dot{Q}}{A_c G_{col}}$$

- $\dot{Q}$ : useful power [W]
- $A_c G_{col}$ : available power [ $m^2 \times W/m^2$ ]
- $A_c$ : Area of collector
- $G_{col}$ : Solar input power per  $m^2$

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### Renewable Energy

**Heat oriented RE technologies are based on three major resources:**

- Solar radiation;
- Biomass / Biogas;
- Geothermal heat.

Solar based solutions are particularly suitable for desalination purposes, given the resource availability in most of the hydric stressed areas

Solar thermal



Biomass



Geothermy

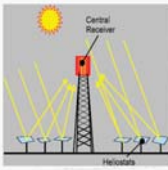


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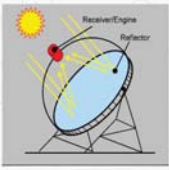
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### Solar thermal electricity

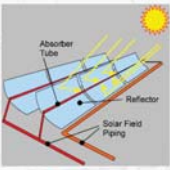
Solar thermal collectors concentrate solar radiation into heat energy to produce steam, which then turns a turbine to produce electricity.



Central Receiver Systems



Dish-Stirling Systems



Parabolic-Trough Collectors

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### Solar photovoltaic energy

Solar PV energy is based on the electric conversion of solar radiation on a solar cell, by means of the photovoltaic effect

Labels in diagram: SUNLIGHT, ANTI-REFLECTIVE COATING, FRONT CONTACT, SPECIALLY TREATED SEMI-CONDUCTOR MATERIAL, BACK CONTACT, PV modules

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### Wave energy

**Examples**

- Wind speed = 10 m/s
- Fetch length = 100 km
- wave height = 1.6 m
- wave period = 6 sec
- wave power density = 7 kW/m

- Wind speed = 12 m/s
- Fetch length = 1000 km
- wave height = 5.0 m
- wave period = 12 sec
- wave power density = 135 kW/m

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### Wind energy

Wind turbine generators convert mechanical energy from the wind to electrical energy.

Labels: Horizontal axis, Vertical axis, Multi blade turbines

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### Wave energy

Worldwide exploitable wave energy resource estimated to be 2 TW  
Intermittent and variable

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### Geothermal energy

Labels: Rainwater, Geothermal Reservoir, Hot Water, Hot Rock

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### Tidal energy

Labels: Sun, Moon, Earth, Neap Tide, Spring Tides

Current best estimate for total worldwide exploitable resource is calculated to be 3 – 4 TW

- 1,500 GW in the UK, Canada and Alaska
- 1,600 GW in China and Japan
- 145 GW in Australia and New Zealand

Labels: Tidal height (cm), March 2000

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### Tidal energy

Tidal stream



Portaferry, Northern Ireland

Tidal barrage



La Rance, France

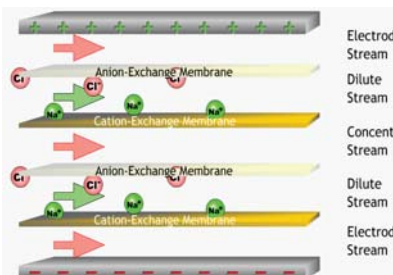
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### Electro Dialysis

Salt water flows through channels made with ionic selective membranes. An electric field forces ions to cross relevant selective membranes, thus generating two streams:

- dilute stream;
- concentrate stream



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### Renewable Energy for Desalination

Depending on the desalination process in use, energy might be required either as heat, power or even a combination of both energy forms

**heat-driven processes**

- Multiple Effect Evaporation
- Thermal Vapour Compression
- Multi Stage Flash
- Membrane Distillation
- Humidif.-Dehumid.

**power-driven processes**

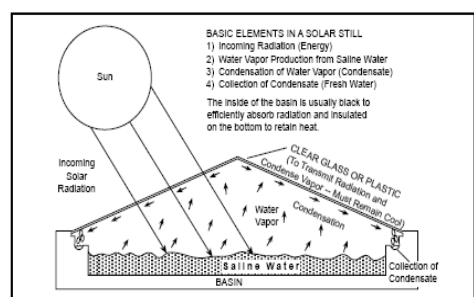
- Mechanical Vapour Compression
- Reverse Osmosis
- Electro Dialysis

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### Solar Stills

#### Basin-type solar still



**BASIC ELEMENTS IN A SOLAR STILL**

- 1) Incoming Radiation (Energy)
- 2) Water Vapor Production from Saline Water
- 3) Condensation of Water Vapor (Condensate)
- 4) Collection of Condensate (Fresh Water)

The inside of the basin is usually black to efficiently absorb radiation and insulated on the bottom to retain heat.

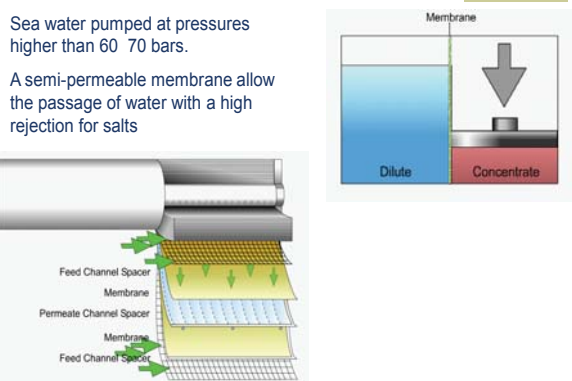
Diagram of a solar still USAID

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### Reverse Osmosis

Sea water pumped at pressures higher than 60-70 bars. A semi-permeable membrane allows the passage of water with a high rejection for salts

