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://wrri.nmsu.edu/conf/conf11/prodes_roadmap_online.pdf)*

PowerPoint Presentation **http://wrri.nmsu.edu/publish/watcon/proc56/Zaragoza.pdf**

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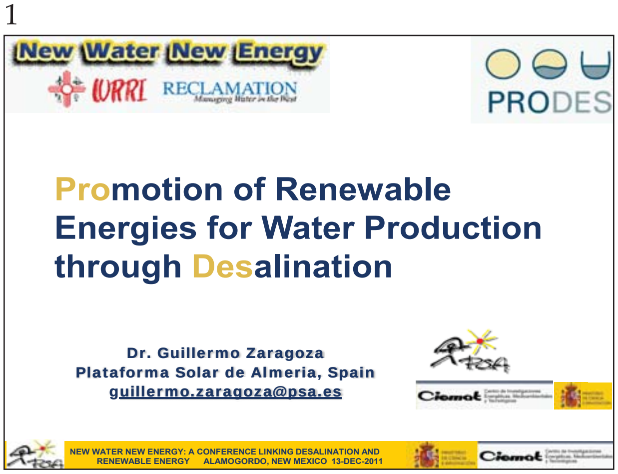

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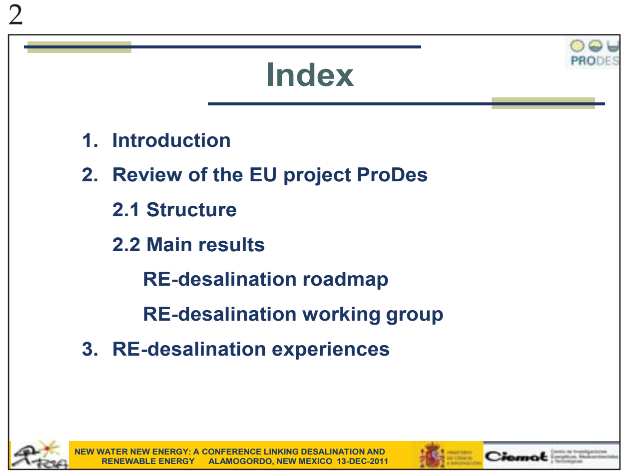

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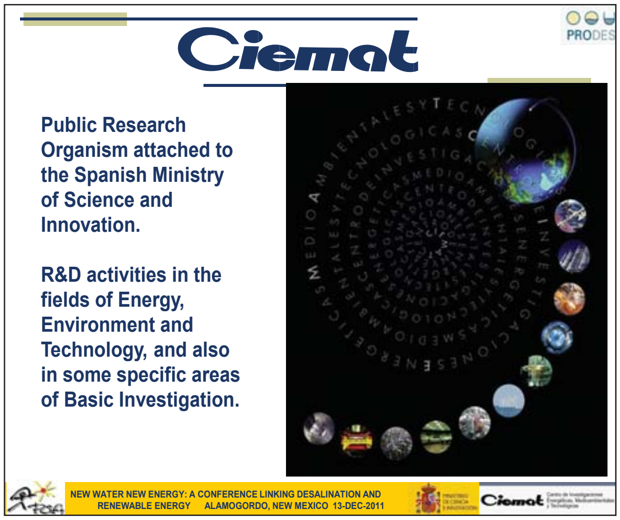
Ciemat
PRODES
Public Research Organism attached to the Spanish Ministry of Science and Innovation.
R&D activities in the fields of Energy, Environment and Technology, and also in some specific areas of Basic Investigation.
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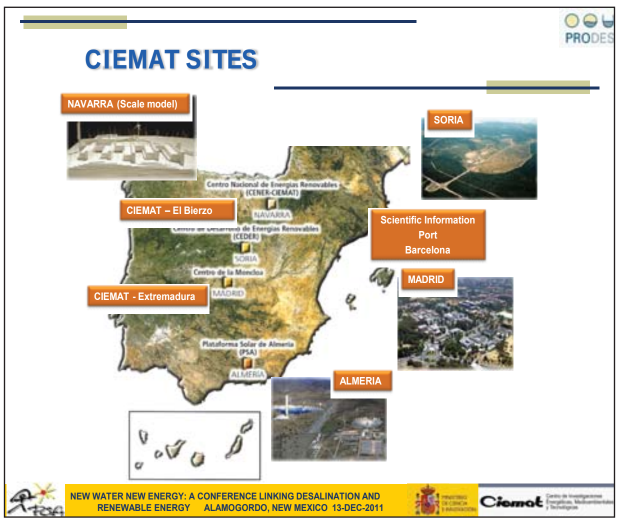
PRODES
CIEMAT SITES
NAVARRA (Scale model)
SORIA
CIEMAT – El Bierzo
Scientific Information Port Barcelona
MADRID
CIEMAT - Extremadura
ALMERIA
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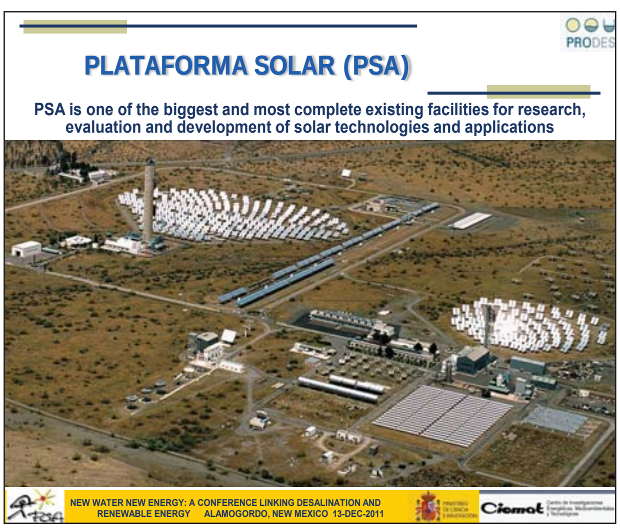
PRODES
PLATAFORMA SOLAR (PSA)
PSA is one of the biggest and most complete existing facilities for research, evaluation and development of solar technologies and applications
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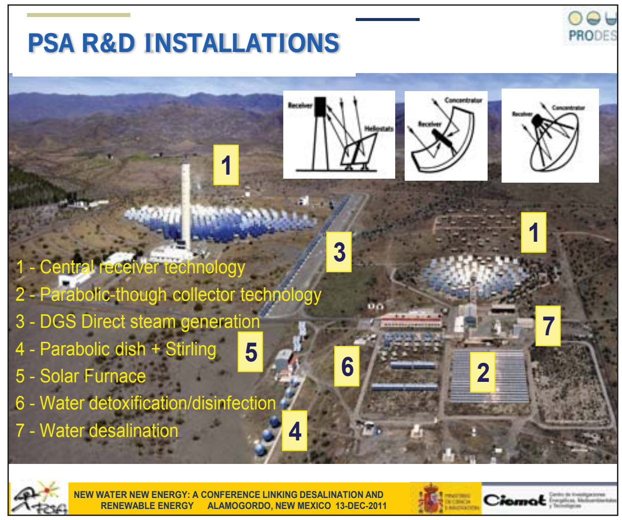
PSA R&D INSTALLATIONS
PRODES
1 - Central receiver technology
2 - Parabolic-though collector technology
3 - DGS Direct steam generation
4 - Parabolic dish + Stirling
5 - Solar Furnace
6 - Water detoxification/disinfection
7 - Water desalination
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PRODES
CIEMAT RESEARCH PROGRAM
ENVIRONMENTAL APLICATIONS OF SOLAR ENERGY
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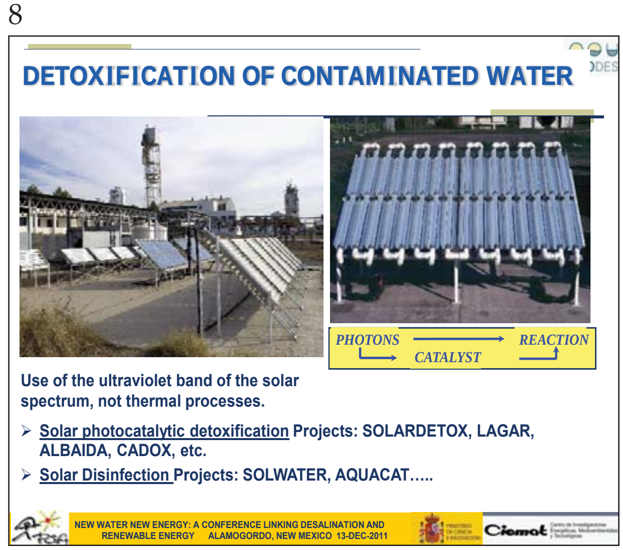
DETOXIFICATION OF CONTAMINATED WATER
PHOTONS
REACTION
CATALYST
Use of the ultraviolet band of the solar spectrum, not thermal processes.
Solar photocatalytic detoxification Projects: SOLARDETOX, LAGAR, ALBAIDA, CADOX, etc.
Solar Disinfection Projects: SOLWATER, AQUACAT.....
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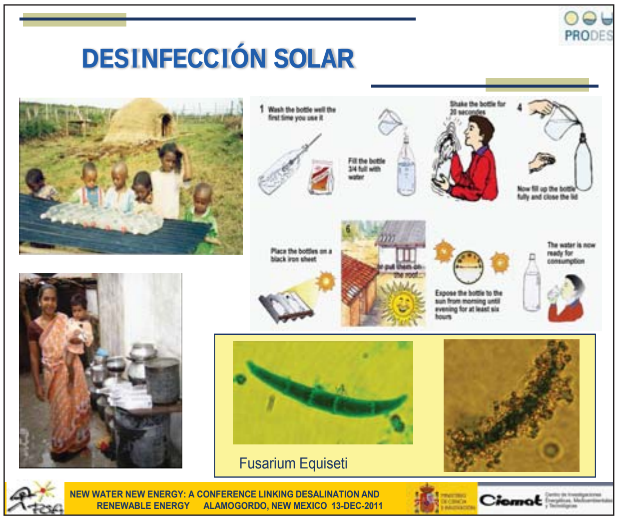

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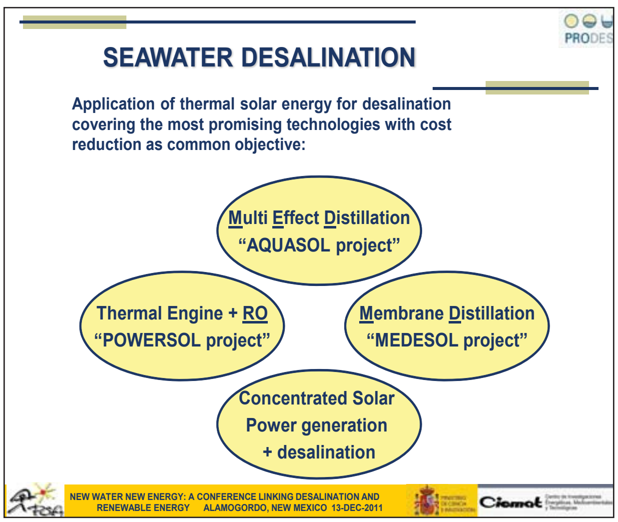

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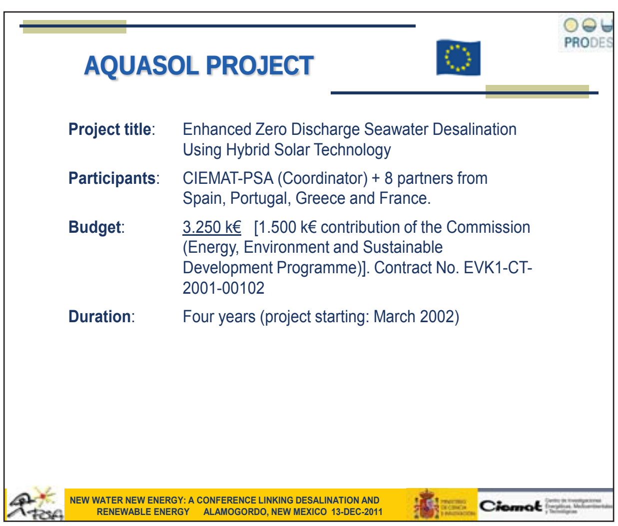

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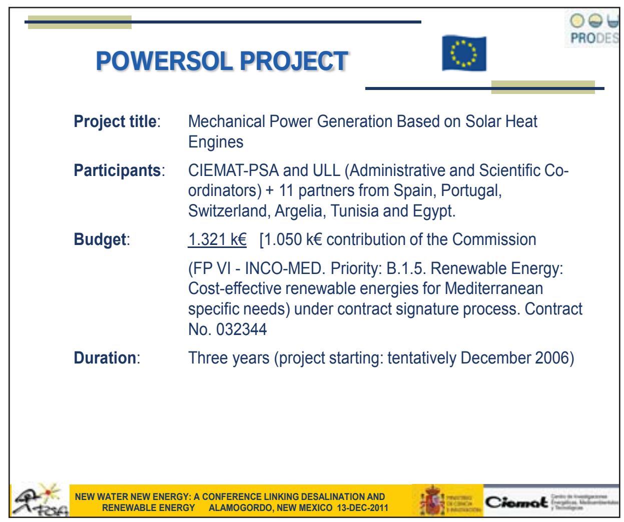

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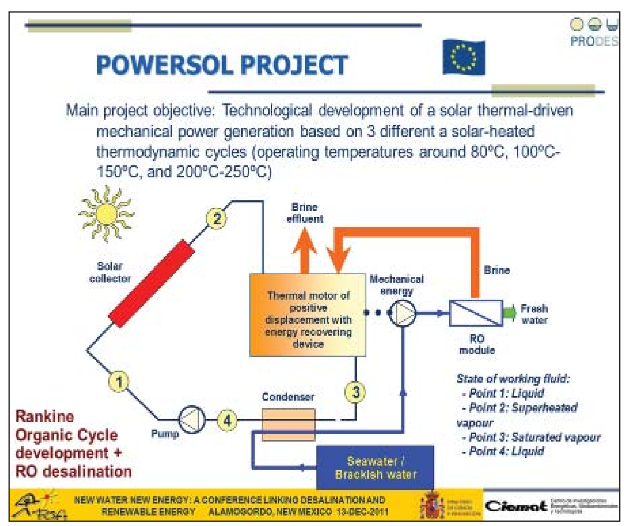

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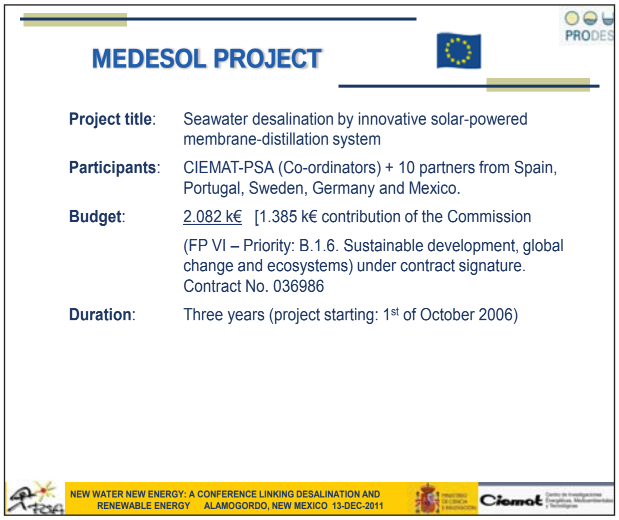

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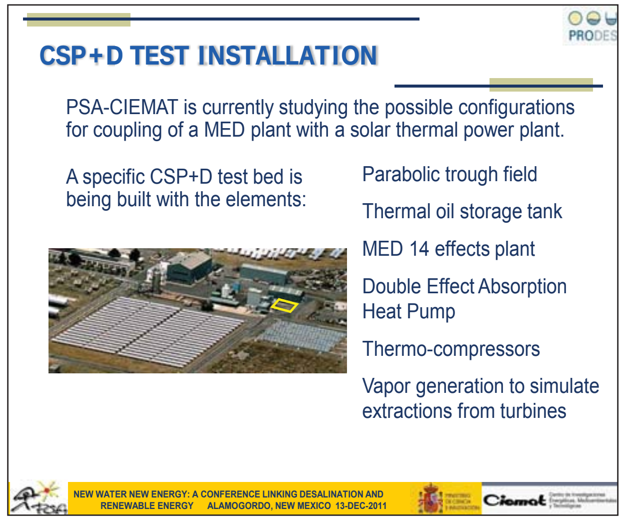

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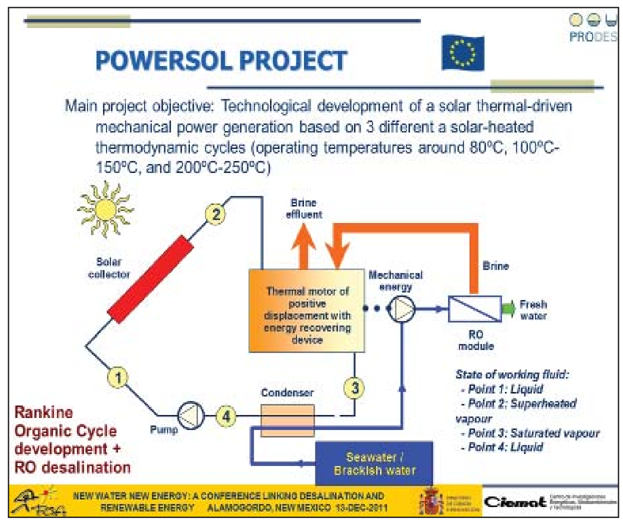

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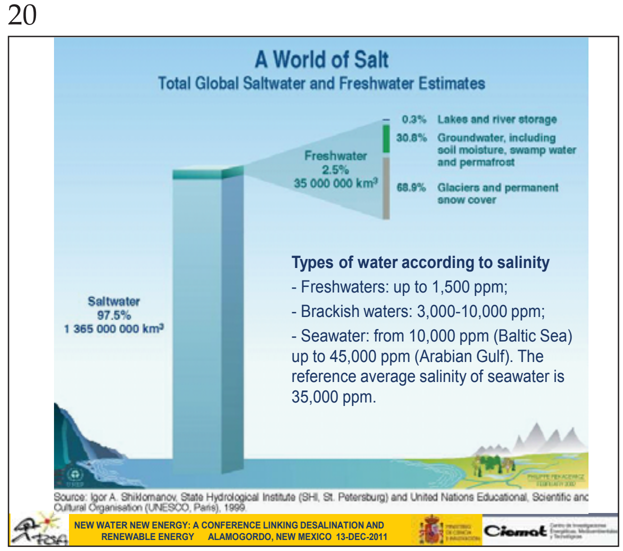