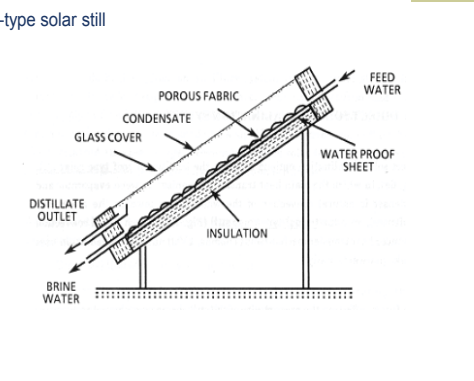


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### Solar Stills

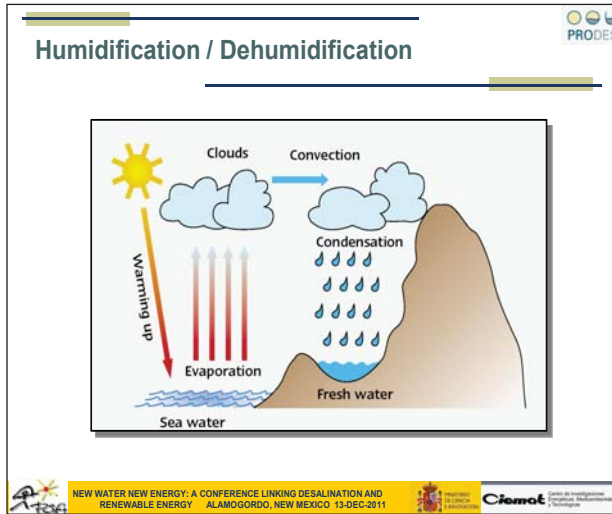
#### Wick-type solar still



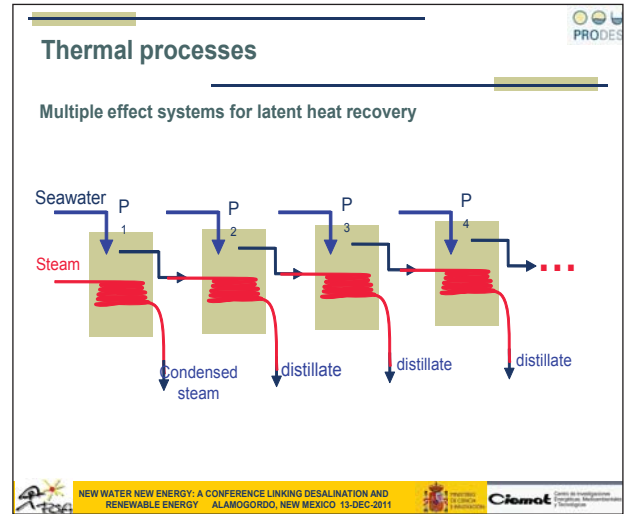
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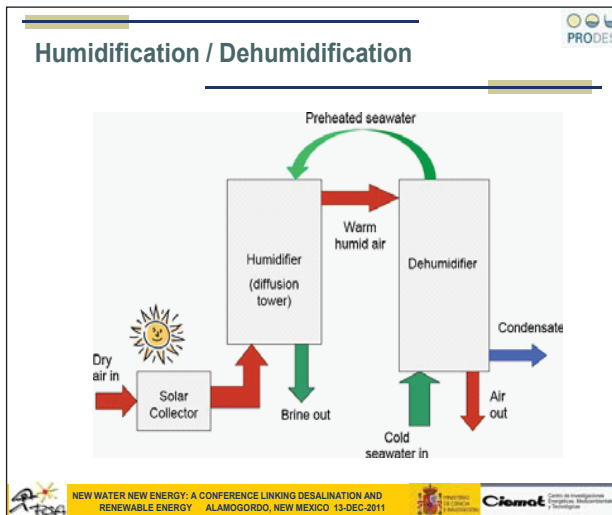
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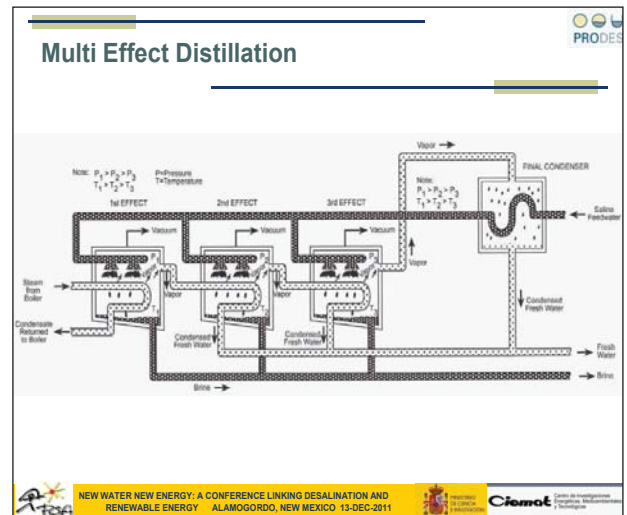
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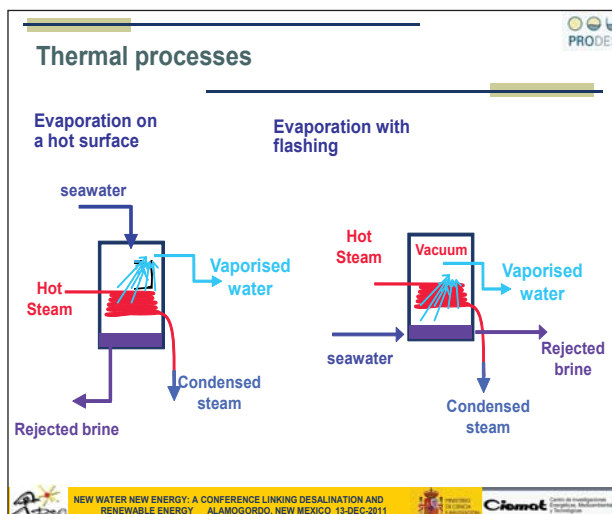
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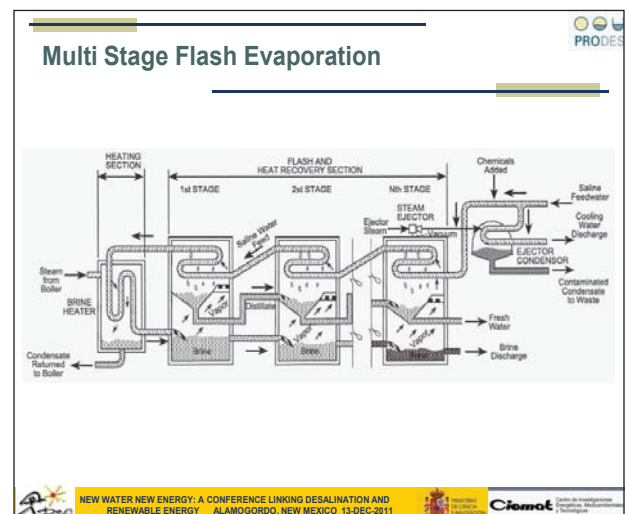
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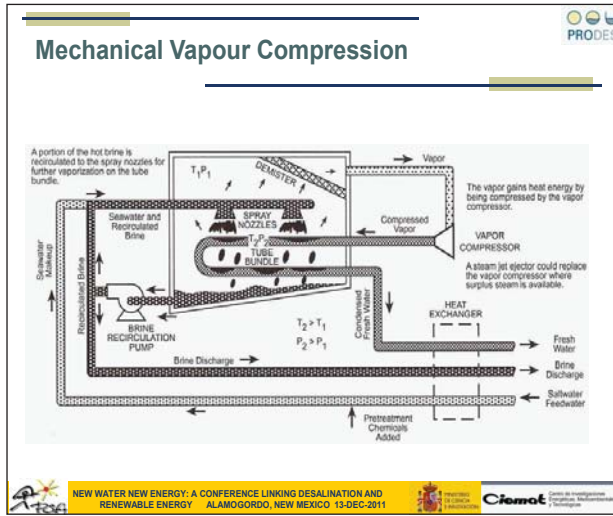
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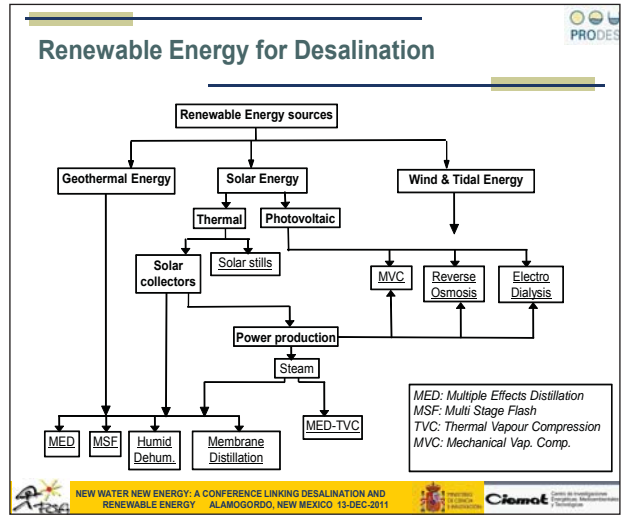
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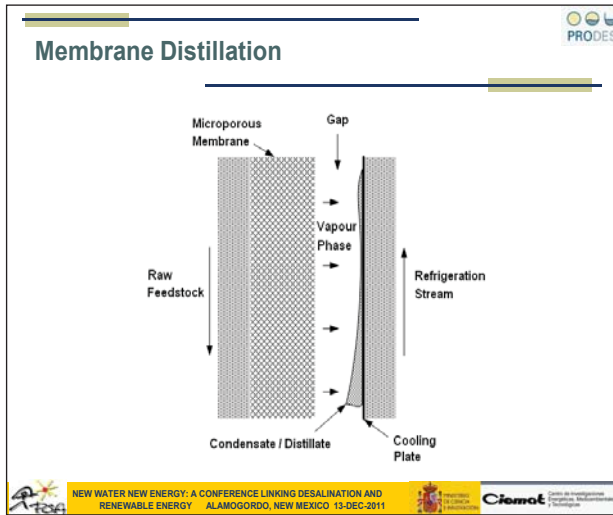
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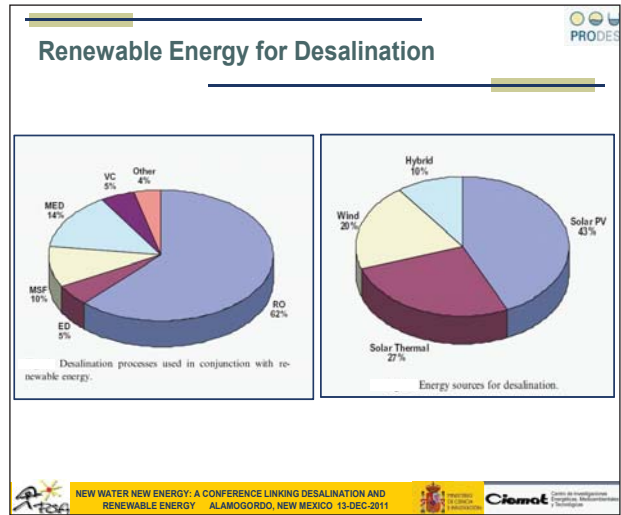
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### Desalination demands

**Mechanical processes**

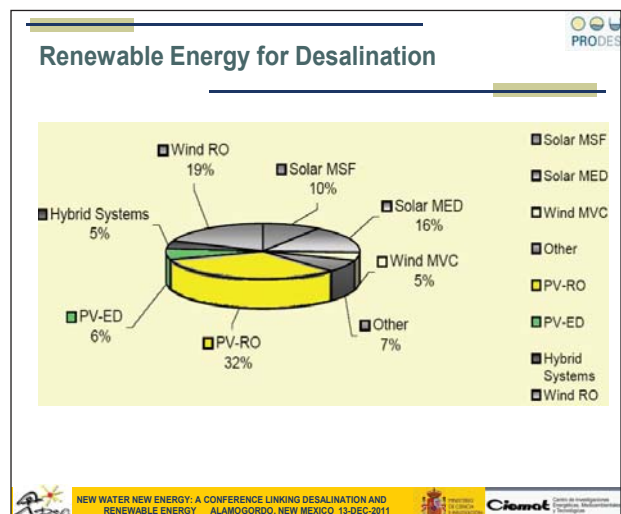
<p><b>MVC</b></p> <ul style="list-style-type: none"> <li>Mechanical power: 7 - 15 kWh/m<sup>3</sup> produced water</li> <li>Sea water intake from 3 to 5 times produced water</li> </ul>	<p><b>RO</b></p> <ul style="list-style-type: none"> <li>Mechanical power 4 - 7 kWh/m<sup>3</sup> produced water</li> <li>Sea water intake from 2 to 4 times produced water</li> </ul>
--	---

**Thermal processes**

<p><b>MED</b></p> <ul style="list-style-type: none"> <li>Low pressure steam (0.8 bar) in a rate of 8 to 12 % of product water</li> <li>Electric power 1.5 - 3 kWh/m<sup>3</sup> product water</li> <li>Seawater intake from 5 to 6 times product water</li> </ul>	<p><b>MSF</b></p> <ul style="list-style-type: none"> <li>Low pressure steam (2 bar) at a rate of 10 to 12 % of product water</li> <li>Electric power 2.5 - 4 kWh/m<sup>3</sup> product water</li> <li>Seawater intake from 3 to 9 times product water</li> </ul>
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### Current status of the RE-desalination technology

**MAGE WATER MANAGEMENT GmbH - Watercone®**

Type: solar still  
Location: Yemen  
Capacity: 1.5 l/d  
Year of Installation: 2007  
Still in operation: yes

Type: solar still  
Location: Yemen  
Capacity: 1.5 l/d  
Year of Installation: 2007  
Still in operation: yes

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### Current status of the RE-desalination technology

**Solar Dew International**

Type: Solar Dew Two – Household application  
Location: under development  
Capacity: 8.5-15 l/day  
Year of Installation: 2010 expected  
Usage: Household pure water supply

Type: Solar Dew One  
Location: South West France  
Capacity: 7-12.5 l/day  
Year of Installation: 2009  
Still in operation: yes  
Usage: drinking water production

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### Current status of the RE-desalination technology

**RSD Solar Rosendahl Systems**

Type: F8, 8 modules 1.25 x 1.25 m<sup>2</sup>  
Location: Alexandria /Egypt  
Capacity: average ca. 50-60 l/d  
Year of Installation: 2004  
Still in operation: yes  
Usage: drinking water for desert camp

Type: F8, 6 modules 1.25 x 1.25 m<sup>2</sup>  
Location: Cuba  
Capacity: average ca. 40 l/d  
Year of Installation: 2006  
Still in operation: yes  
Usage: drinking water for a family

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### Current status of the RE-desalination technology

**Solar Dew International**

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### Current status of the RE-desalination technology

**RSD Solar Rosendahl Systems**

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### Current status of the RE-desalination technology

	2.1 Watercone	2.2 RSD	2.3 Solar Dew
Capacities available	1.5 l/d	6 l/m <sup>2</sup> /d average, scalable to any capacity required	Basic unit: 6-30 l/m <sup>2</sup> /day. Available products range between 4 and 5,000 litres/day
quality of produced water	Distillate	Distillate	Distillate
pre-treatment	None	Sieving/filtration needed when raw water has organic growth	Removal of sediment through a pre-filter and sedimentation.
post treatment requirements	Remineralisation if desired to improve the taste	Remineralisation if desired to improve the taste	Remineralisation if desired to improve the taste
O&M requirements	Cleaning of the cone and the dish	Regular cleaning & rinsing of the collector surface, when dusty	The brine requires disposal at weekly intervals. After a minimum of 3 years the membrane modules need replacement - a simple task requiring a minimal amount of time

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### Current status of the RE-desalination technology



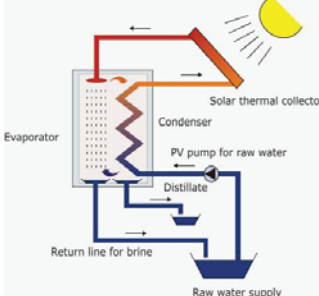
- Technology: Multi Effect Solar Basins
- Daily Capacity (nominal): 15-18 liter/m<sup>2</sup>
- Year of installation: 2005
- Location: Gran Canaria (Spain)
- Installed by: Solar-Institut Jülich

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### Current status of the RE-desalination technology

#### MAGE WATER MANAGEMENT GmbH – MEH Systems

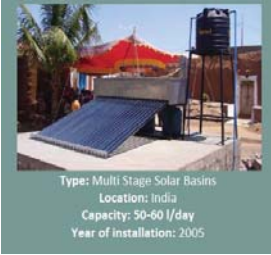
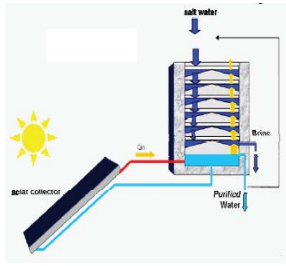


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### Current status of the RE-desalination technology

#### IBEU, Solar Institut Juelich AQUASOL


Type: Multi Stage Solar Basins  
Location: India  
Capacity: 50-60 l/day  
Year of installation: 2005

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### Current status of the RE-desalination technology

#### TERRAWATER GmbH – Solar distillation



Type: Module TW 5  
Location: Thailand, using industrial waste heat  
Capacity: 5m<sup>3</sup>/day  
Year of installation: 2009  
Still in operation: yes  
Usage: waste water concentration, RO brine, Pilot

Type: Module TW 5  
Location: India, using industrial waste heat  
Capacity: 5m<sup>3</sup>/day  
Year of installation: 2009  
Still in operation: yes  
Usage: waste water concentration, RO brine, Pilot

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### Current status of the RE-desalination technology

#### MAGE WATER MANAGEMENT GmbH – MEH Systems




Type: Solar Thermal MidSal™ 5000 Desalination System  
Location: Dubai, 150 m<sup>2</sup> flat plate collectors  
Capacity: 5,000 l/d  
Year of installation: 2008  
Still in operation: Yes  
Usage: Drinking water for a desert camp



Type: Solar Thermal MiniSal™ 1000 Desalination System  
Location: Cyprus, 45 m<sup>2</sup> flat plate collectors for the desalination system  
Capacity: 1,000 l/d  
Year of installation: 2007  
Still in operation: Yes  
Usage: For water losses in a local swimming pool

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### Current status of the RE-desalination technology

#### SOLAR SPRING - Oryx 150

Type: Oryx 150  
Location: Tenerife, Spain  
Capacity: 120l/day  
Year of installation: 2007  
Still in operation: yes

Type: Two-Loop System  
Location: Gran Canaria, Spain  
Capacity: 1800l/day  
Year of installation: 2005  
Still in operation: extension 3m<sup>3</sup>/day

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### Current status of the RE-desalination technology

#### SOLAR SPRING - Oryx 150

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### Current status of the RE-desalination technology

#### Canary Islands Institute of Technology (ITC) – DESSOL®

Type: PV-RO for brackish water  
Location: Morocco  
Capacity: 1,000 l/h  
Year of installation: 2008  
Still in operation: yes  
Usage: supply to local people