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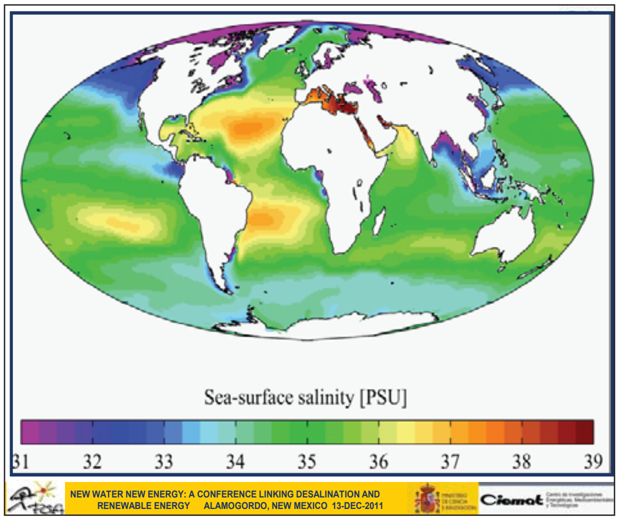

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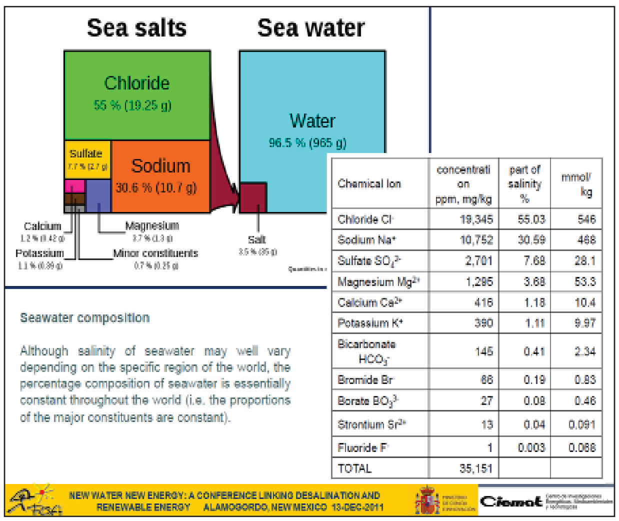

Chemical Ion	concentration ppm, mg/kg	part of salinity %	mmol/kg
Chloride Cl^-	19,345	55.03	546
Sodium Na^+	10,752	30.59	468
Sulfate SO_4^{2-}	2,701	7.68	28.1
Magnesium Mg^{2+}	1,295	3.68	53.3
Calcium Ca^{2+}	416	1.18	10.4
Potassium K^+	390	1.11	9.97
Bicarbonate HCO_3^-	145	0.41	2.34
Bromide Br^-	66	0.19	0.83
Borate BO_3^{3-}	27	0.08	0.46
Strontium Sr^{2+}	13	0.04	0.091
Fluoride F^-	1	0.003	0.068
TOTAL	35,151		

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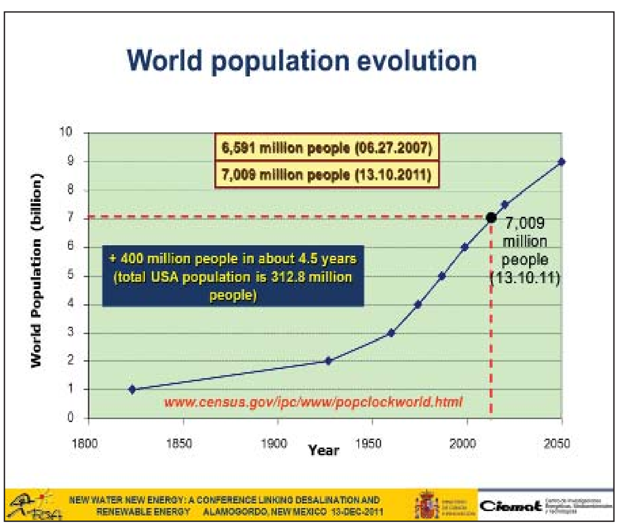

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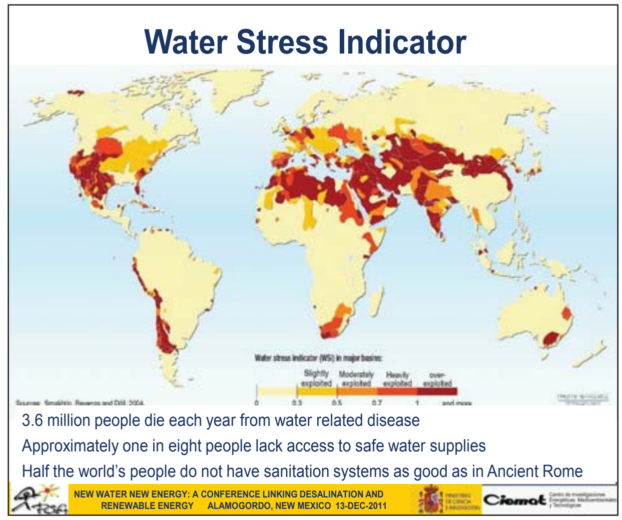

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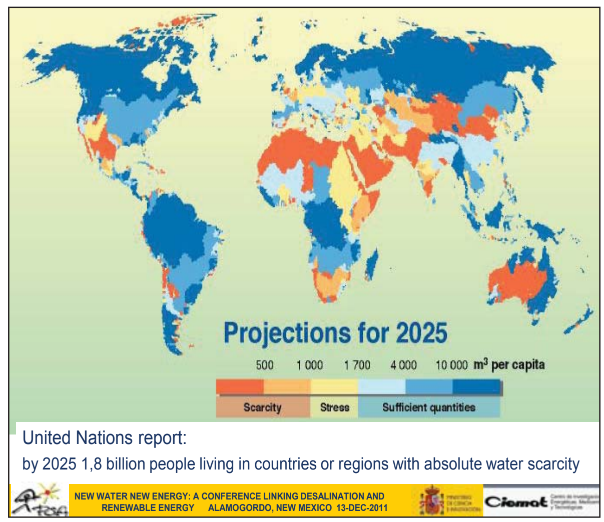

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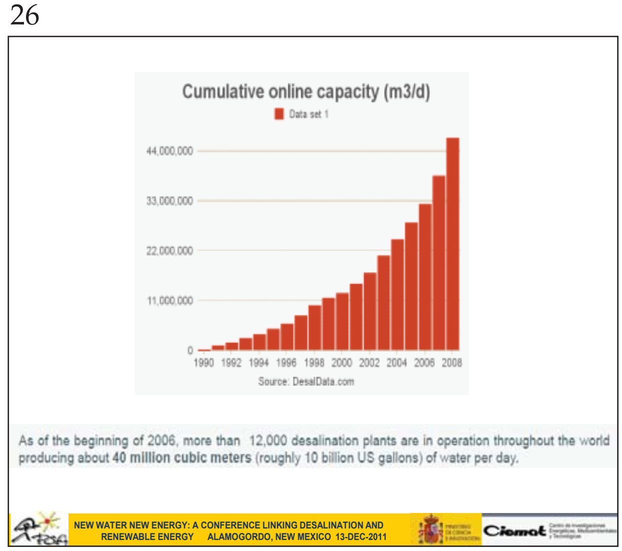

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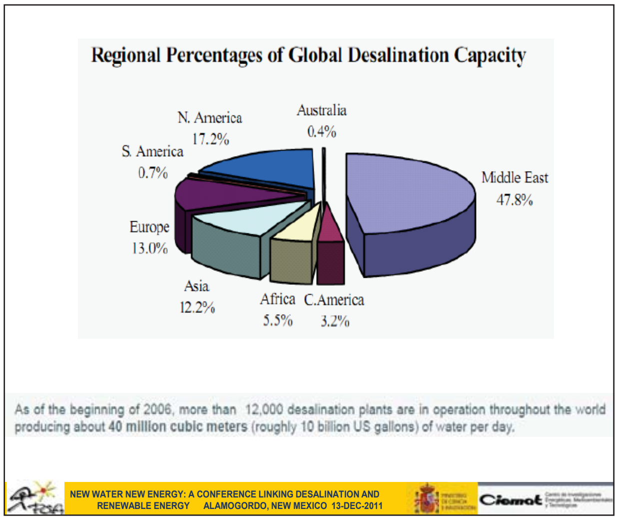

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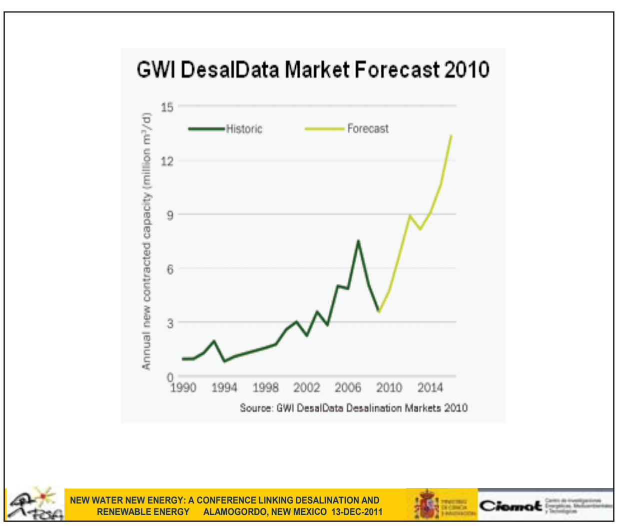

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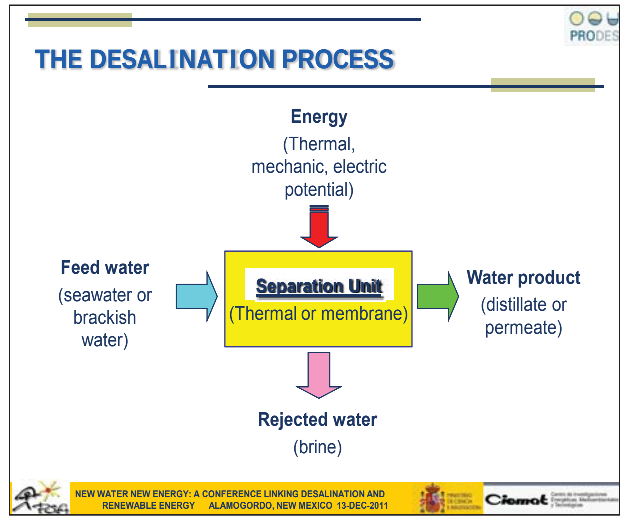

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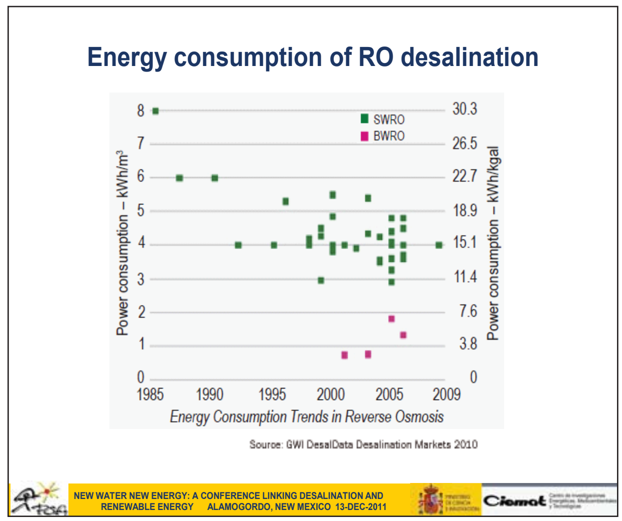

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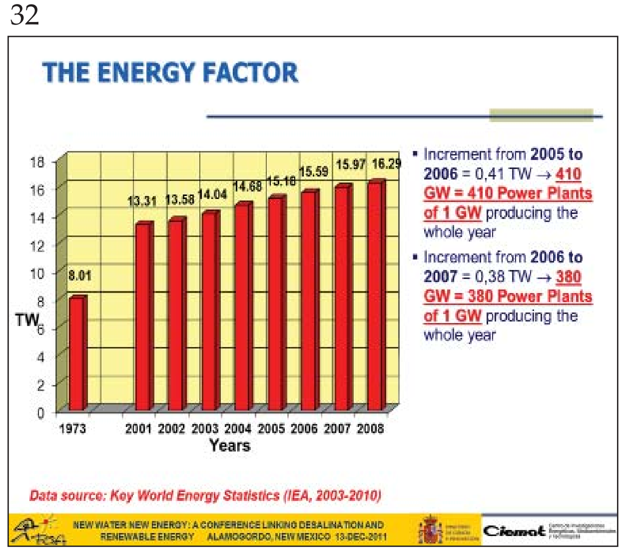

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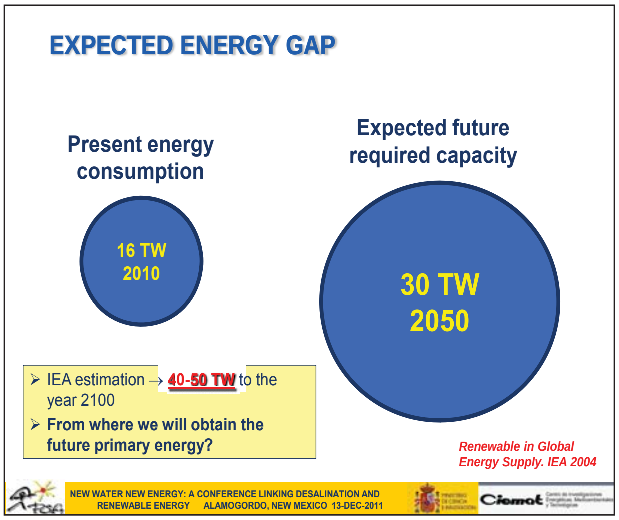

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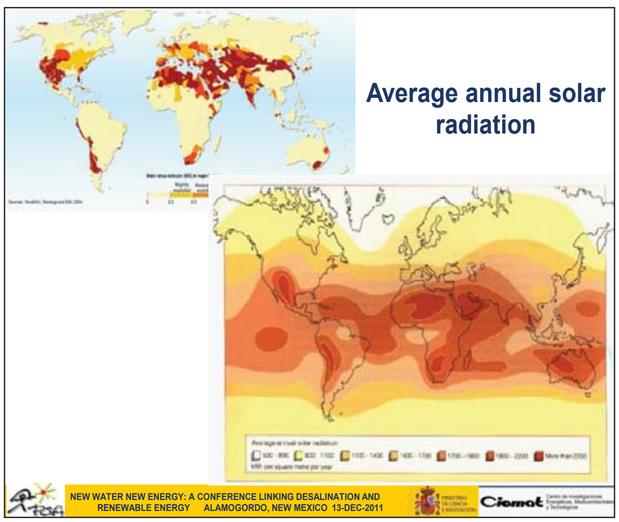

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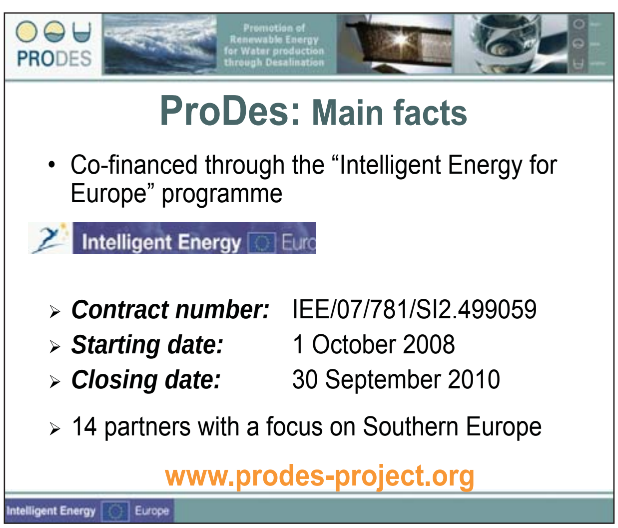

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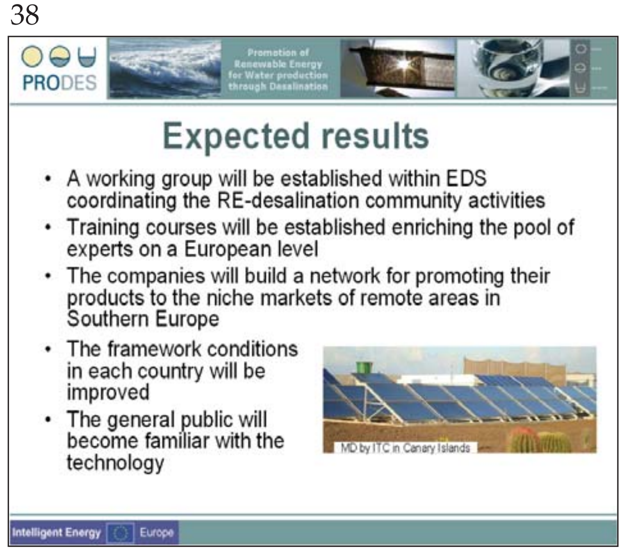

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Specific objectives of PRODES

- 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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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
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

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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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 electrodialysis reversal. [10%]

4.3. Wind energy and desalination. Combination of electricity produced by wind energy and desalination using techniques of reverse osmosis and electrodialysis 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
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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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

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PRODES
Introducing RE-desal to higher education

E-LEARNING COURSE ON INTRODUCTION TO DESALINATION BY RENEWABLE ENERGIES

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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 byThe Canary Islands Institute of Technology (ITC), with a long history (since 1996) 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
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.

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

EDS European Desalination Society

Other EDS Courses

Desalination with Solar Energy

A 3-day intensive course

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

April 18-20, 2012, Almeria, 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.

The general purpose of this 3-day intensive course is to provide experts, professionals and postgraduate students from all around the world with the latest knowledge of the different existing technologies involving the use of solar energy to drive desalination techniques. More specifically, the course will instruct scientists and technicians on the basic principles of desalination using solar energy, the state of the art of the most promising technologies and the experiences acquired so far. Theory lessons will be complemented with visits to the test facilities of Plataforma Solar de Almeria operating on solar power production and desalination, which are the most advanced in the Mediterranean area.