Type: PV-RO for brackish water  
Location: Tunisia  
Capacity: 2,100 l/h  
Year of installation: 2006  
Still in operation: yes  
Usage: supply to local people

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### Current status of the RE-desalination technology

	3.3 AQUASOL	3.2 MEH System	3.3 Ferrawater	3.4 Solar Spring
Capacities available	30-70 l/d 100-250 l/d hybrid system Modular up to 3m <sup>2</sup>	Minisal™ 1000 l/d Midasal™ 5000 l/d Megasal™ 10000 l/d Maxisal™ 50000 l/d	TW 5 Modules up to 6000 l/d combining TW5 modules up to 300 m <sup>3</sup> /day	Compact System: 150 l/d Two Loop System: 1,000 l/d
quality of produced water	Distillate	Distillate	Distillate	Distillate
pre-treatment	Use of a sand filter if necessary - depends on the feedwater	30 µm backwash filter or sand filter	in some cases coarse filter < 1mm	Standard pre-filtration at 80-150 micron filter element depending on raw water quality
post treatment requirements	Remineralisation if desired to improve the taste	Remineralisation if desired to improve the taste	Remineralisation if desired to improve the taste	Remineralisation if desired to improve the taste
O&M requirements	plants can be cleaned by simple detouring of the condenser steel trays	cleaning of solar thermal collectors and PV (monthly) Backwashing of raw water filter if turbid raw water is used (weekly 10 years) Exchange of evaporation sheets (heavy and cheap, every 1-2 years) Maintenance of circulation pumps (every 5 years)	Visual check every Month (water tightness) Change pumps and ventilator (every 3 years) Change humidifier material (every 3 years) cycles depending on raw water quality	Every 2 years acid and chlorine cleaning (depending on the raw water source) New MID-Module every 3 years, Pump every 10 years

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### Current status of the RE-desalination technology

#### ENERCON GmbH – Wind RO

Type: Seawater Desalination System  
Location: Greek Island  
Capacity: 500m<sup>3</sup>/day  
Year of installation: 1998  
Still in operation: no, until 2004  
Usage: Public water supply

Type: ED5 1200 SW  
Location: Aurich, Germany  
Capacity: 1200m<sup>3</sup>/day  
Year of installation: 2004  
Still in operation: yes  
Usage: Demonstration

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### Current status of the RE-desalination technology

Technology: solar MED  
Energy Source: Solar thermal (CPC collectors)  
Daily Capacity (nominal): 72m<sup>3</sup>/d  
Year of installation: 2005  
Type of installation: R&D  
Location: Almeria, Spain  
Installed by: Plataforma Solar de Almeria; Aquasol Project

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### Current status of the RE-desalination technology

#### WME – Wind driven vapour compression

Type: wind-vapour compression  
Location: Rügen Island, Germany  
Capacity: 15 m<sup>3</sup>/h  
Year of installation: 1995  
Still in operation: yes  
Usage: drinking water

Type: wind-vapour compression  
Location: Syml, Greece  
Capacity: 20m<sup>3</sup>/h  
Year of installation: 2009  
Still in operation: yes  
Usage: drinking water

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### Current status of the RE-desalination technology

	4.1 DESOC	4.2 Emmon	4.3 WINE
Capacities available	1.5-20 m <sup>3</sup> /d	300-1.200 m <sup>3</sup> /day	300-3000 m <sup>3</sup> /day
specific energy consumption	8W: 0.55-1.7 kWh/m <sup>3</sup>	5W: 2.5 kWh/m <sup>3</sup>	7-11 kWh/m <sup>3</sup>
quality of produced water	150-450 ppm	WHO/EU requirements	< 5ppm Remineralisation possible if required
pre-treatment	Physical: Sand filter + carbon active filter + cartridge filter Chemical: Sodium hypochlorite - Acid - Jetting	project specific	Raw filtration
post treatment requirements	Sodium hypochlorite	no	no
O&M requirements	Daily: Visual inspection, flushing the membranes Weekly: Cleaning the PV, chemical product stocks, cleaning the filters Monthly: Revision of leakages, batteries density Yearly: Checking the electric connections, batteries state, chemical cleaning of membranes, replacement of cartridges 4.5 years change of membranes	Remote control system and fully automatic operation Care-taker on site for small O&M works is recommended Annual O&M by Enercon	Automatic operation, lubrication of bearings once a year

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### PV energy

The current and power produced by a PV cell vary according to its voltage under given temperature and irradiation conditions

Under reference irradiation and temperature conditions we obtain the characteristic I-V curves.

The values under reference conditions are called Peak or reference values.

Cells inter-comparison are made upon characteristic I-V curves.

$P_{mp}$  - maximum (peak) power  
 $I_{mp}$  - current at peak power  
 $V_{mp}$  - voltage at peak power

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### PV energy

Solar PV energy is based on the electric conversion of solar radiation on a solar cell, by means of the photovoltaic effect.

Free electrons created by absorption of photons are in excess in the N layer of a semi-conductor, migrating to P layer through an external circuit, thus creating an electric current.

$E = h \nu$

Similar cells are connected in series to form a PV module.

PV modules are connected in series or parallel to assemble a Solar panel with the required current and voltage.

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### PV energy

The current and power produced by a PV cell vary according to its voltage under given temperature and irradiation conditions

I-V curves for a PV generator at different solar radiation levels.

When connected to a 12 V battery the operating zone lies on the gray band.

$P_{mp}$  - maximum (peak) power

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### PV energy

#### Functional principle of a silicon solar cell

Different types of conventional solar cells are available for typical applications.

Thin film technologies are presently under strong research effort, enabling higher efficiencies and applications on a high diversity of substrates.

Typical efficiency

- amorphous silicon: ~5%
- multicrystalline silicon: ~15%
- monocrystalline silicon: ~20%

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### PV energy

Two technologies currently dominate the PV market

Single Crystals:

- highest efficiency.
- slow process.
- high costs.

Poly (multi) crystalline:

- low cost.
- fast process.
- lower efficiency.

Auxiliary equipment for PV systems

Storage units:

- Lead/liquid batteries.
- Alkaline batteries.
- Charge controllers.
- DC/AC Inverters.

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### Coupling of PV with RO desalination

Photovoltaic Reverse Osmosis is today one of the most promising coupling between desalination and RES.

Two configurations are possible:

- Stand alone PV-RO plants
- Grid connected PV-RO plants

Where the system is grid-connected the plant can operate continuously as a conventional plant and the renewable energy source merely acts as a fuel substitute. Stand alone plants need technological development allowing for the intermittent energy source.

The main problem with stand alone plants are the effects of not constant power input on the membrane operability and durability: it has to cope with unpredictable phenomena due to start-stop cycles and partial load operating.

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### Coupling of PV with RO desalination

Power requirements (with pressure exchanger)

Overall power required = 133,5 kW  
Daily energy consumption = 3203 kWh  
Accumulator = 4271 kWh  
Surface = 4617 m²

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### Coupling of PV with RO desalination

Overall layout of a PV-RO plant (including electrical facilities)

Grid connection

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### Coupling of PV with RO desalination

Description of the case

- Estimation of the basic design of a seawater to be powered by a RE stand alone system consisting of a PV with a backup (batteries) system.
- Main input data:
  - Population: 250 inhabitants
  - Per capita water consumption: 50 l/day
  - Feed water type: seawater

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### Coupling of PV with RO desalination

Power requirements (no pressure exchanger)

Overall power required = 263,5 kW  
Daily energy consumption = 6323 kWh  
Accumulator = 8432 kWh  
Photovoltaic field Surface = 9114 m²

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### Coupling of PV with RO desalination

Calculation process

1. Calculation of RO unit data
2. Calculation of demanded energy
3. Calculation of energy to be stored in batteries
4. Calculation of energy produced from the PV modules

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### Coupling of PV with RO desalination

PRODES

Promotion of Renewable Energy for Water production through Desalination

#### RO unit. Basic diagram

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### Coupling of PV with RO desalination

PRODES

Promotion of Renewable Energy for Water production through Desalination

#### Energy demanded by the system

$Energy = Power \times Time$

Element	Operation time (h)	Power (W)	Energy (Wh)
Feed pump	7.5	1,167	8,752
HP pump	7.5	8,750	65,625
<b>TOTAL</b>			<b>74,377</b>