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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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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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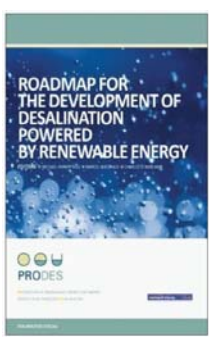
RE Desalination Roadmap

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



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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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Current status of the RE-desalination technology

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

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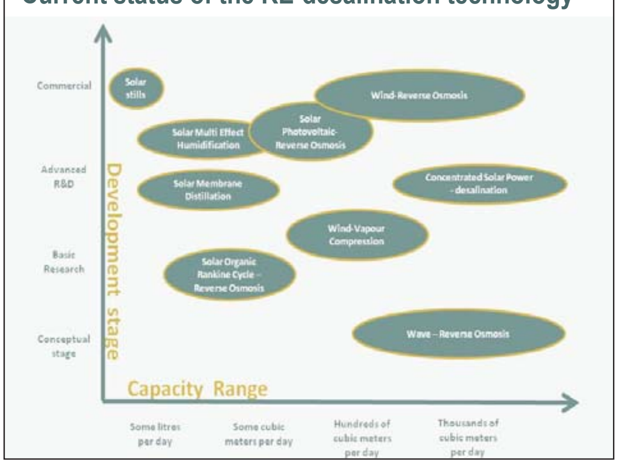
Current status of the RE-desalination technology



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

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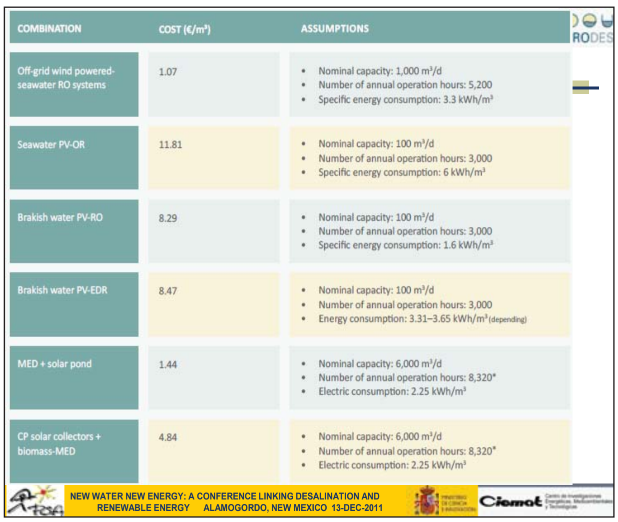

COMBINATION	COST (€/m^3)	ASSUMPTIONS
Off-grid wind powered-seawater RO systems	1.07	• Nominal capacity: 1,000 m^3/d • Number of annual operation hours: 5,200 • Specific energy consumption: 3.3 kWh/m^3
Seawater PV-OR	11.81	• Nominal capacity: 100 m^3/d • Number of annual operation hours: 3,000 • Specific energy consumption: 6 kWh/m^3
Brakish water PV-RO	8.29	• Nominal capacity: 100 m^3/d • Number of annual operation hours: 3,000 • Specific energy consumption: 1.6 kWh/m^3
Brakish water PV-EDR	8.47	• Nominal capacity: 100 m^3/d • Number of annual operation hours: 3,000 • Energy consumption: 3.31–3.65 kWh/m^3 (depending)
MED + solar pond	1.44	• Nominal capacity: 6,000 m^3/d • Number of annual operation hours: 8,320* • Electric consumption: 2.25 kWh/m^3
CP solar collectors + biomass-MED	4.84	• Nominal capacity: 6,000 m^3/d • Number of annual operation hours: 8,320* • Electric consumption: 2.25 kWh/m^3

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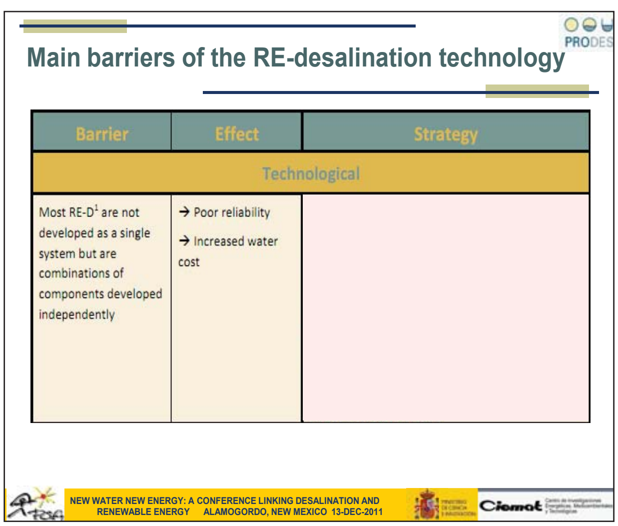

Main barriers of the RE-desalination technology

Barrier	Effect	Strategy
Technological		
Most RE-D[1] are not developed as a single system but are combinations of components developed independently	→ Poor reliability → Increased water cost	

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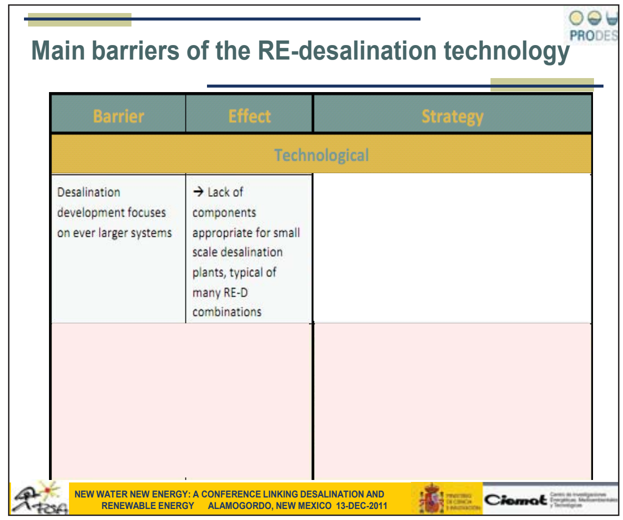

Main barriers of the RE-desalination technology

Barrier	Effect	Strategy
Technological		
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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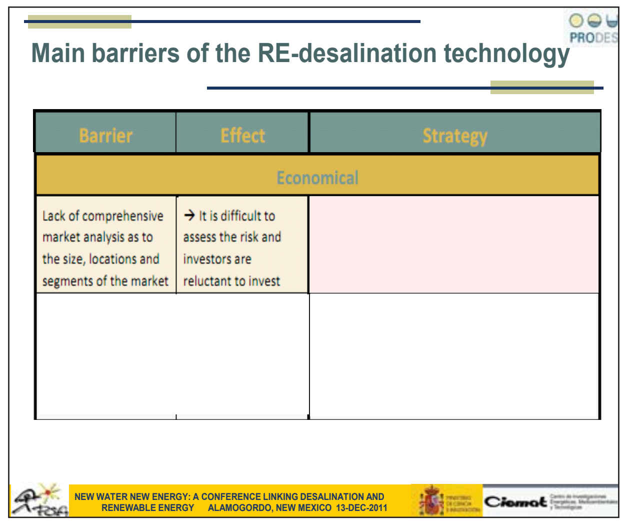

Main barriers of the RE-desalination technology

Barrier	Effect	Strategy
Economical		
Lack of comprehensive market analysis as to the size, locations and segments of the market	→ It is difficult to assess the risk and investors are reluctant to invest	

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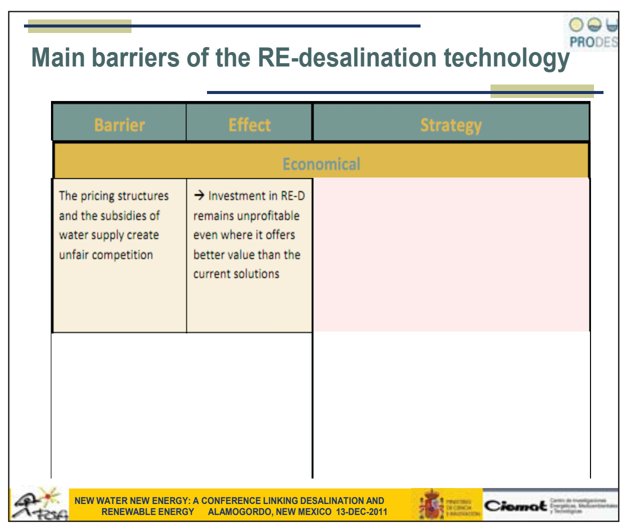

Main barriers of the RE-desalination technology

Barrier	Effect	Strategy
Economical		
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

PRODES

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

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Main barriers of the RE-desalination technology

PRODES

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	• Promote simpler and straightforward processes to obtain a license for independent water production • Lobby for greater cooperation between the power and water branches in governmental and non-governmental institutions
Lack of training and infrastructure	→ Reduced plant availability → Lack of personnel for operation and maintenance	• Support education and training at all levels
Cultural gap between project developers and the end-users	→Projects fail for non-technological reasons like conflict about control	• Encourage adequate consideration of socio-cultural factors and establishment of communication channels with the end-users

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Targets for the RE-desalination technology

PRODES

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 m³/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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R&D priorities for the RE-desalination technology

PRODES

- 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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R&D priorities for the RE-desalination technology

PRODES

- 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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Legislative and institutional issues

PRODES

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 m³/day: serious risks for the environment, <100 m³/day: subject to general specifications, terms and restrictions for reasons of environmental protection.

→ proposed: <50 m³/day to belong at Category C (insignificant risk or nuisance or degradation to the environment).

<10 m³/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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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**

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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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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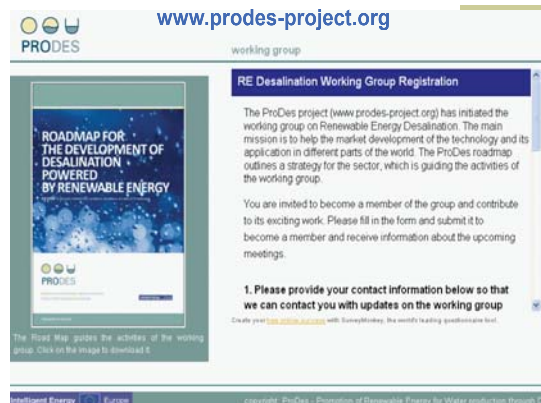
RE-desalination Working Group



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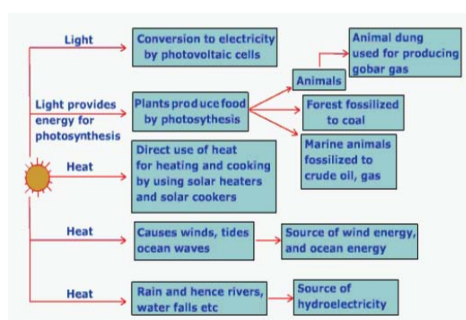
Renewable Energy

Renewable energy resource: illimitably available and not generate pollution



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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 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

Solar Thermal electricity

Wind Power

Wave Power

Solar Photovoltaic

power production RE technologies

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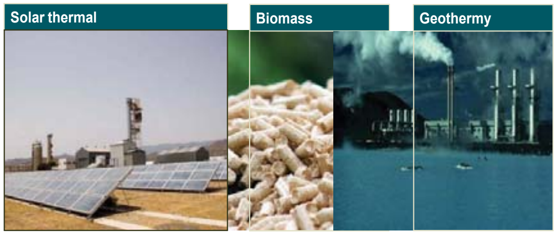
Renewable Energy

Heat oriented RE technologies are based on three major resources:

1. Solar radiation;
2. Biomass / Biogas;
3. 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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Renewable Energy

Power oriented RE technologies are based on three major resources:

1. Solar radiation;
2. Wind;
3. Waves.

Solar photovoltaic / thermal

Wind

Waves

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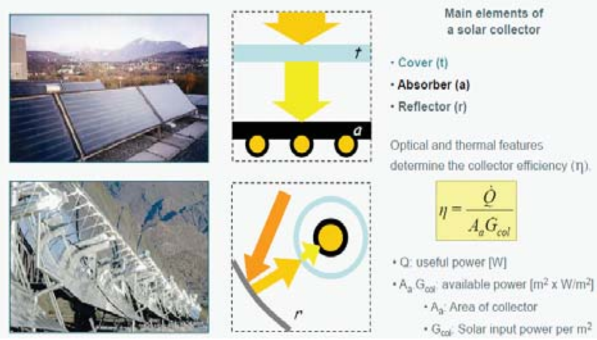
Solar thermal energy



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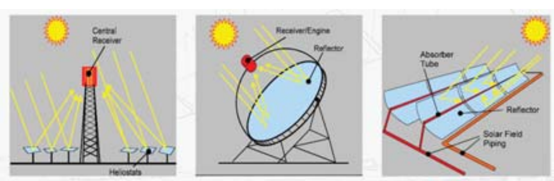
Solar thermal electricity

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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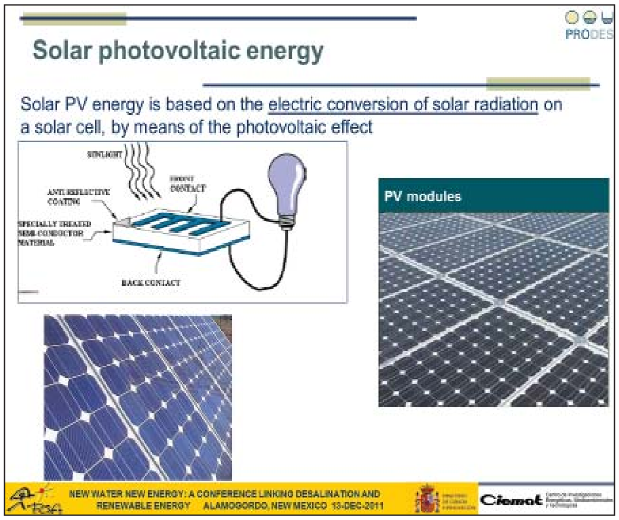

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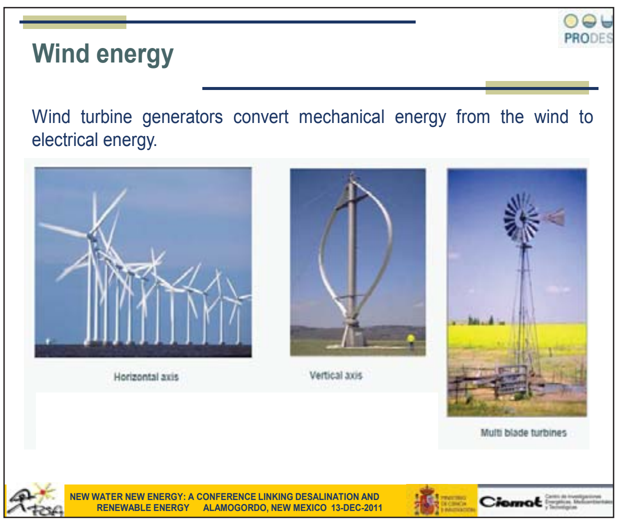

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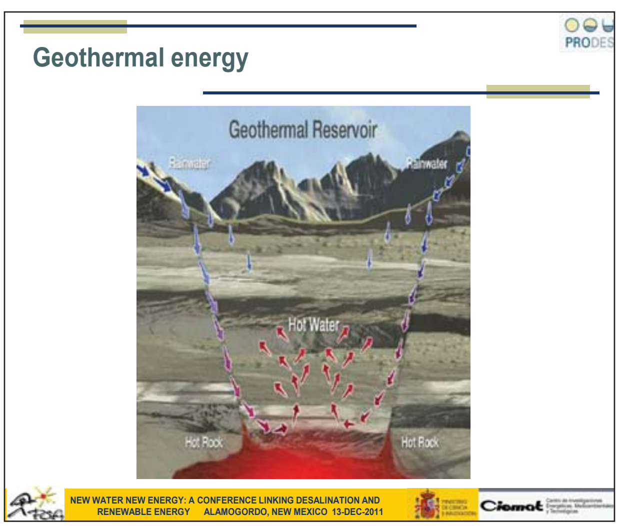

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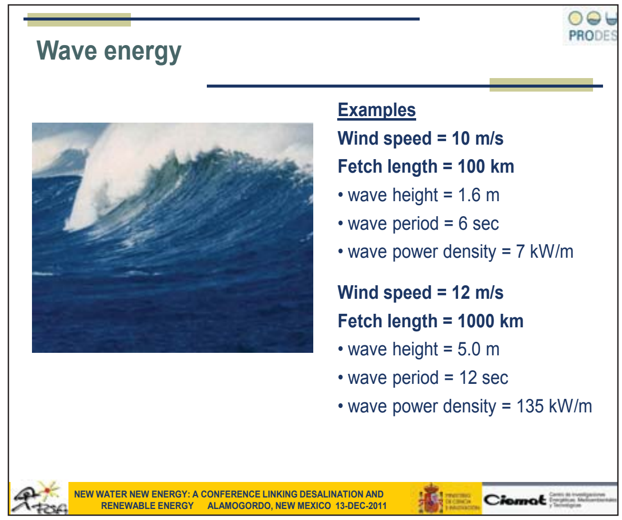

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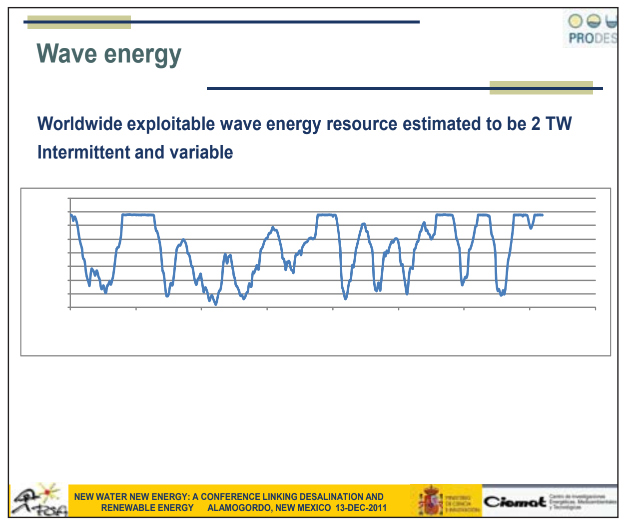

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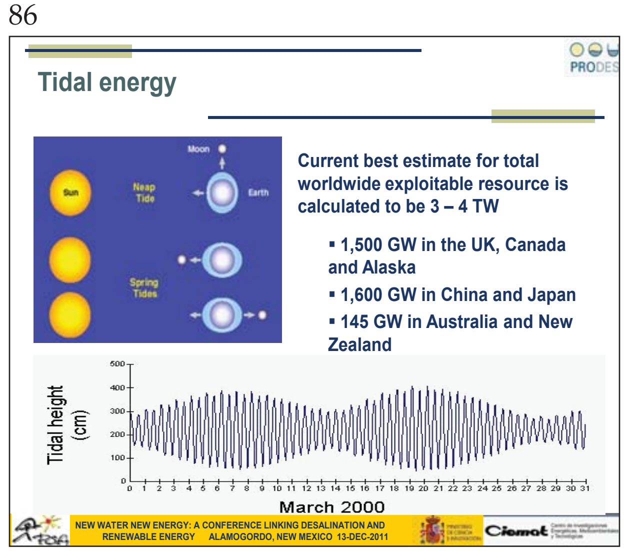

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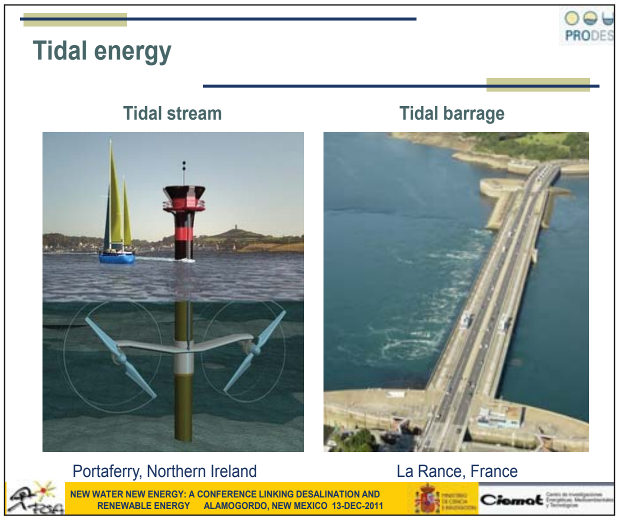

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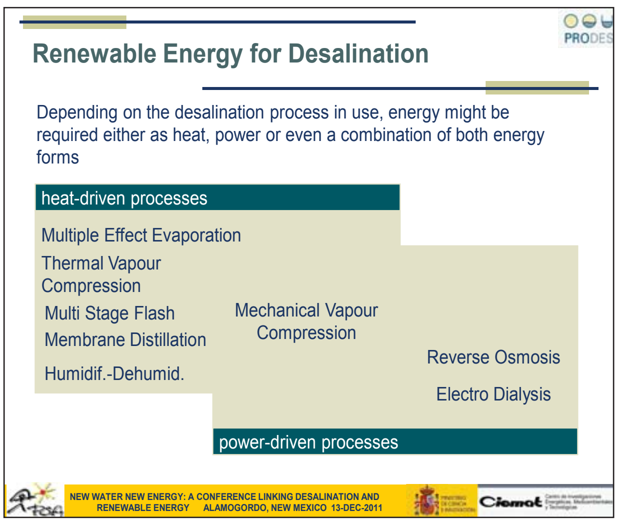

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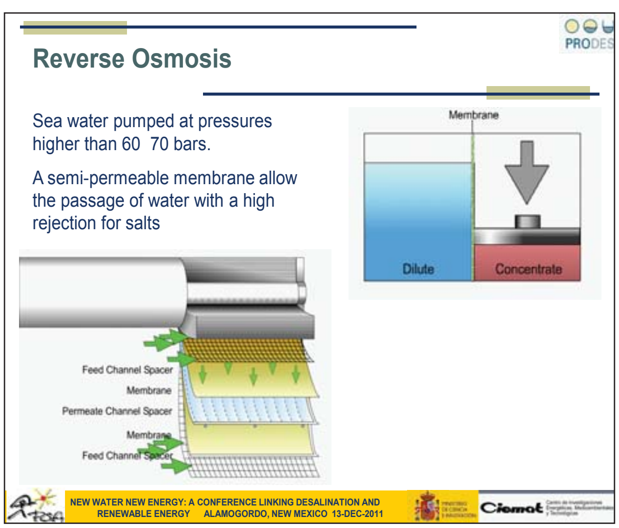

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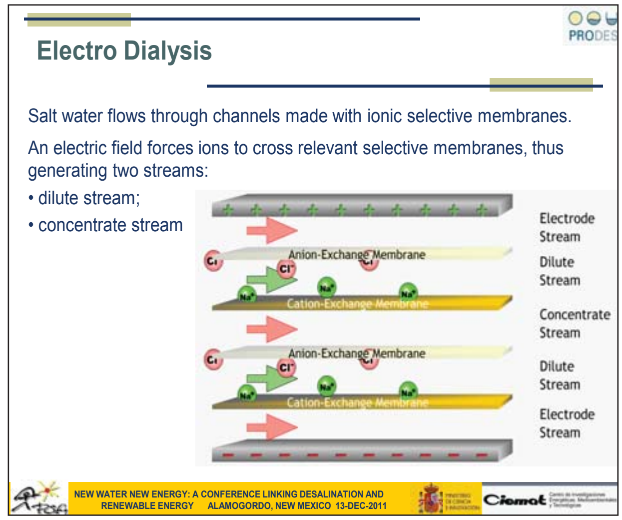

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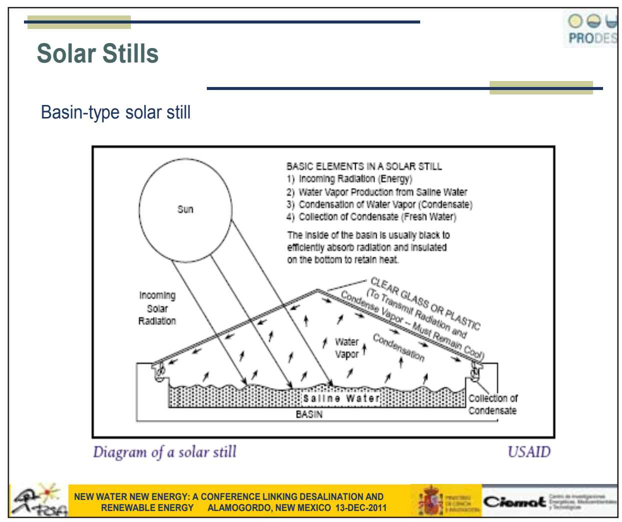

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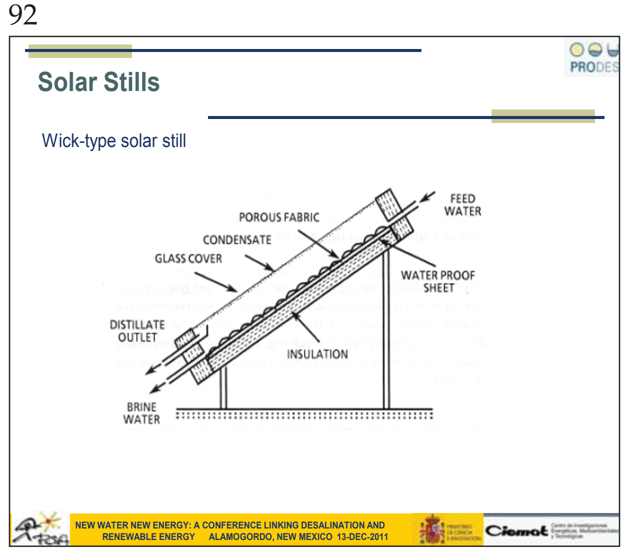

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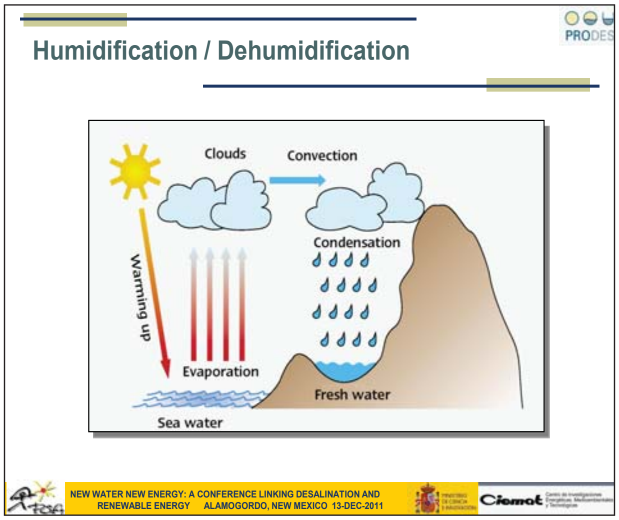

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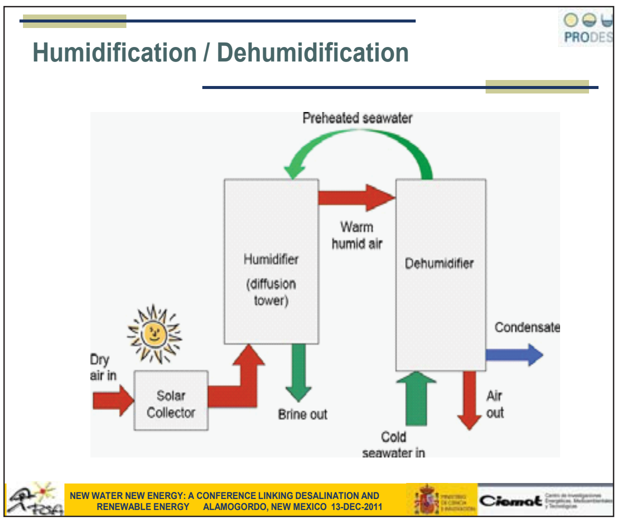

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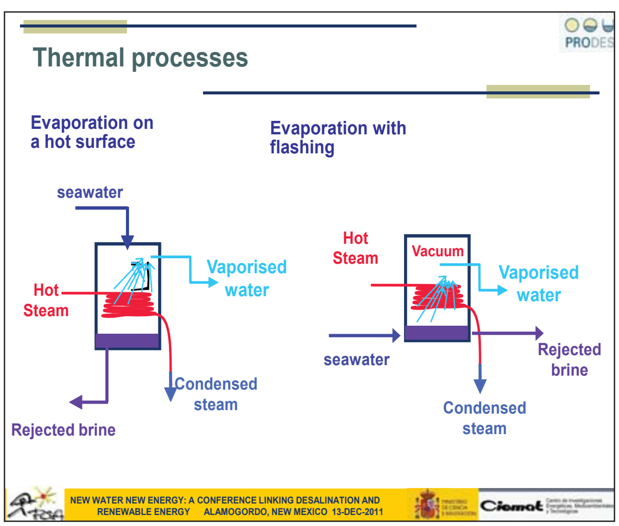

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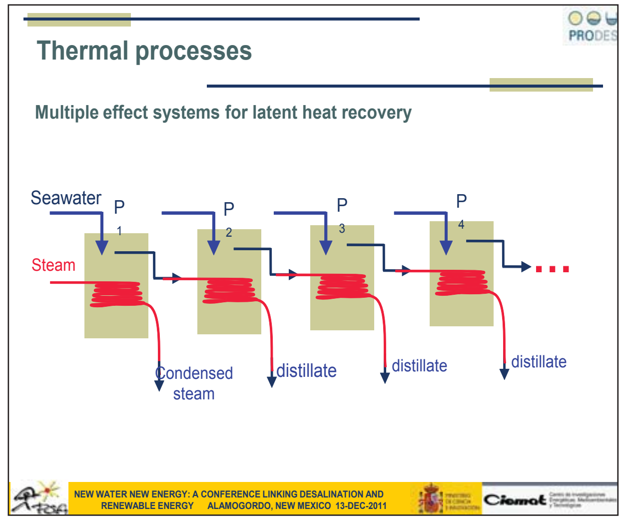

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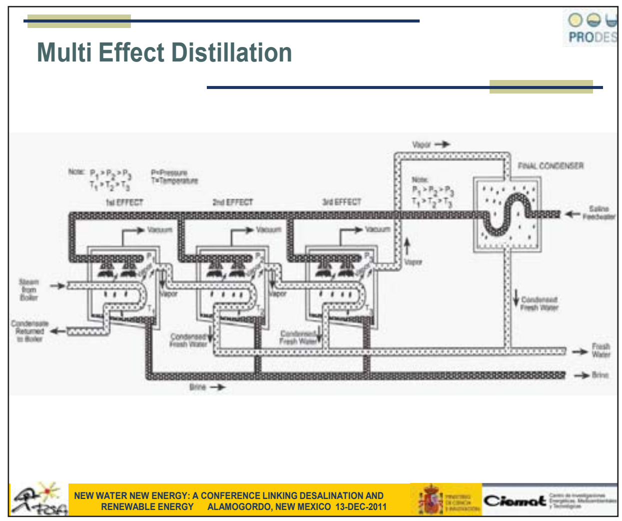

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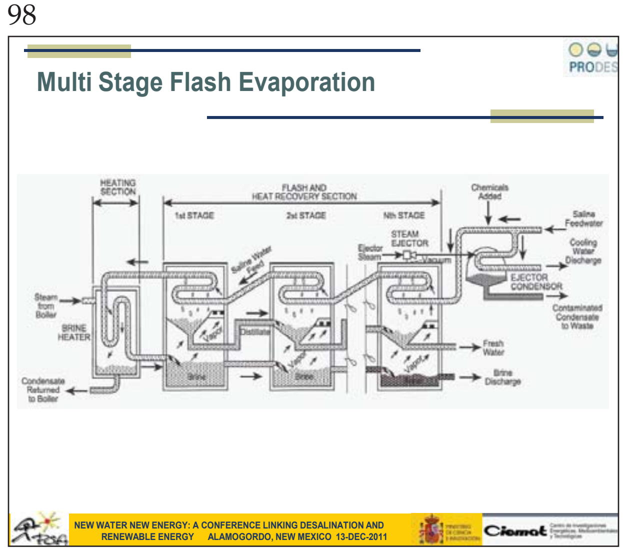

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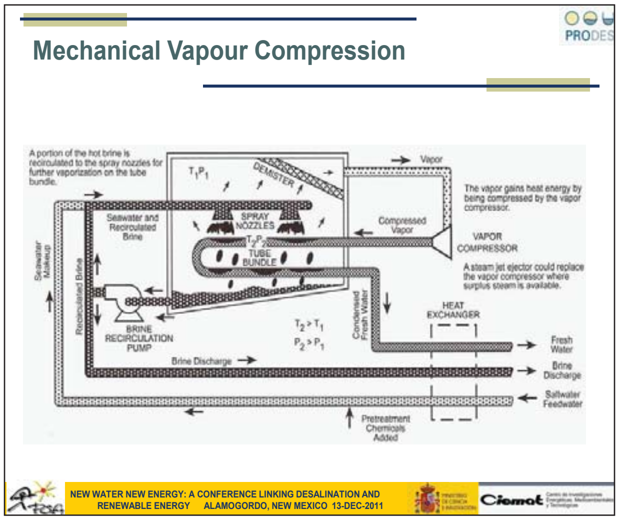

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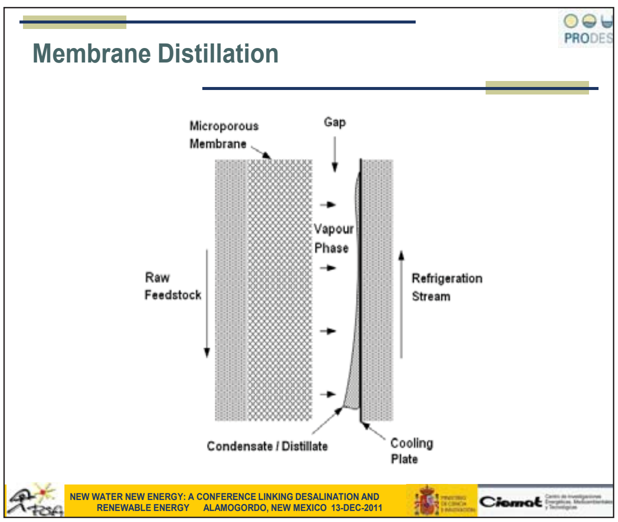

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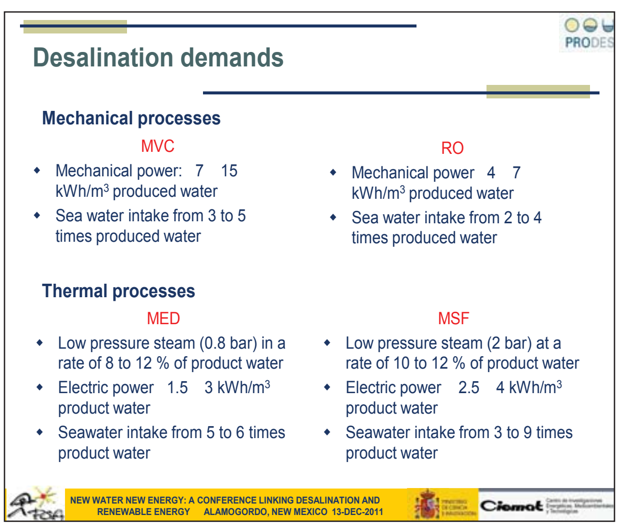

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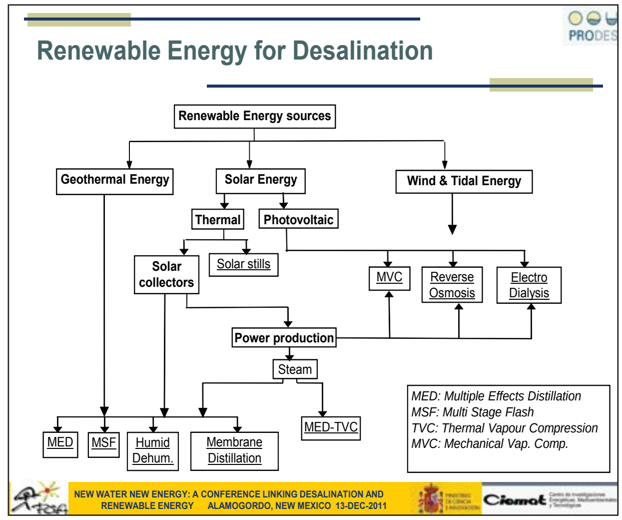

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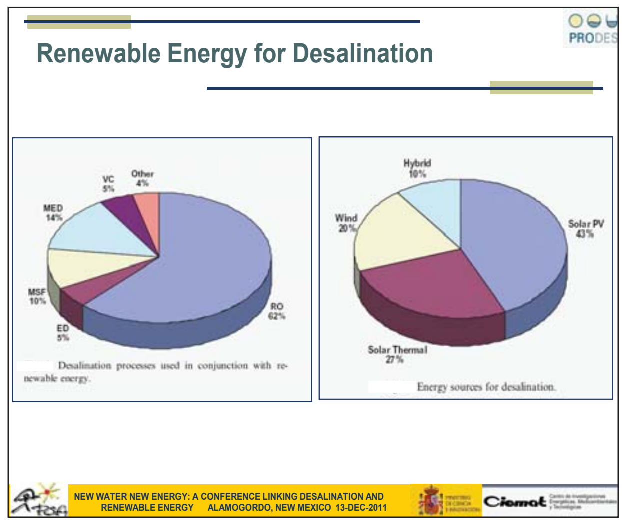