#### Energy storage calculation

The autonomous electric system has a set of energy losses, which include the inefficiencies of the different components: batteries, inverter and others. The energy that must be stored has to take into account these losses by a global efficiency factor: R. A usual value is 0.7. Therefore:

Energy from batteries = Energy demanded / R = 106,253 Wh

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### Coupling of PV with RO desalination

PRODES

Promotion of Renewable Energy for Water production through Desalination

#### RO unit 1. Flows

Data	Value
Recovery ratio	40%
Average daily operation hours	7.5 h

- Water demand: 250 persons x 50 l / p d = 12,500 l / d = 12.5 m<sup>3</sup> / d
- Product water flow [Qp]:
  - 12,5 m<sup>3</sup>/d / 7.5 h/d = 1.7 m<sup>3</sup> / h
- Feed water flow [Qa]:
 
$$r = \frac{Q_p}{Q_a} \times 100$$
  - Qa = Qp / r = 1.7 / 0.4 = 4.2 m<sup>3</sup> / h

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### Coupling of PV with RO desalination

PRODES

Promotion of Renewable Energy for Water production through Desalination

#### Capacity of batteries

Data	Value
Operation voltage (Vo)	48 Vdc
Number of autonomy days (N)	1 day
Discharge depth (Pd)	60%
Unitary voltage of one vessel	2 Vdc

- Useful capacity:
  - C<sub>U</sub> = E<sub>b</sub> \* N / Vo = 106,253 Wh x 1 / 48 V = 2,214 Ah
- Nominal capacity (manufacturer)
  - C<sub>n</sub> = C<sub>U</sub> / P<sub>d</sub> = 2,214 Ah / 0.6 = 3,689 Ah
  - Number of vessels connected in serial: 48 / 2 = 24

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### Coupling of PV with RO desalination

PRODES

Promotion of Renewable Energy for Water production through Desalination

#### RO unit 2. Power

Data	Value
Operation pressure of RO pump	60 bar
Operation pressure of feed pump	5 bar
Pumps efficiency of RO pump	80%
Pumps efficiency of feed pump	50%

$$P = \frac{P(Pa) \cdot Q(m^3/s)}{\eta} (W)$$

- Pumps power calculation
  - Feed pump: 4.2 / 3600 (m<sup>3</sup>/s) x 5 E5 (Pa) / 0.5 = 1,167 W
  - High pressure pump: 4.2 / 3600 (m<sup>3</sup>/s) x 60 E5 (Pa) / 0.8 = 8,750 W
  - Total power: 1,167 W + 8,750 W = 10,211 W

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### Coupling of PV with RO desalination

PRODES

Promotion of Renewable Energy for Water production through Desalination

#### PV modules

Data	Value
Efficiency of charge controller	90%
Solar peak hours (SPH)	3.9
Relation between maximum and real efficiency of the modules	0.9
Power of one module (P)	125 W

$$E_{panels} = \frac{E_{batteries}}{0.9}$$

$$N_p = \frac{E_p}{0.9P(SP H)}$$

Solar peak hours is a parameter that means the number of solar hours with a radiation of 1,000 W/m<sup>2</sup> (maximum radiation that produces the maximum power from the PV modules). This value changes each month, thus calculation is made for the most unfavorable month (normally December).

- Energy from the panels: E<sub>p</sub> = E<sub>b</sub> / 0.9 = 106,253 / 0.9 = 118,059 Wh
- Number of panels: N<sub>p</sub> = 118,059 / 0.9 x 125 x 3.9 = 269 modules
- Total installed PV power: W<sub>p</sub> = 269 modules x 125 W / mod. = 33,635 W

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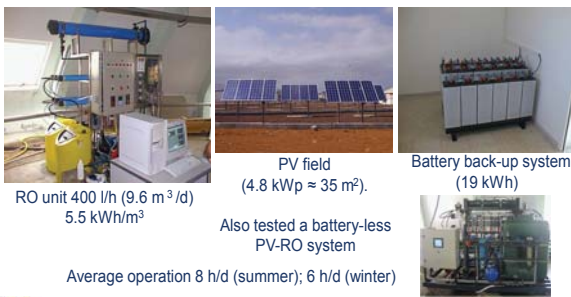


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### Coupling of PV with RO desalination

**Seawater PV desalination unit** (since 1999) in Canary Islands

First autonomous PV-RO system, designed to satisfy a small water demand (50-75 inhabitants) isolated from the electric grid. DESSOL® is an ITC patent.



RO unit 400 l/h (9.6 m<sup>3</sup>/d)  
5.5 kWh/m<sup>3</sup>

PV field (4.8 kWp ≈ 35 m<sup>2</sup>).  
Also tested a battery-less PV-RO system

Battery back-up system (19 kWh)

Average operation 8 h/d (summer); 6 h/d (winter)

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### Coupling of PV with RO desalination

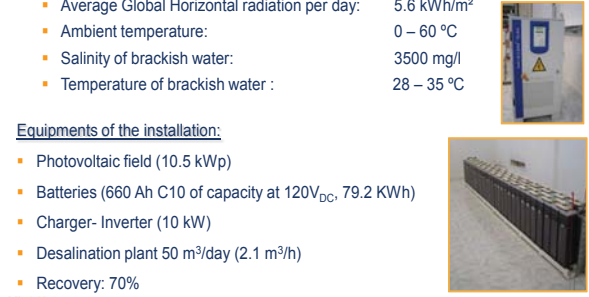
**PV-RO: CASES OF STUDY. KSAR GHILÈNE**

**Design parameters:**

- Water consumption: 15 m<sup>3</sup>/day (summer)
- Average Global Horizontal radiation per day: 5.6 kWh/m<sup>2</sup>
- Ambient temperature: 0 – 60 °C
- Salinity of brackish water: 3500 mg/l
- Temperature of brackish water : 28 – 35 °C

**Equipments of the installation:**

- Photovoltaic field (10.5 kWp)
- Batteries (660 Ah C10 of capacity at 120V<sub>DC</sub>, 79.2 KWh)
- Charger- Inverter (10 kW)
- Desalination plant 50 m<sup>3</sup>/day (2.1 m<sup>3</sup>/h)
- Recovery: 70%




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### Coupling of PV with RO desalination

**PV-RO: CASES OF STUDY. DESSOL®**

Integration of 3 PV systems with solar trackers from different manufacturers in a SWRO desalination plant including an Energy Recovery Device.



RO unit 1.25 m<sup>3</sup>/h (30 m<sup>3</sup>/d)  
2.54 kWh/m<sup>3</sup>.  
Average operation 8 h/d

Degertracker and Lorentz (2 kWp each), Traxle (1.6 kWp). Total power: 5.6 kWp. Battery back-up system (41 kWh).

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### Coupling of PV with RO desalination

**PV-RO: CASES OF STUDY. KSAR GHILÈNE**

**RO + PV for brackish and seawater desalination**

- Advantages:
  - Easy to operate
  - Modularity RO can adapt to energy available
- Disadvantages:
  - High investment cost due to photovoltaic
  - Brackish water: 4.5 €/m<sup>3</sup> produced



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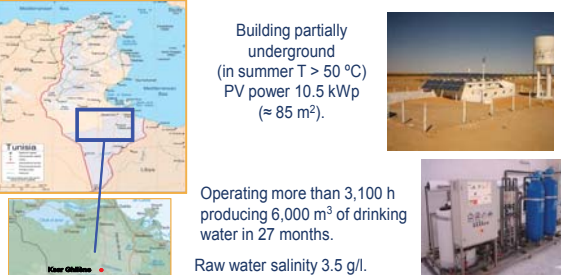
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### Coupling of PV with RO desalination

**PV-RO: CASES OF STUDY. KSAR GHILÈNE**

**Cooperation project. Autonomous PV-RO unit in Tunisia** (since 2006)

The village of Ksar Ghilène 1<sup>st</sup> African location with 2 years operating PV-RO system. 300 inhabitants with no access to electric grid (nearest at 150 km) or fresh water.



Building partially underground (in summer T > 50 °C)  
PV power 10.5 kWp (= 85 m<sup>2</sup>).

Operating more than 3,100 h producing 6,000 m<sup>3</sup> of drinking water in 27 months.  
Raw water salinity 3.5 g/l.