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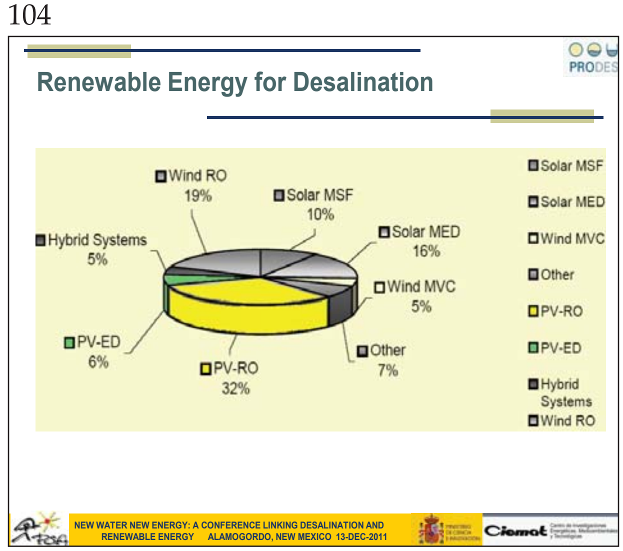

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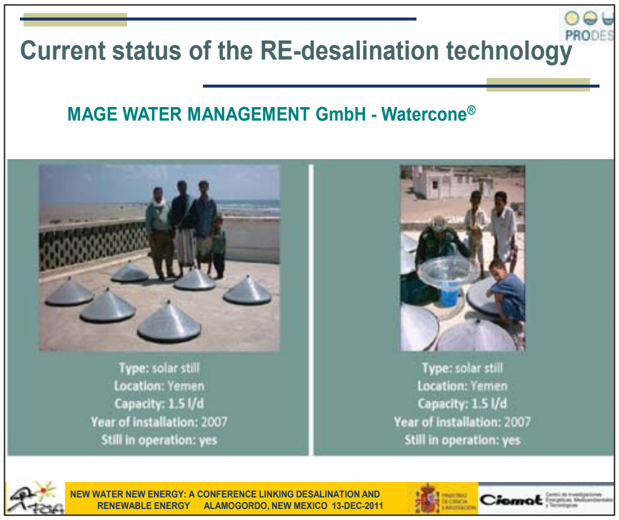

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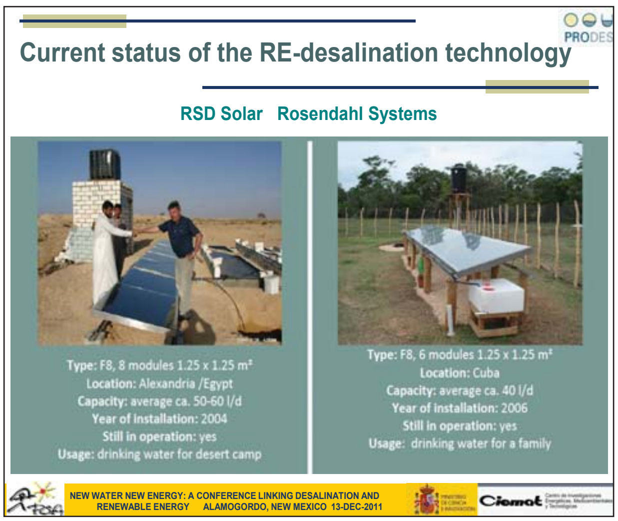

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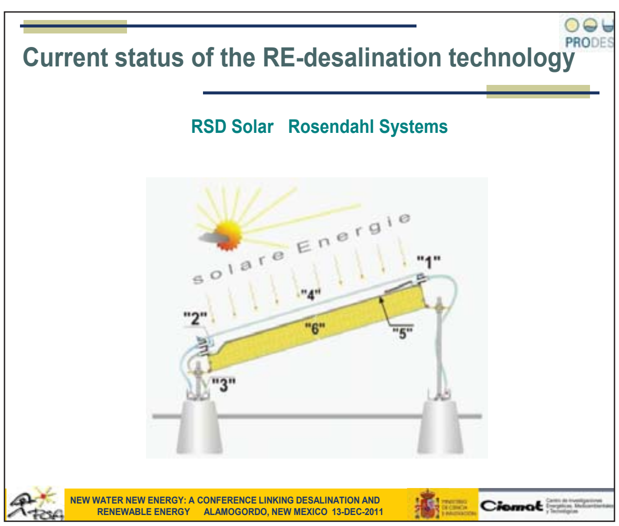

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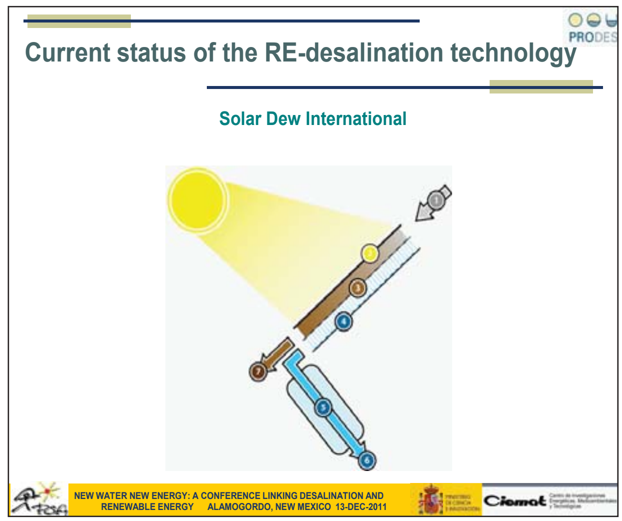

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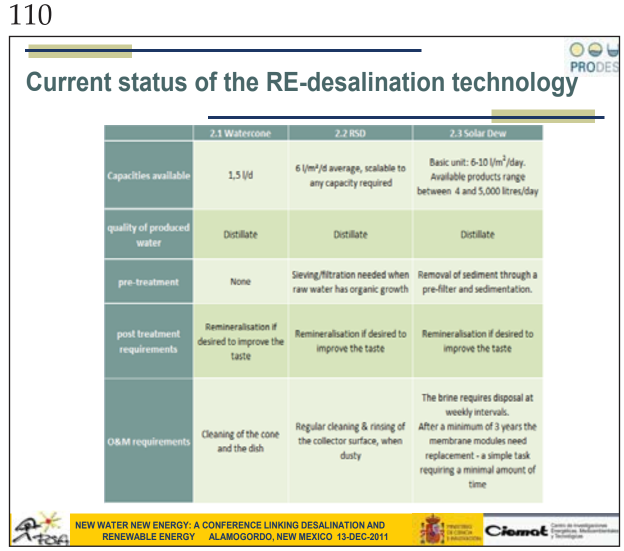

	2.1 Watercone	2.2 RSD	2.3 Solar Dew
Capacities available	1,5 l/d	6 l/m²/d average, scalable to any capacity required	Basic unit: 6-10 l/m²/day. Available products range between 4 and 5,000 litres/day
quality of produced water	Distillate	Distillate	Distillate
pre-treatment	None	Sieving/filtration needed 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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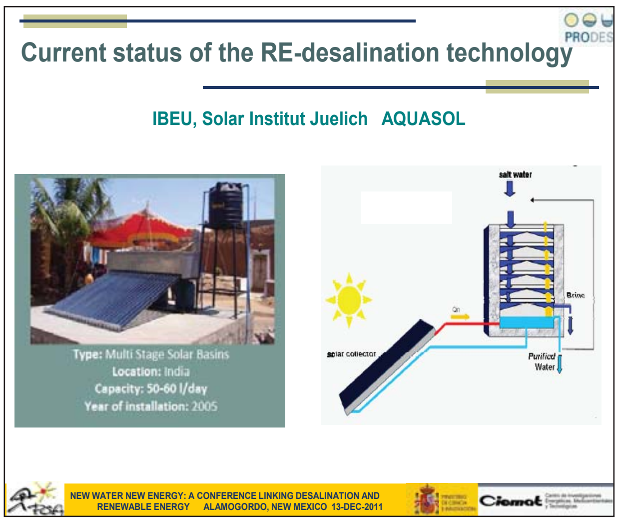

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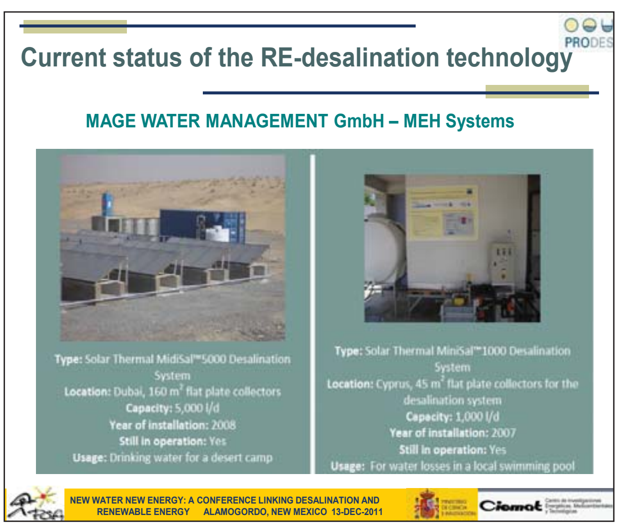

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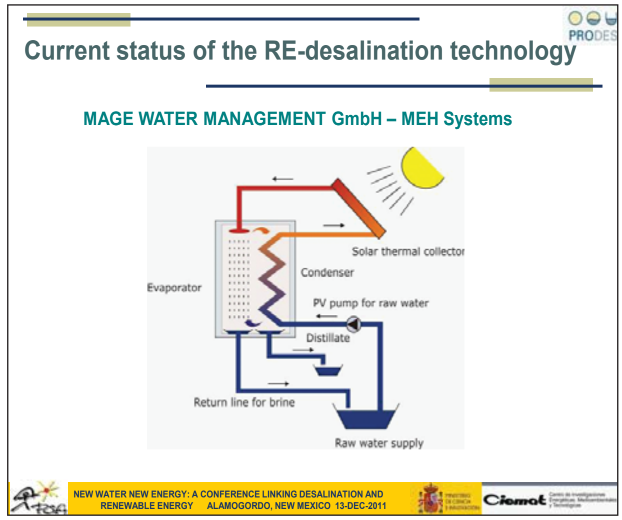

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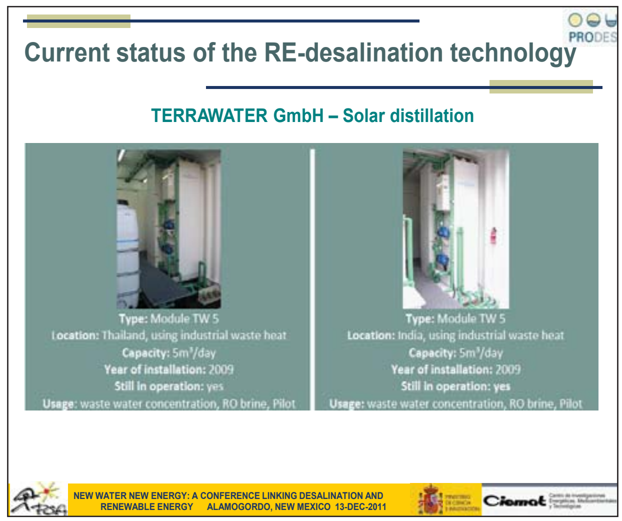

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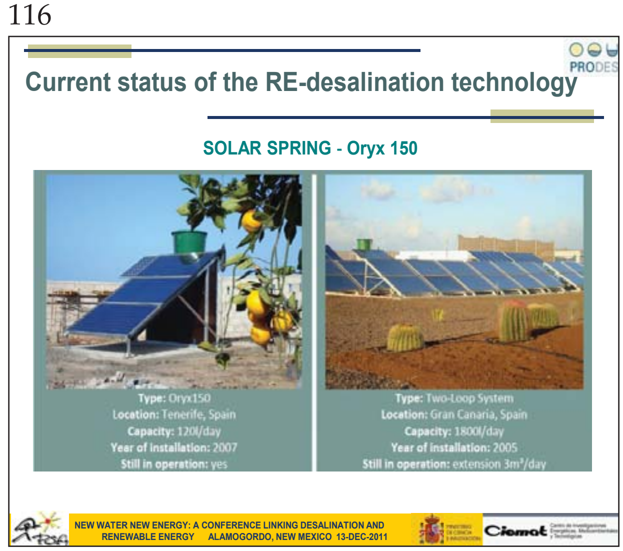

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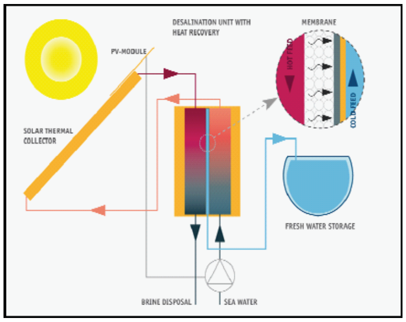
Current status of the RE-desalination technology

SOLAR SPRING - Oryx 150



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Current status of the RE-desalination technology

	3.1 AQUASOL	3.2 MEH-System	3.3 Terrawater	3.4 Solar Spring
Capacities available	30-70 l/d 100- 250 l/d hybrid system Modular up to 5m³	MiniSal™ 1000 l/d MidiSal™ 5000 l/d MegaSal™ 10000 l/d MaxiSal™ 50000 l/d	TW 5 Modules up to 6000 l/d combining TWS modules up to 500 m³/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	50 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 demounting 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 to yearly) Exchange of evaporation sheets (easy 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 5 years) cycles depending on raw water quality	Every 2 years acid and chlorine cleaning (depending on the raw water source) New MD-Module every 5 years, Pump every 10 years

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Current status of the RE-desalination technology

Technology: **solar MED**
Energy Source: **Solar thermal (CPC collectors)**
Daily Capacity (nominal): 72m³/d
Year of installation: 2005
Type of installation: R&D
Location: Almeria, Spain
Installed by: Plataforma Solar de Almeria; Aquasol Project

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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

ENERCON GmbH – Wind RO

Type: Seawater Desalination System
Location: Greek Island
Capacity: 500m³/day
Year of installation: 1998
Still in operation: no, until 2004
Usage: Public water supply

Type: EDS 1200 SW
Location: Aurich, Germany
Capacity: 1200m³/day
Year of installation: 2004
Still in operation: yes
Usage: Demonstration

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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 m³/h
Year of installation: 1995
Still in operation: yes
Usage: drinking water

Type: wind-vapour compression
Location: Symi, Greece
Capacity: 20m³/h
Year of installation: 2009
Still in operation: yes
Usage: drinking water

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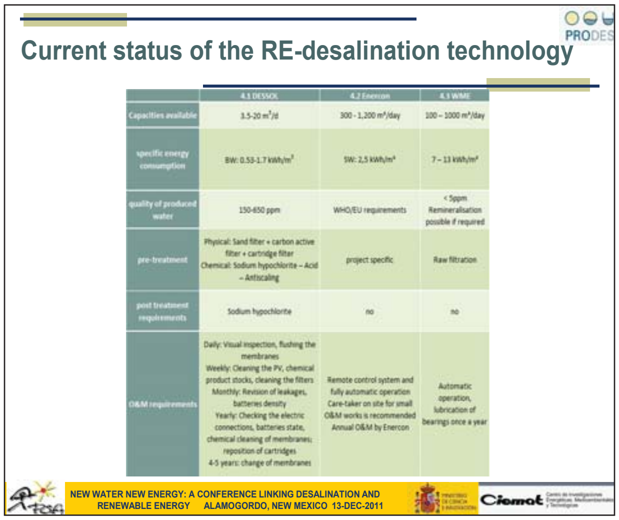

	4.1 DESSOL	4.2 Enercon	4.3 WME
Capacities available	3.5-20 m³/d	300 - 1,200 m³/day	100 – 1000 m³/day
specific energy consumption	BW: 0.53-1.7 kWh/m³	SW: 2,5 kWh/m³	7 – 13 kWh/m³
quality of produced water	150-650 ppm	WHO/EU requirements	< 5ppm Remineralisation possible if required
pre-treatment	Physical: Sand filter + carbon active filter + cartridge filter Chemical: Sodium hypochlorite – Acid – Antiscaling	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; reposition 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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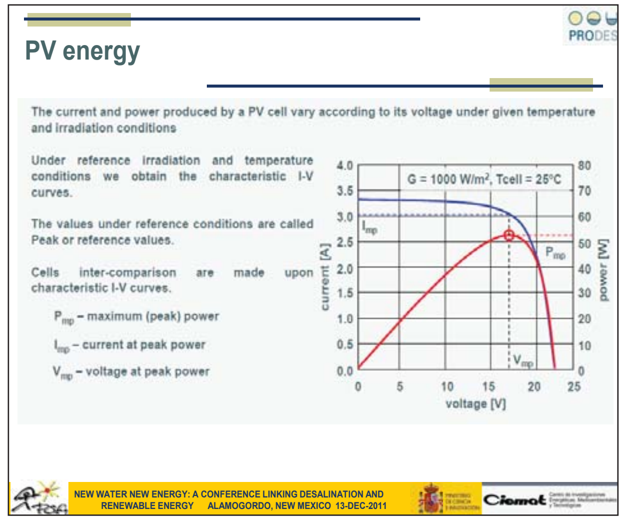

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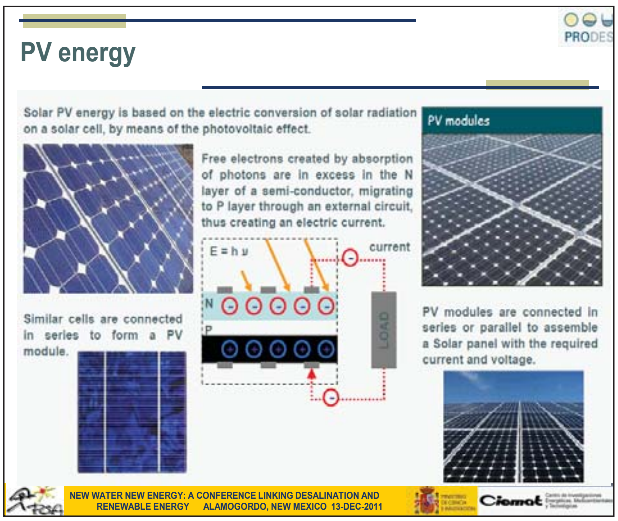

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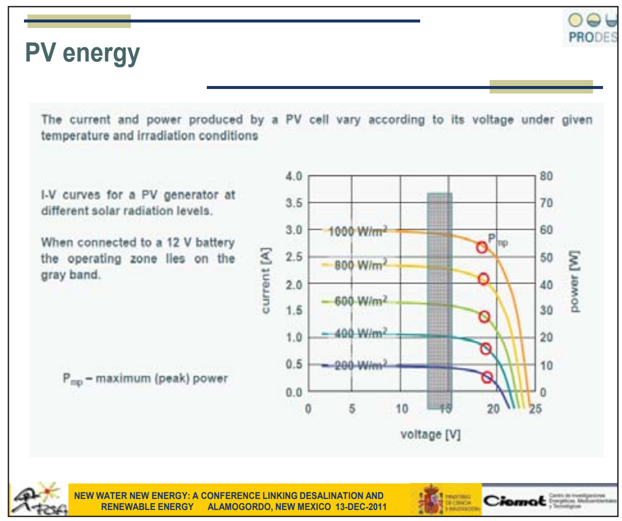

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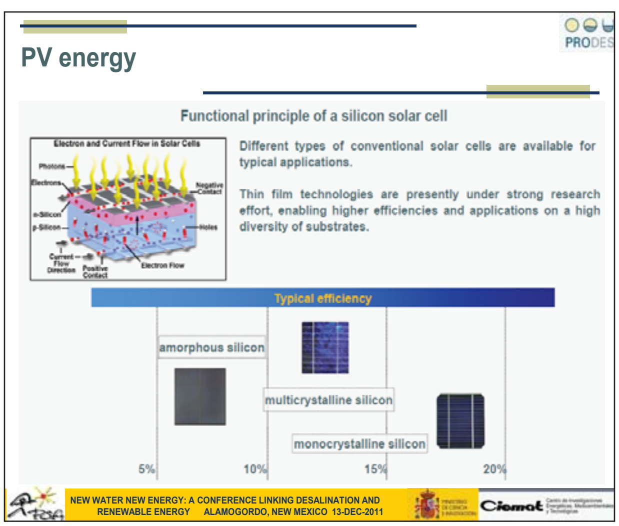

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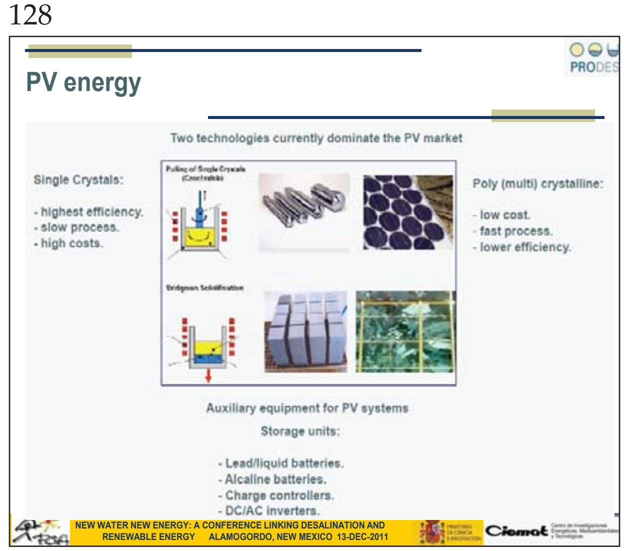

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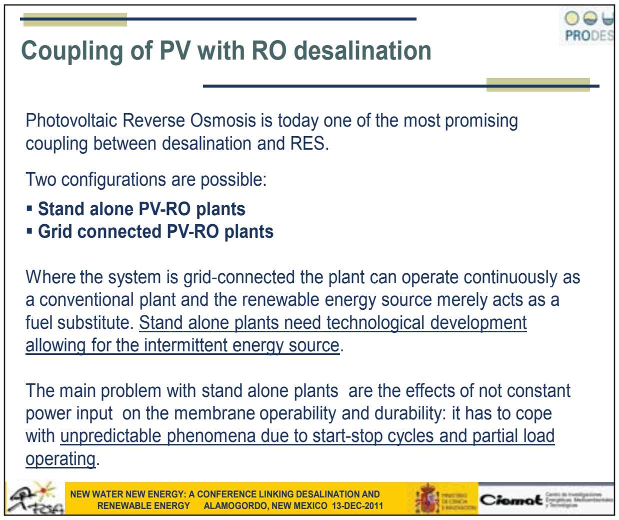

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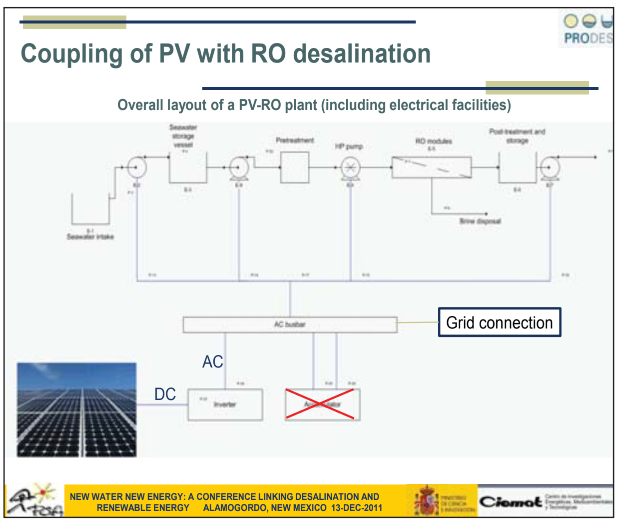

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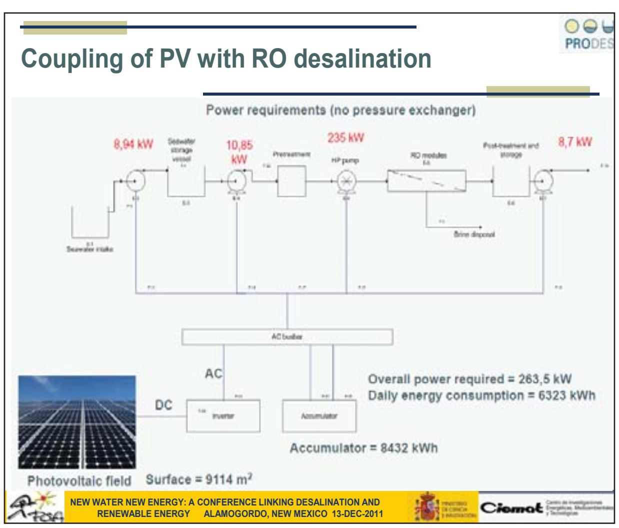

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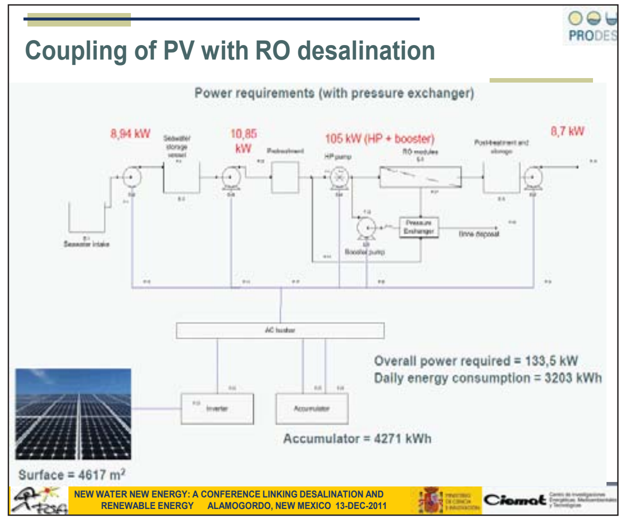

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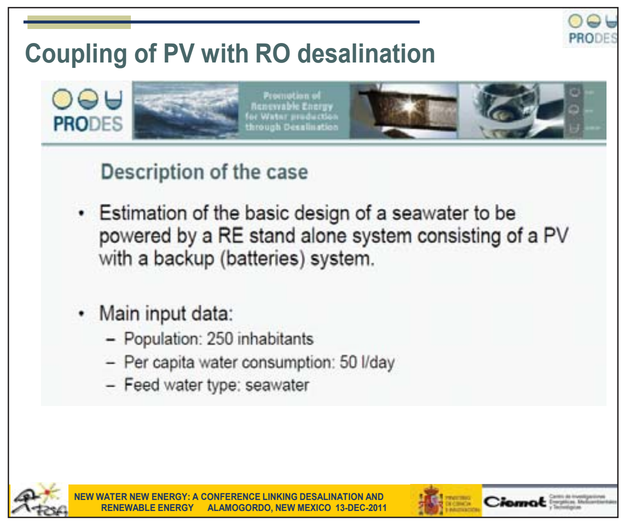

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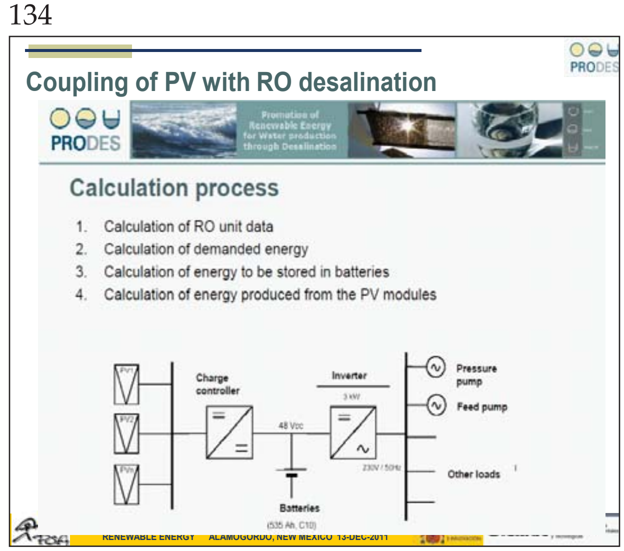

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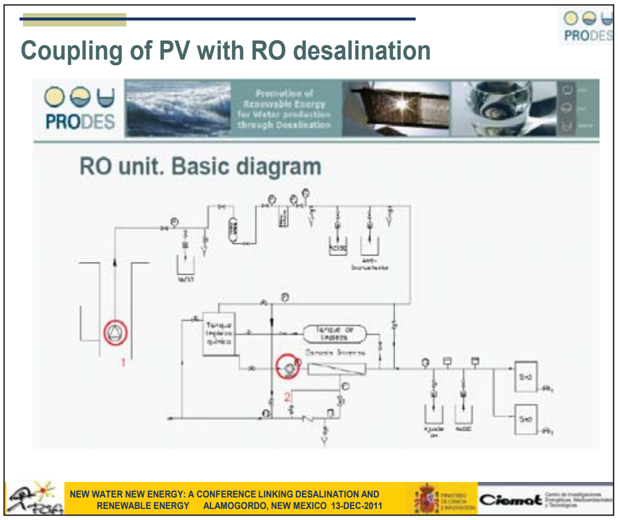

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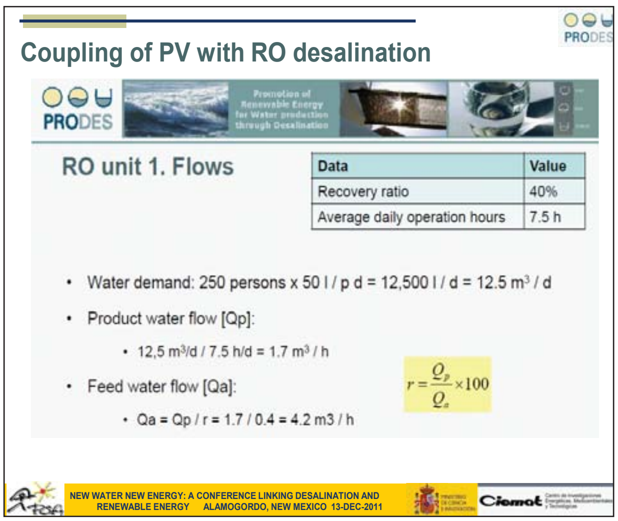

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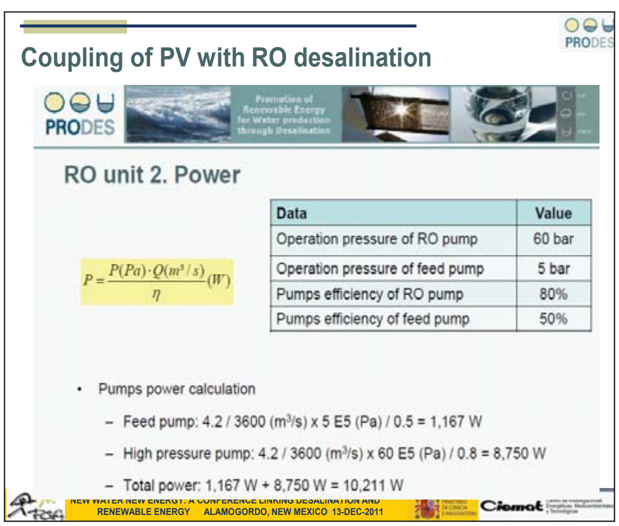

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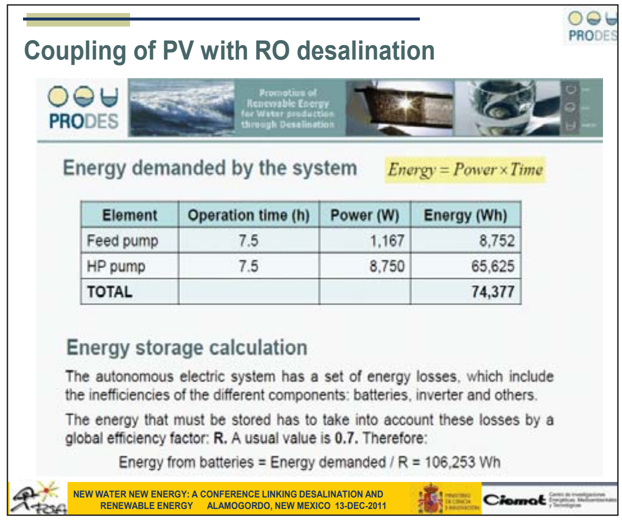

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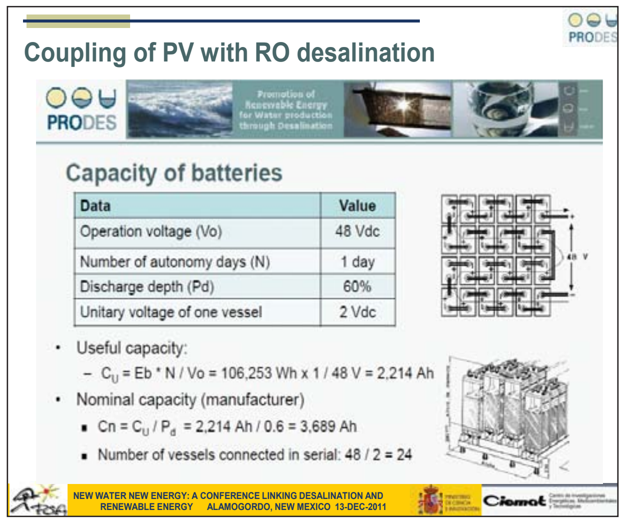

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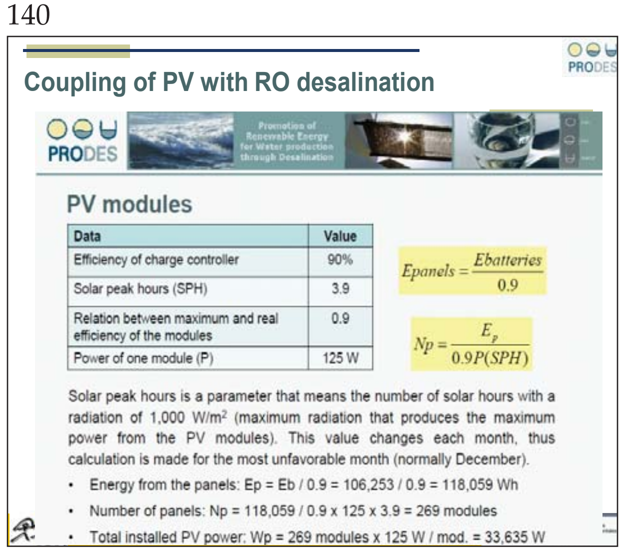

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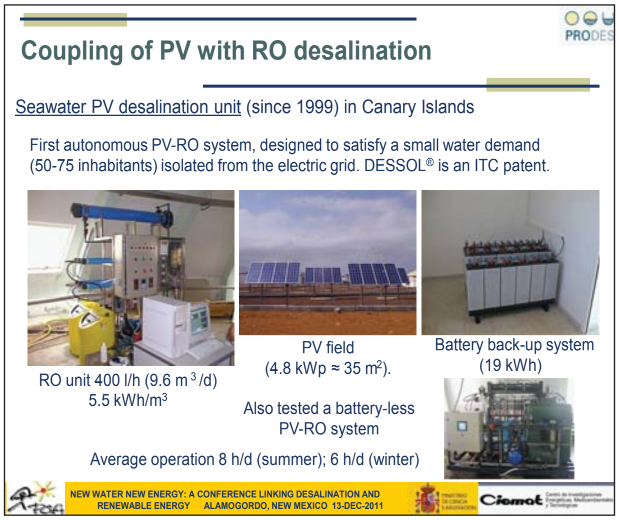

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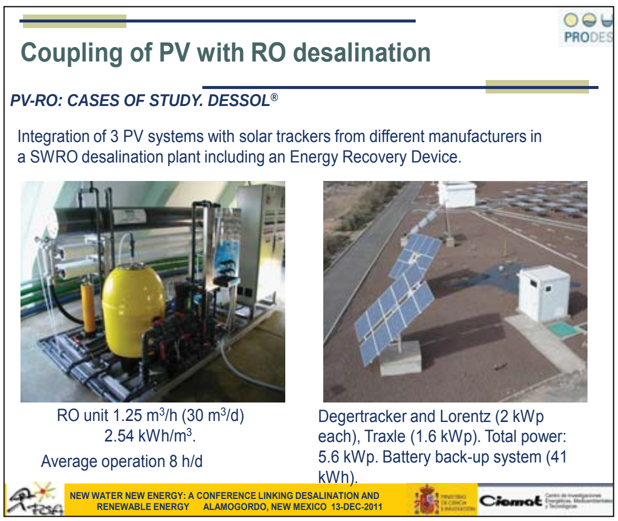