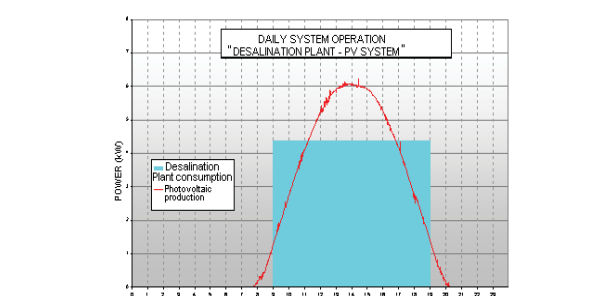
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### Coupling of PV with RO desalination

**PV-RO: CASES OF STUDY. KSAR GHILÈNE**

**Off-grid desalination unit (stand-alone system):** control strategies to adjust the energy supply (RES) to the demand (desalination unit). Energy / water storage



DAILY SYSTEM OPERATION "DESALINATION PLANT - PV SYSTEM"

POWER (kWp)

Desalination Plant consumption  
Photovoltaic production

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### Coupling of PV with RO desalination

**PV-RO: CASES OF STUDY. KSAR GHILÈNE** Design & operational data

	Water production (m <sup>3</sup> )	Days of operation	Hours of operation
TOTAL Since June 06	4,565	483	2,370.6
1 <sup>o</sup> year	2,537	281	1,356.5
2 <sup>o</sup> year (Until March, 2008)	2,028	202	1,014.1
Mean 1 <sup>o</sup> year	6.9 m <sup>3</sup> /day	23.4 days/month	3.7 h/day
Mean 2 <sup>o</sup> year	7.4 m <sup>3</sup> /day	22.4 days/month	3.7 h/day

	Design	Real	
Water production (m <sup>3</sup> /year)	4,200-4,500	2,537	1 <sup>o</sup> year: July 06-June 07
Days of operation/year	320-350	281	2 <sup>o</sup> year: July 07-March 08

	Summer		Winter	
	Design	Real	Design	Real
Hours of operation/day	7	4.25	5	3.3

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### Coupling of PV with RO desalination

**CONCLUSIONS**

LESSONS LEARNT:

PV - RO for brackish and seawater desalination (low water demands)

Advantages: 2 mature technologies, easy operation (power control system required), modularly RO can adapt to available energy.

Disadvantages: high investment cost, relatively non competitive prices of water produced (BW: from 5 to 9 €/m<sup>3</sup>, SW: from 9 to 12 €/m<sup>3</sup>).

- Main recommendations for RE desalination projects:
  - Design simple and tough, adapted to the local conditions (tailor-made project).
  - Elaboration of a specific control system, programmed for each particular case (reduces maintenance, maximizes water production and extends equipment life).

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### Coupling of PV with RO desalination

**PV-RO: CASES OF STUDY. MOROCCO**

Cooperation project. Autonomous PV-RO units in Morocco (since 2008).

Four PV-RO systems installed in 4 locations of Morocco. Raw water is brackish water from inland wells (salinity 2.5 – 8.7 g/l).

Co-funded by EU, MEDA-water programme.

PV field (4 kWp ≈ 36 m<sup>2</sup>).

RO unit (24 m<sup>3</sup>/d).

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### Coupling of PV and Wind with RO desalination

**HYBRID WIND & PV- RO: CASES OF STUDY. MORENA**

Hybrid wind & PV driven RO unit (since 2005)

MORENA system (energetically self-sufficient rural module) is a wind/PV/battery hybrid system powering a SWRO desalination unit (552 W) and a DC load. System mounted in & on a container of 15 m<sup>2</sup> divided into 3 zones: one for the desalination unit and ERD, the battery bank and the electrical acquisition panels.

RO unit 154 l/h, 3.74 kWh/m<sup>3</sup>. WT 890 W, PV array 600 Wp, battery 21 kWh.

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### Coupling of PV with RO desalination

**PV-RO: CASES OF STUDY. MOROCCO**

COSTS: Investment of one BWRO unit (1 m<sup>3</sup>/h): 90.000 €

Total investment 360.000 €

Total water cost: 5.3 €/m<sup>3</sup>

O&M: 3.5 €/m<sup>3</sup>

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### Coupling of PV and Wind with RO desalination

**HYBRID WIND & PV- RO: CASES OF STUDY. LAVRIO ISLAND**

Lavrio island (Greece) – drinking water (2001)

SWRO hybrid autonomous system with photovoltaic solar energy and wind energy (0.13 m<sup>3</sup>/h – 4 kWp – 900 W); CRES

Source: ADU-RES

**Installed equipment:**

- Photovoltaic field (36 modules; 4 kWp)
- Wind turbine (900 W)
- Batteries (capacity 1,800 Ah C100 24V<sub>DC</sub>)
- 2 Regulator-Inverter of 1.5 y 3.0 kW
- RO desalination plant of 3.2 m<sup>3</sup>/d (recovery rate 20%)

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### Coupling of PV and Wind with RO desalination

HYBRID WIND & PV-RO: CASES OF STUDY. LAVRIO ISLAND

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### Coupling of Wind energy with RO desalination

In the recent years, few manufacturers/suppliers, in majority from the wind turbine industry, provide to the market compact Wind-RO solutions for electricity and water production.

1. Power and control container
2. Desalination/RO container
3. Water storage container
4. Pretreatment container

#### Wind RO Market

- Two German companies provide to the market compact W/T-RO solutions for brackish and SW desalination, in the range of 176 to 2000 m<sup>3</sup>/day, fitted in containers. The systems can operate as stand-alone or connected to an electricity grid.
- A Danish company provides turnkey solutions for fresh water production with the use of wind turbines. The RO units are designed as containerized modules with production capacities from 10 to 3800 m<sup>3</sup>/day.

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### Coupling of PV and Wind with RO desalination

HYBRID WIND & PV-RO: CASES OF STUDY. KERATEA

CRES, Keratea, Greece, seawater, stand-alone  
 Desalination: 3 m<sup>3</sup>/day RO plant  
 Power Supply: 1 kW W/T, 4 kWp PV, 1850 Ah/100h  
 Year of installation/operation: 2001  
 Unit Water Cost: >10 €/m<sup>3</sup>

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### Coupling of Wind energy with RO desalination

AEROGEDESA project. Pozo Izquierdo, Gran Canaria, seawater, stand-alone  
 Desalination: 19 m<sup>3</sup>/d RO plant  
 Power Supply: 15 kW W/T, 190Ah battery bank  
 Year of installation/operation: 2003/4  
 Unit Water Cost: 3-5 €/m<sup>3</sup>

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### Coupling of Wind energy with RO desalination

Location	RO capacity (m <sup>3</sup> /h)	Electricity supply	Year of installation
Ile du Planier, France	0.5	4kW W/T, no batteries	1982
Island of Suderoog, Germany	0.25 - 0.37	6kW W/T, no batteries	1983
Pozo Izquierdo, SDAWES	8 x 1.0	2x230 kW W/T, no batteries	1995
Tenerife, Spain; JOULE	2.5 - 4.5	30kW W/T, no batteries	1997/8
Loughborough Univ, UK	0.5	2.5kW W/T, no batteries	2001/2
Delf Univ., The Netherlands	0.2 - 0.4	Windmill, no batteries	2007/2008
Therassia Island, APAS RENA	0.2	15 kW W/T, 440Ah batteries	1995/6
Keratea, Greece PAVET Project	0.13	900W W/T, 4 kWp PV, batteries	2001/2
Pozo Izquierdo, Spain, AEROGEDESA project	0.80	15kW W/T, 190Ah batteries	2003/4
Heraklia island, Greece OPC programme	3.3	30 kW W/T off shore, batteries	2007
Island of Helgoland, Germany	40	1.2MW W/T +diesel	1988
Fuerteventura, Spain	2.3	225 kW W/T + 160 KVA diesel	1995
Syros island, Greece; JOULE	2.5 - 37.5	500 kW W/T, grid connected	1998
Milos island, Greece OPC programme	2 x 42	850kW W/T, grid connected	2007

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### Coupling of Wind energy with RO desalination


SDAWES project. Pozo Izquierdo, Gran Canaria, seawater, stand-alone  
 Desalination: 8 x 25 m<sup>3</sup>/d RO units  
 Power Supply: 2 x 230 kW + 100 kVA synchronous machine  
 Year of installation/operation: 2001

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### Coupling of Wind energy with RO desalination

Fuerteventura Island, seawater  
Desalination: 56 m<sup>3</sup>/d RO plant  
Power Supply: 225 kW W/T, 2x160KVA diesel, flywheel  
Year of installation/operation: 2003/4



Wind turbine	
Model	VESTAS V-27
Main characteristics	Diameter: 27m, Height of tower: 30m, multiplier gear box, 50 and 225 kW twin spool asynchronous generator.
Diesel Generating Sets	
Main characteristics	2 diesel groups (105 kW each) coupled to flywheels and synchronous generators (75 kVA).
SWRO desalination plant	
Nominal production capacity	2.3 m <sup>3</sup> /h
RO plant operating hours	800 hours/year

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### COSTS

Technologies combination (water demand)	Operation cost (€/m <sup>3</sup> ) <sup>a</sup>	Remarks
SWRO - PV (low demand)	11.81	< 100 m <sup>3</sup> /d < 6 kWh/m <sup>3</sup> > 3,000 hr operation
BWRO - PV (low demand)	8.29	< 100 m <sup>3</sup> /dia < 12 g/L (1.6 kWh/m <sup>3</sup> ) > 3,000 hr operation
EDR - PV (low demand)	8.47	< 100 m <sup>3</sup> /d < 4.5 g/L (3.3 kWh/m <sup>3</sup> ) > 3,000 hr operation
SWRO - Wind energy (medium demand)	2.00	< 1,000 m <sup>3</sup> /d > 3.3 kWh/m <sup>3</sup> > 3,500 hr-eq

<sup>a</sup>This costs include capital and running costs (O&M)

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### Coupling of Wind energy with RO desalination

Heraklia Island, Greece, seawater, offshore, stand-alone  
Desalination: 80 m<sup>3</sup>/d RO plant  
Power Supply: 30 kW W/T, battery bank  
Year of installation/operation: 2007

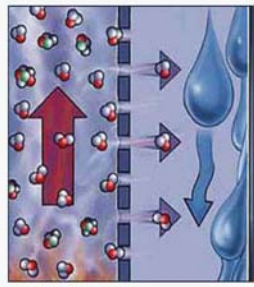



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### Membrane Distillation

#### Membrane Distillation



Membrane Distillation is an evaporative process in which water vapor, driven by a difference in vapor pressure (i.e., temperature), permeates through a hydrophobic membrane, thus separating from the salt water phase.

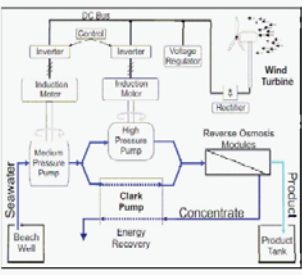

Once the vapor has passed through the membrane, it can be extracted or directly condensed in the channel on the other side of the membrane.

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### Coupling of Wind energy with RO desalination

CREST, Loughborough University, UK., seawater (<35000 ppm TDS)  
Desalination: 12 m<sup>3</sup>/day RO plant  
Power Supply: 2.5 kW W/T, direct coupling  
Year of installation/operation: 2003  
Unit Water Cost: 1.78€/m<sup>3</sup>

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### Membrane Distillation

The MD technique holds important advantages with regard to the implementation of solar driven stand-alone operating desalination systems.

The most important advantages are:



- The operating temperature of the MD process is in the range of 60 to 80°C. This means that **the MD process can utilize alternative energy sources such as freely available solar energy.**
- The membranes used in MD are **tested against fouling and scaling.**
- **Chemical** feed water pre-treatment is not necessary.
- **Intermittent operation** of the module is **possible.** Contrary to RO, there is no danger of membrane damage if the membrane falls dry.

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### Membrane Distillation

- 100% theoretical salt rejection.
- Lower operating pressure than Reverse Osmosis process.
- Reduced vapor space compared to conventional thermal processes, thus reduced volumes.
- System efficiency and high product water quality are almost independent from the salinity of the feed water.

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### Membrane Distillation

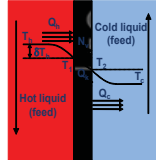


#### Heat Transport in MD

The heat flux is related to the passage of heat from the hot liquid to the cold permeate, and is characterized by three resistances in series:

- Resistance from the hot bulk to the membrane surface, due to convective transport;
- Resistance across the membrane, related to the transport of latent heat due to the vapor flux  $N_v$  and the conductive transport due to the thermal conductivity of the membrane and the fluid filling the pores ( $k_m$ );
- Resistance from the membrane surface to the cold bulk, due to convective transport.

$$Q_h = h_h \cdot (T_h - T_1)$$

$$Q_m = Q_k + \lambda_{ev} \cdot N_v = k_m \cdot (T_1 - T_2) + C'_m \cdot \lambda_{ev} \cdot (T_1 - T_2)$$

$$Q_c = h_c \cdot (T_2 - T_c)$$




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### Membrane Distillation

Contrary to membranes for RO, which have a pore diameter in the range of 0.1 to 3.5 nm, membranes for MD have a pore diameter of about 0.2 mm.

The separation effect of these membranes is based on the hydrophobicity of the polymer material constituting the membrane.

This means that up to a certain limiting pressure (bubble pressure) the membrane cannot be wetted by liquid water.

Molecular water in the form of steam can pass through the membrane.

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### Membrane Distillation

#### Temperature Polarization in MD

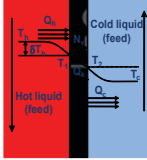


$T_h - T_c$  = Total temperature difference available;

$P_1 - P_2 = f(T_1 - T_2)$  = effective driving force available for vapour crossing through the membrane;

$T_h - T_1$  ( $dT_h$ ) = "driving force losses" due to the Temperature Polarization;

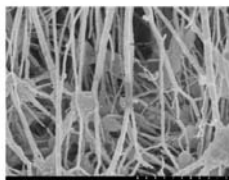
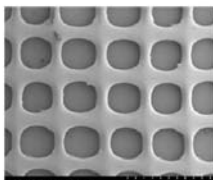
$$(T_1 - T_2) / (T_h - T_c) = \text{Temperature polarization coefficient}$$

Strictly related to the heat transfer coefficients from the bulk to the membrane surface and that through the membrane itself

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### Membrane Distillation

Biaxial extended hydrophobic Membrane

Backing

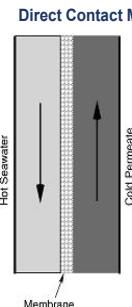
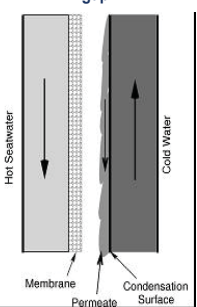


Manufacturer :	GORE	Material:	Polypropylene
Material:	PTFE	Thickness:	280µm
Average PoreSize:	0.2µm	covered membrane area:	40%
Thickness δ of membrane:	35µm		
Wetting pressure:	4.9 bar		
Porosity:	80%		

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### Membrane Distillation

#### Configurations of MD

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### Membrane Distillation

Configurations of MD

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### Membrane Distillation

MD modules developed by the Fraunhofer Institute in Freiburg (Germany)

A possible design for a MD module is the formation of channels by spiral winding of membrane and condenser foils to form a spiral-wound module.

spiral wound MEMBRANE DISTILLATION module

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### Membrane Distillation

Solar Powered MD

For the design of a solar-powered desalination system, the question of **energy efficiency** is very important since the investment costs mainly depend on the **area of solar collectors** to be installed.

Also the **power consumption** of the **auxiliary equipment** (for example, the pump) has an important influence on total system costs.

Therefore, the system design to be developed has to **focus on a very good heat recovery** to minimise the need of thermal energy required.

Heat recovery can be carried out by an external heat exchanger or by an internal heat recovery function, where the cold feed water is directly used as coolant for the condenser channel.