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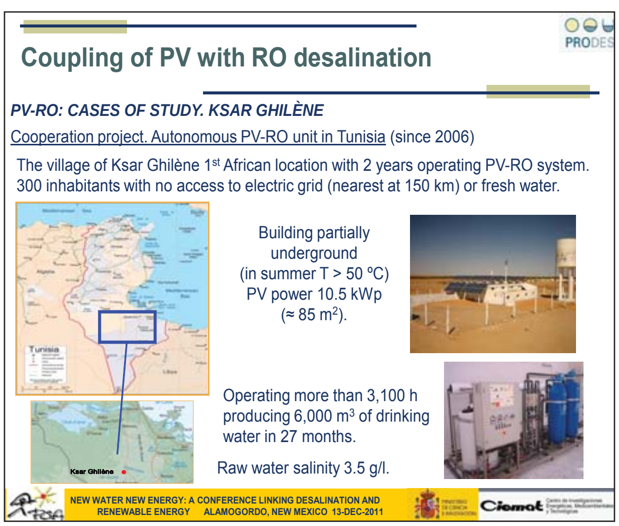

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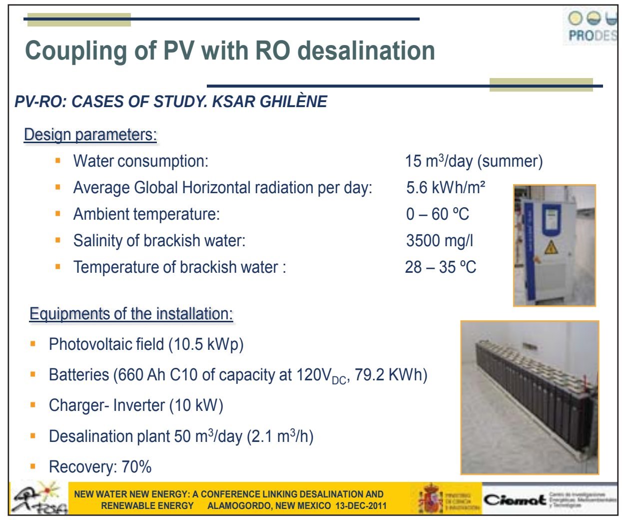

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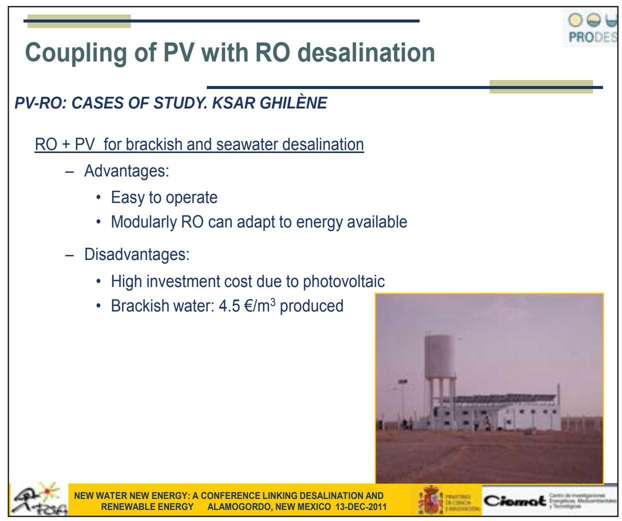

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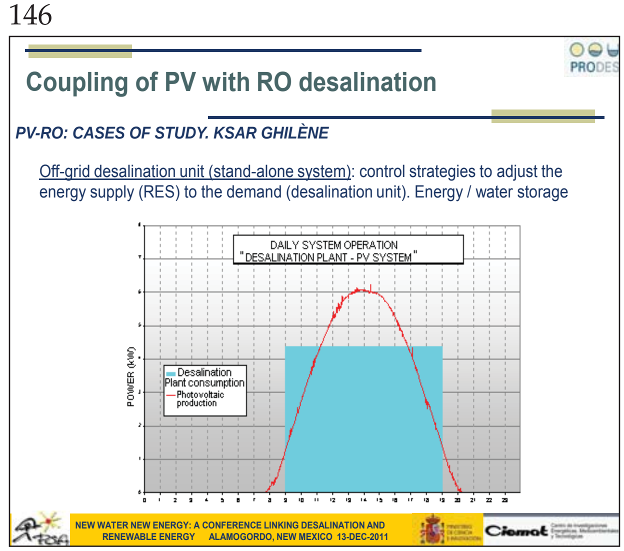

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Coupling of PV with RO desalination

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

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

	Design	Real
Water production (m^3/year)	**4,200-4,500**	**2,537**
Days of operation/year	**320-350**	**281**

1° year: July 06-June 07
2° 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

PV-RO: CASES OF STUDY. MOROCCO

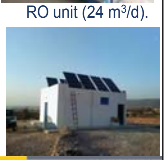
Cooperation project. Autonomous PV-RO units in Morocco (since 2008)

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).

Dessol®.

RO unit (24 m^3/d).

Co-funded by EU, MEDA-water programme.



PV field (4 kWp ≈ 36 m^2).

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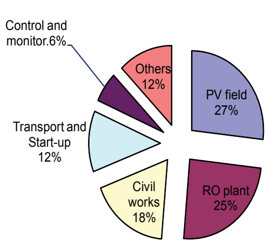
Coupling of PV with RO desalination

PV-RO: CASES OF STUDY. MOROCCO

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

Total investment 360.000 €



Total water cost: 5.3 €/m^3

O&M: 3.5 €/m^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^3, SW: from 9 to 12 €/m^3).

- 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 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^2 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^3.

WT 890 W, PV array 600 Wp, battery 21 kWh.

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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^3/h – 4 kWp – 900 W); CRES

Installed equipment:

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

Source: ADU-RES

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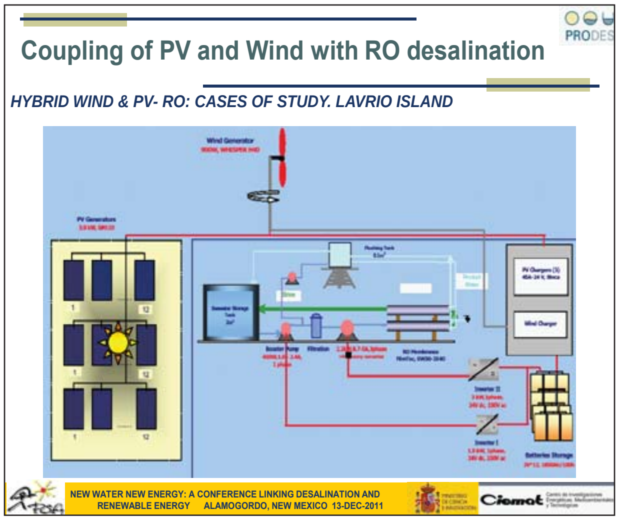

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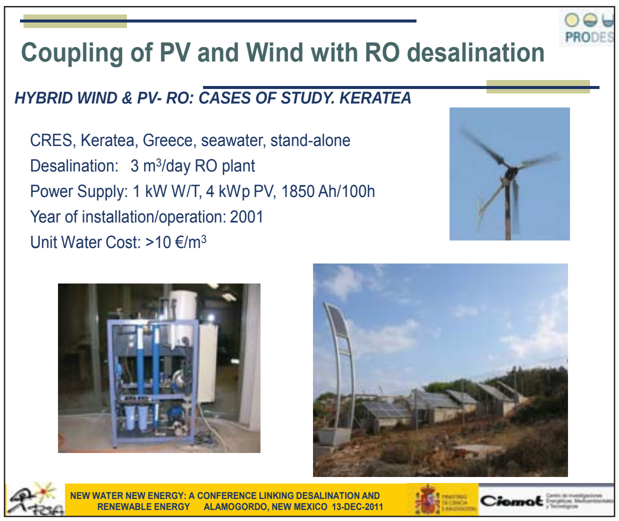

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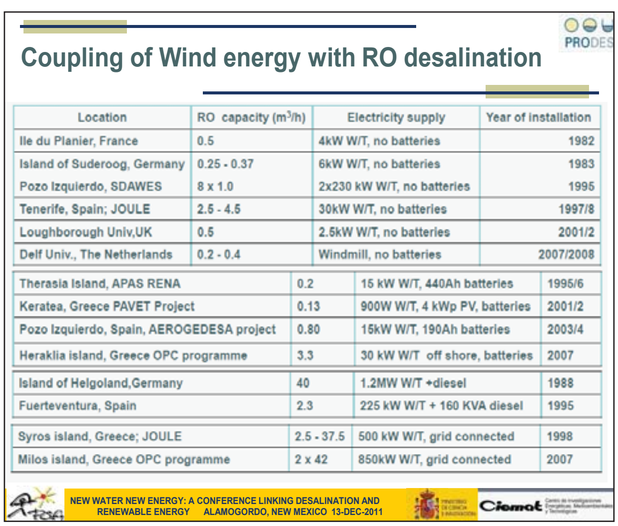

Location	RO capacity (m^3/h)	Electricity supply	Year of installation
Ile du Planier, France	0.5	4kW W/T, no batteries	1982
Island of Suderoog, Germany	0.25 - 0.37	6kW W/T, no batteries	1983
Pozo Izquierdo, SDAWES	8 x 1.0	2x230 kW W/T, no batteries	1995
Tenerife, Spain; JOULE	2.5 - 4.5	30kW W/T, no batteries	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
Therasia 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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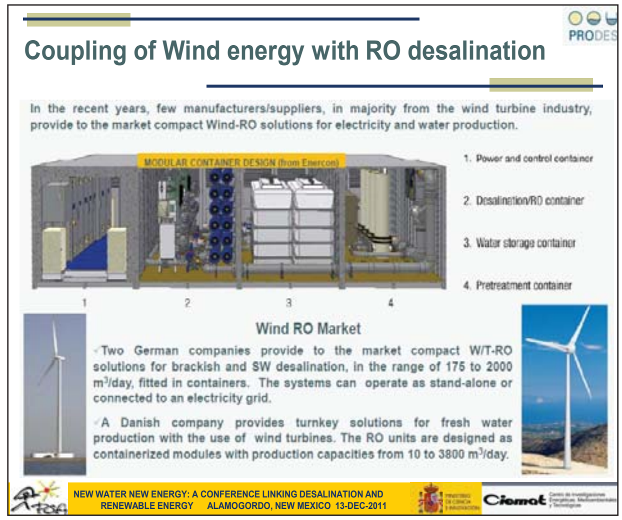

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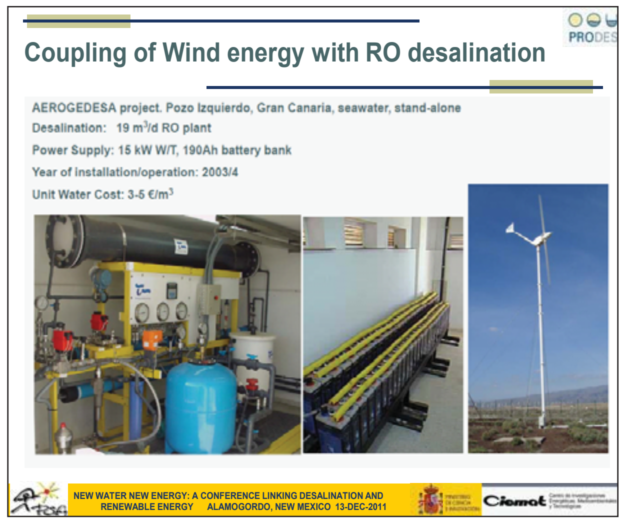

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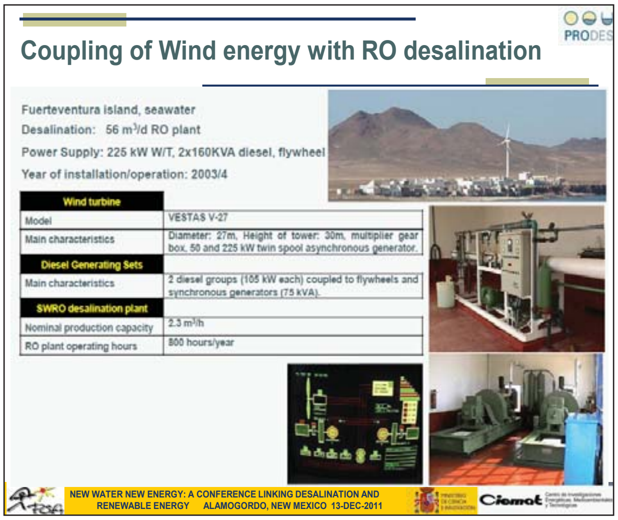

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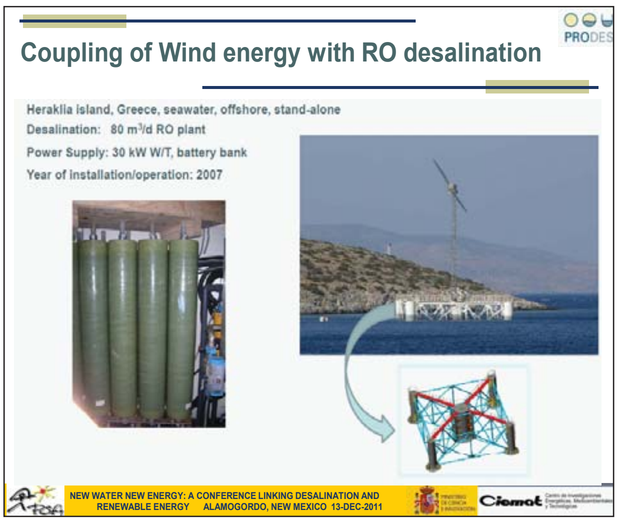

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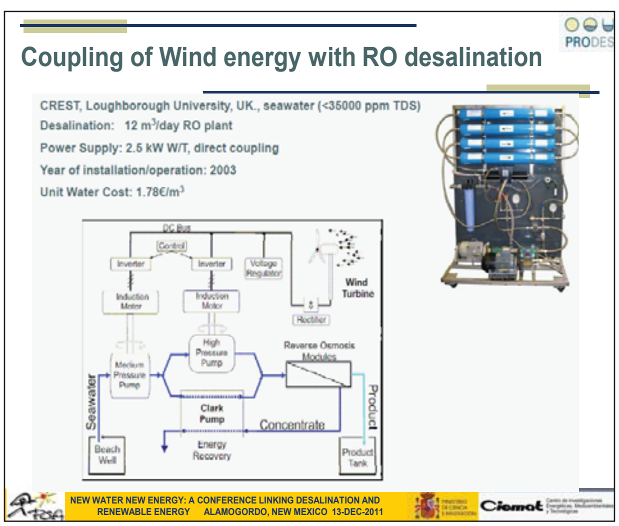

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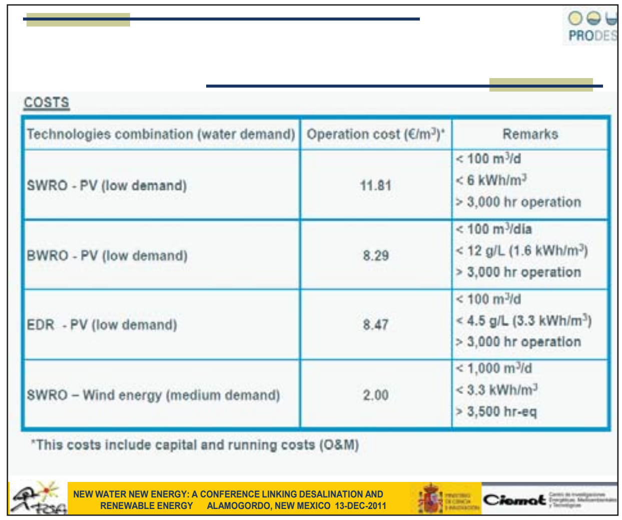

Technologies combination (water demand)	Operation cost (€/m³)*	Remarks
SWRO - PV (low demand)	11.81	< 100 m³/d < 6 kWh/m³ > 3,000 hr operation
BWRO - PV (low demand)	8.29	< 100 m³/dia < 12 g/L (1.6 kWh/m³) > 3,000 hr operation
EDR - PV (low demand)	8.47	< 100 m³/d < 4.5 g/L (3.3 kWh/m³) > 3,000 hr operation
SWRO – Wind energy (medium demand)	2.00	< 1,000 m³/d < 3.3 kWh/m³ > 3,500 hr-eq

*This costs include capital and running costs (O&M)

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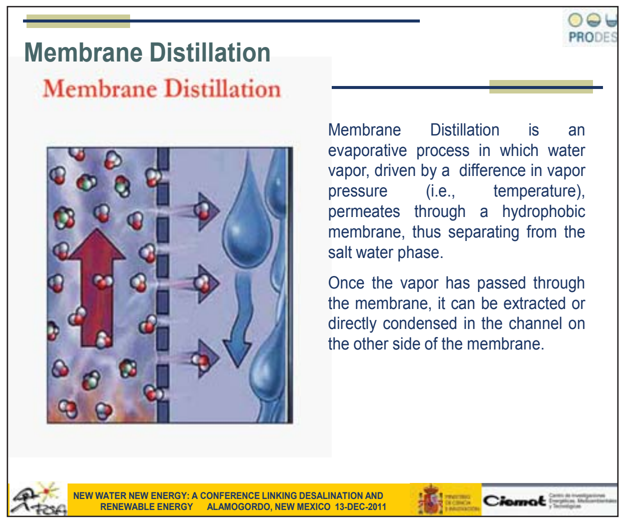

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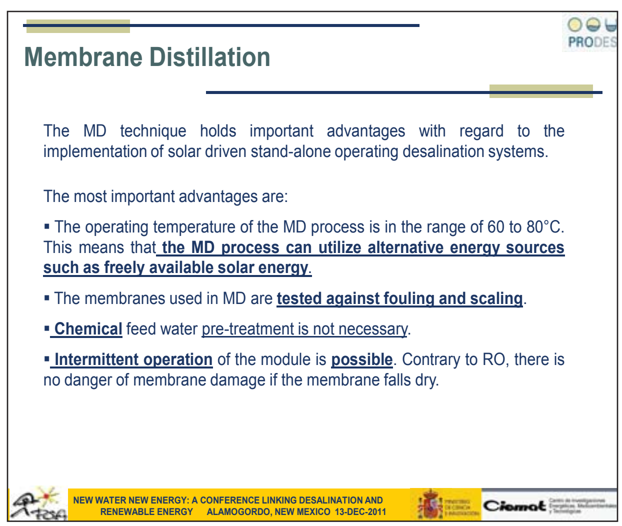

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Membrane Distillation

- **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

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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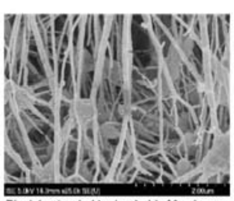
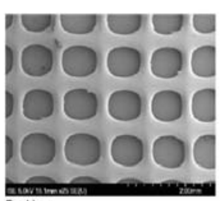
Membrane Distillation



Biaxial extended hydrophobic Membrane

Manufacturer :	GORE
Material:	PTFE
Average Poresize:	0.2µm
Thickness δ of membrane:	35µm
Wetting pressure:	4.9 bar
Porosity:	80%



Backing

Material:	Polypropylene
Thickness:	280µm
covered membrane area:	40%

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Membrane Distillation

Heat Transport in MD

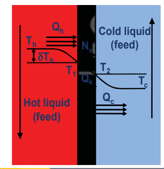
The heat flux is related to the passage of heat from the hot liquid to the cold permeate, and is characterized by three resistances in series:

1. Resistance from the hot bulk to the membrane surface, due to convective transport;
2. 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);
3. Resistance from the membrane surface to the cold bulk, due to convective transport.