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### Membrane Distillation

Properties of MD-modules

- Dimensions: diameter 30-40 cm, height 85 cm
- distillate output 10-30 l/h (80°C evaporator inlet, 300 l/h feed flow)
- thermal energy demand about 90 to 200 kWh per m<sup>3</sup>
- Wide range of operation temperatures possible (50°C to 85°C)
- favourable behaviour under dynamic operation conditions
- no pre-treatment of feed water
- high quality of water because of distillation (conductivity of distillate 5 to 50 µS/cm)
- modular set up for systems from 100 to 20000 litres per day

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### Membrane Distillation

MD with internal heat recovery

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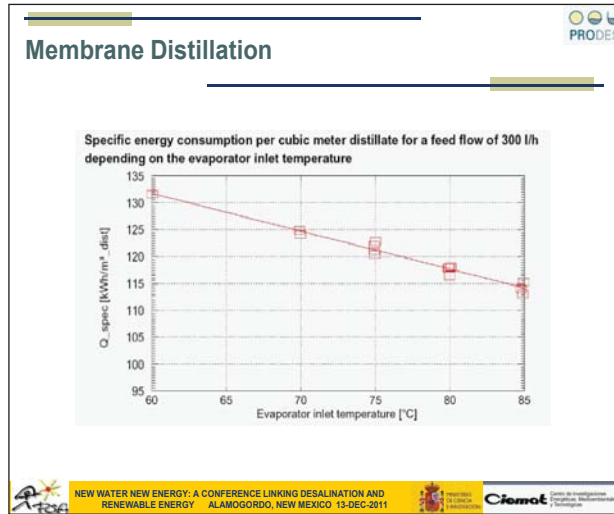
### Membrane Distillation

Distillate mass flow depending on the evaporator inlet temperature for different feed volume flows

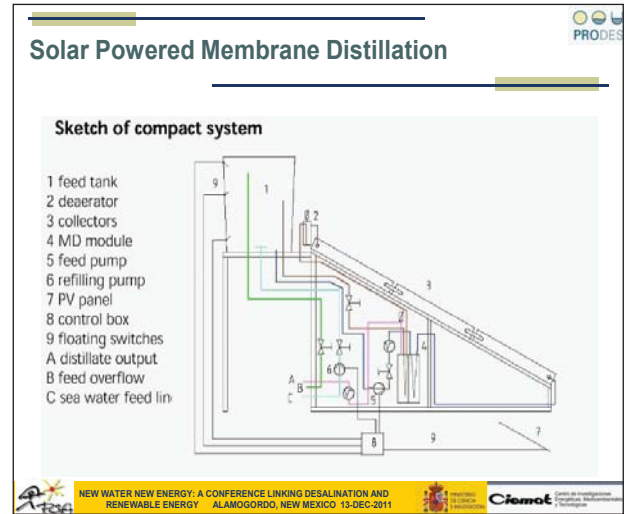
Evaporator inlet temperature [°C]	200 l/h	250 l/h	300 l/h	350 l/h	400 l/h
65	5	7	9	11	13
70	8	10	12	14	16
75	10	12	14	16	18
80	12	14	16	18	20
85	15	17	19	21	23

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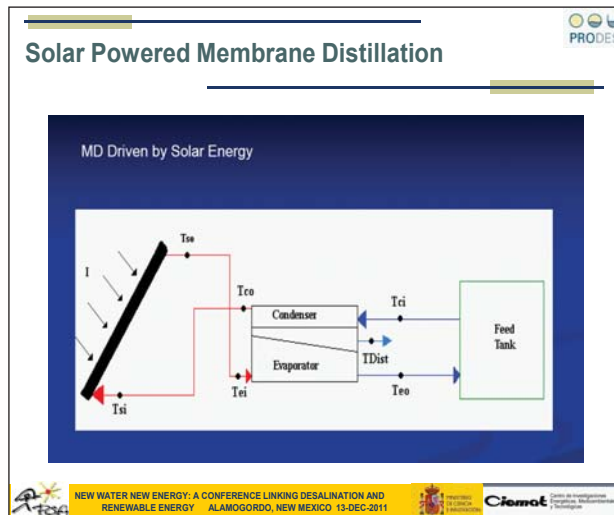
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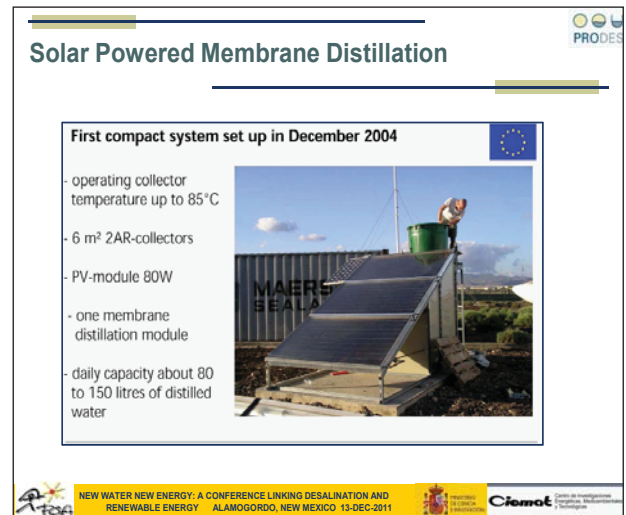
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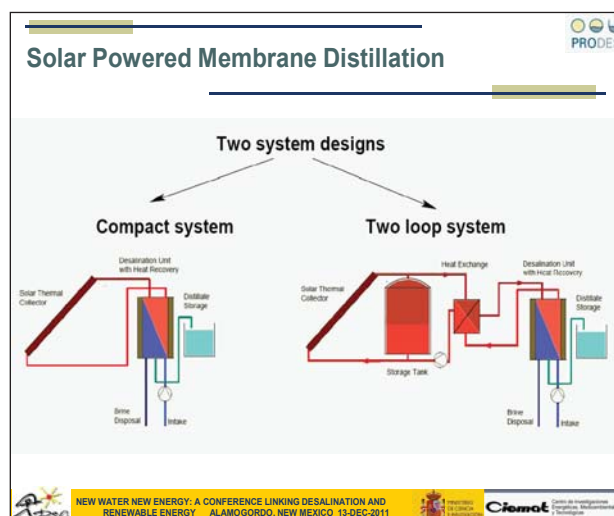
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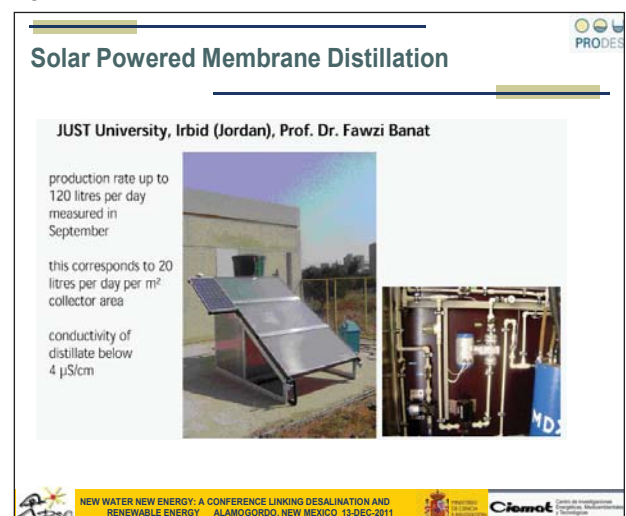
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### Solar Powered Membrane Distillation

Alexandria University (Egypt), Prof. Dr. Hassan Fath

installed in July 2005




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### Solar Powered Membrane Distillation

Installation of Aqaba system (Jordan) in December 2005



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### Solar Powered Membrane Distillation

Kelaa system, Morocco (50 km from Marrakech)

installed in August 2005

in a village with about 50 inhabitants to desalinate water from a brackish well

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### Solar Powered Membrane Distillation

Installation of Aqaba system (Jordan)



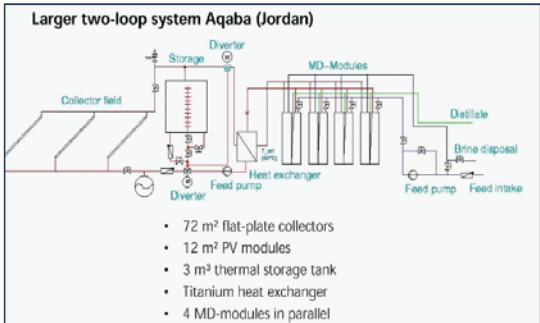
- thermal storage tank 3 m<sup>3</sup>
- membrane expansion vessels
- mixing valves for storage control
- Titanium heat exchanger
- 4 MD modules

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### Solar Powered Membrane Distillation

Larger two-loop system Aqaba (Jordan)




- 72 m<sup>2</sup> flat-plate collectors
- 12 m<sup>2</sup> PV modules
- 3 m<sup>3</sup> thermal storage tank
- Titanium heat exchanger
- 4 MD-modules in parallel

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### Solar Powered Membrane Distillation

Installation of Aqaba system (Jordan)



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**THANK YOU**

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