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

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

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



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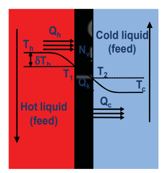
Membrane Distillation

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 trough the membrane;

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

$(T_1 - T_2)/(T_h - T_c)$ = **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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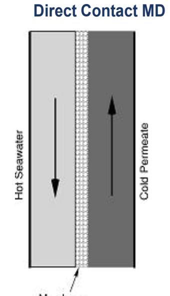
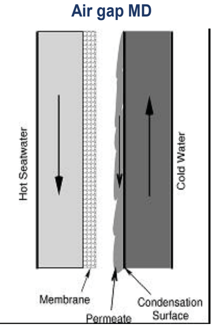
Membrane Distillation

Configurations of MD

Direct Contact MD



Air gap MD



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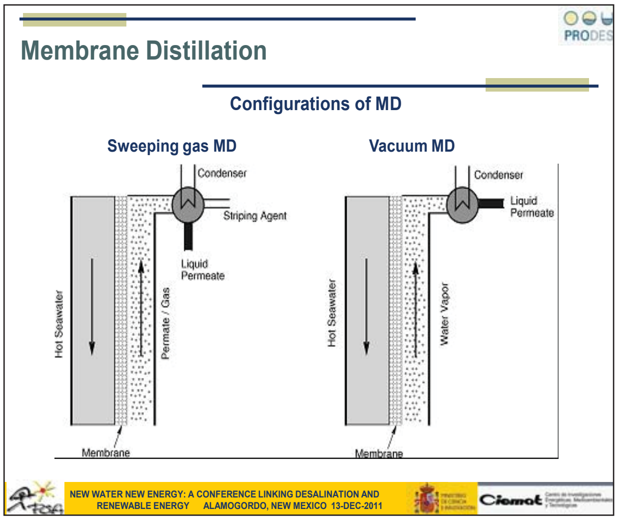

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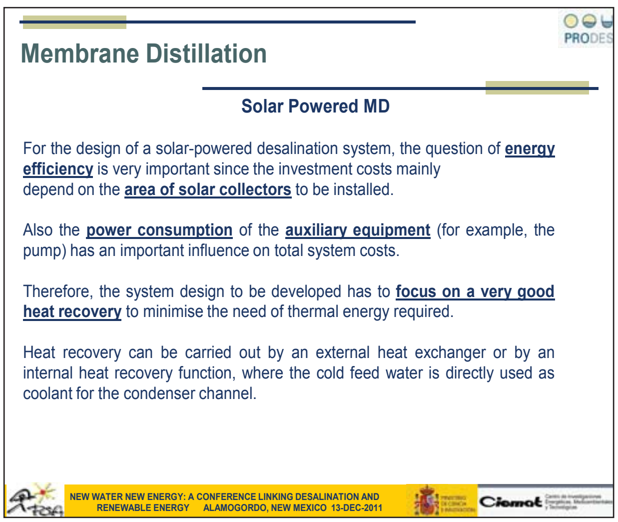

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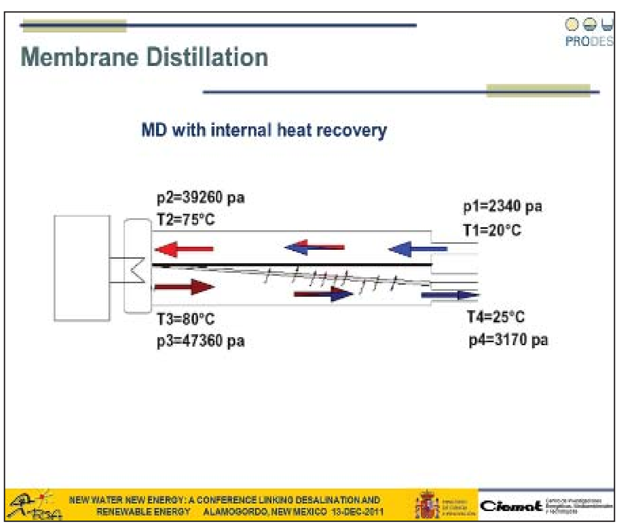

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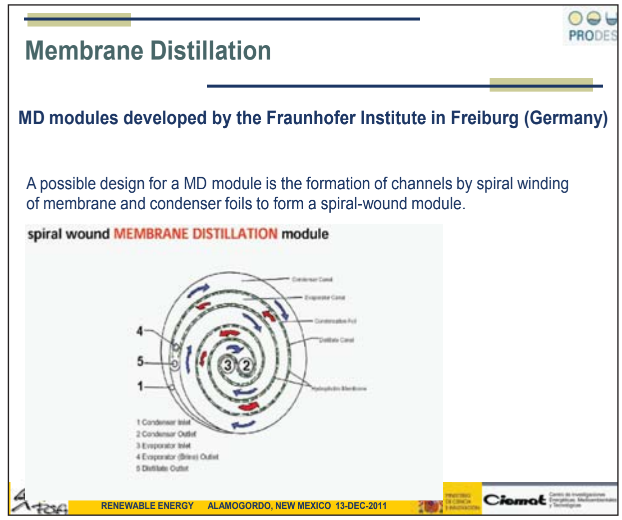

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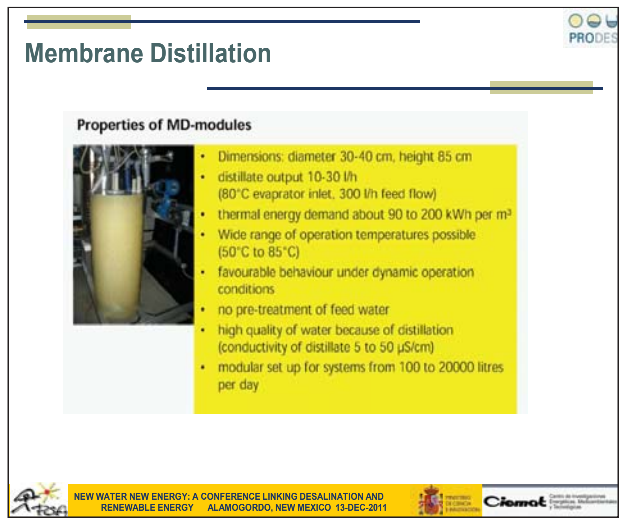

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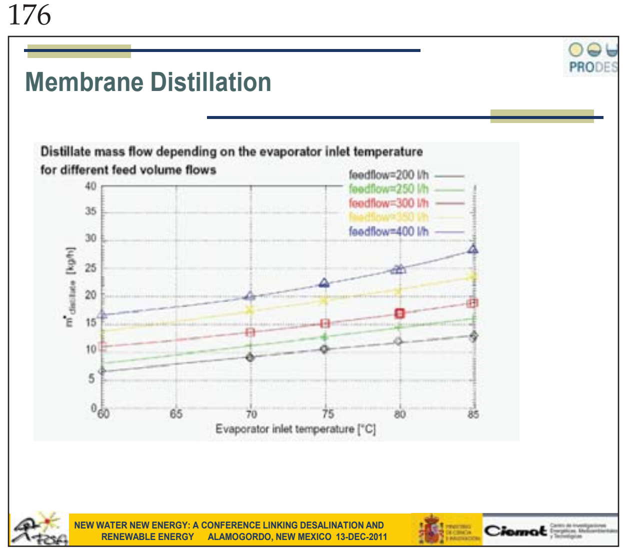

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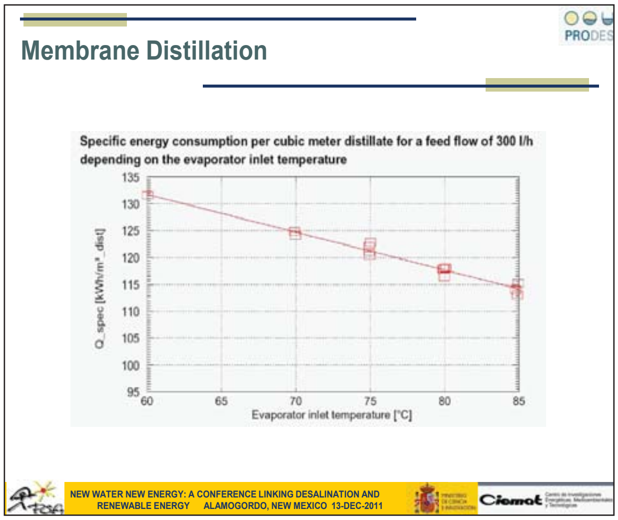

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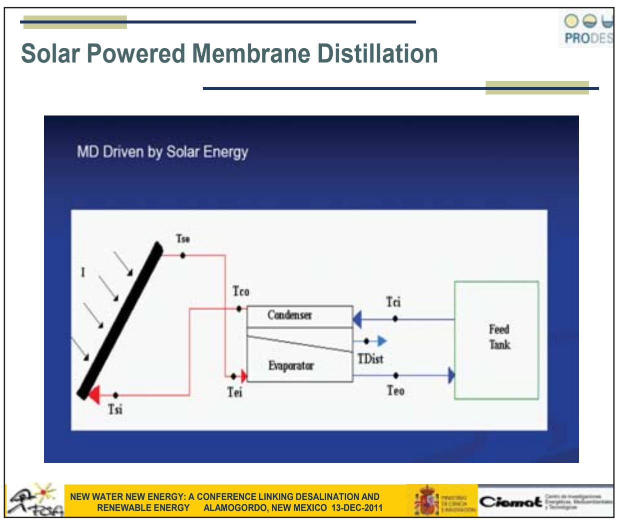

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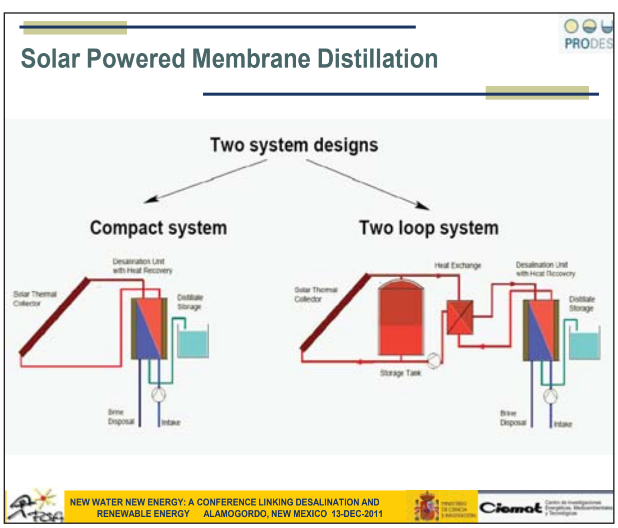

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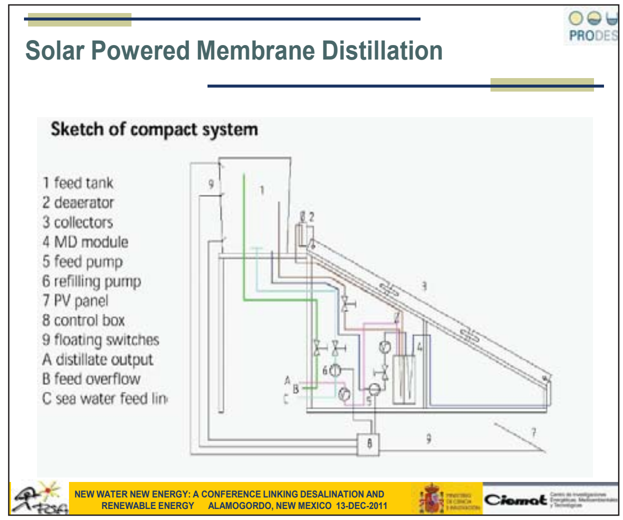

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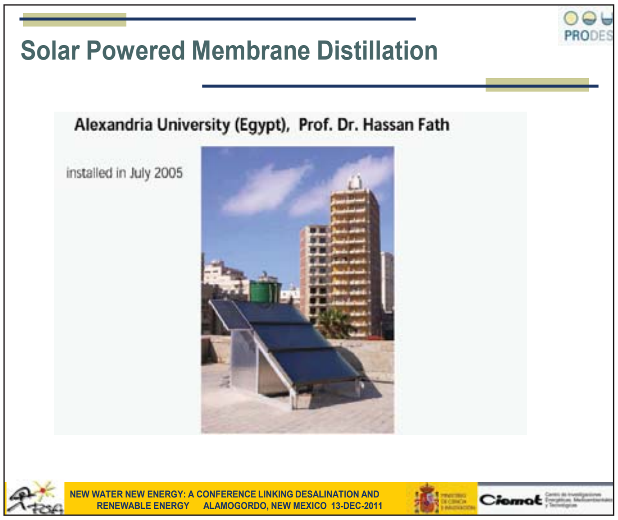

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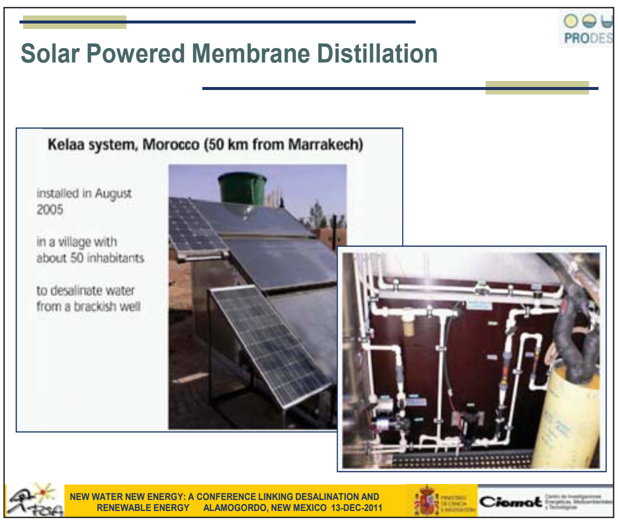

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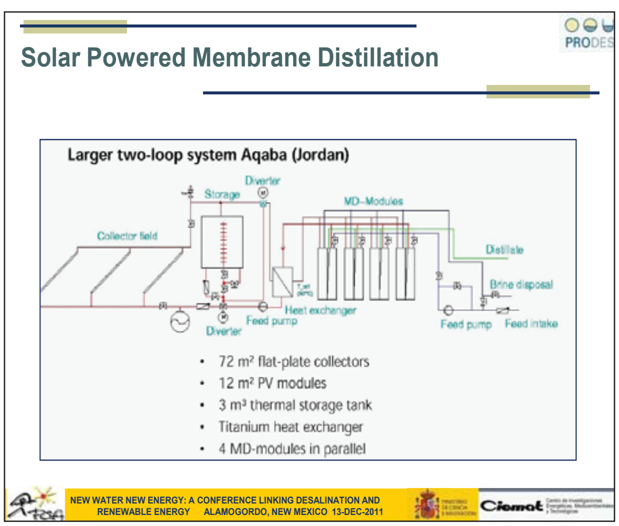

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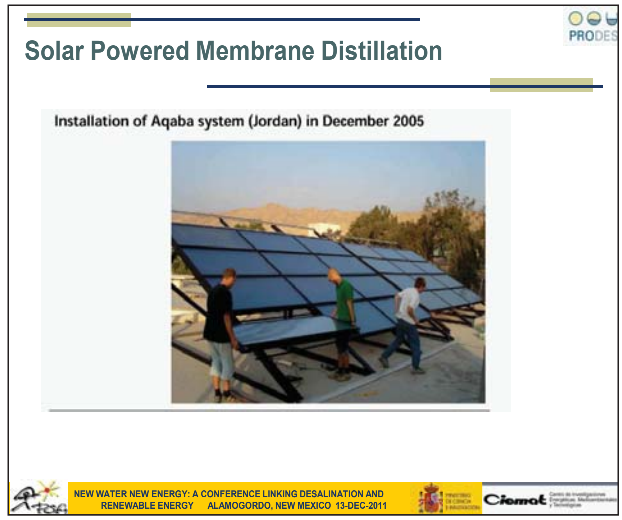

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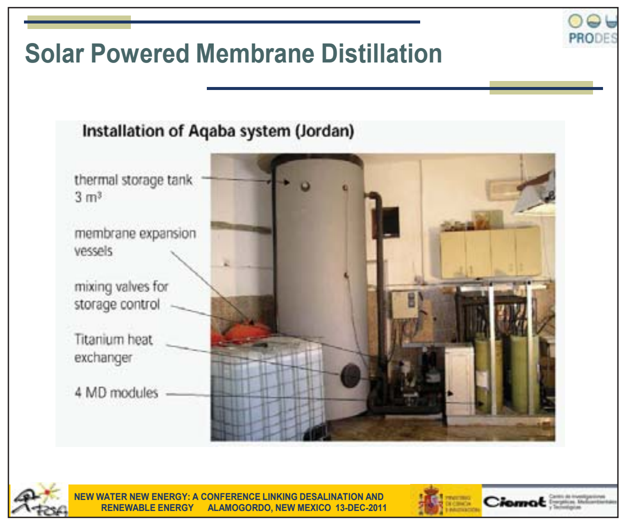

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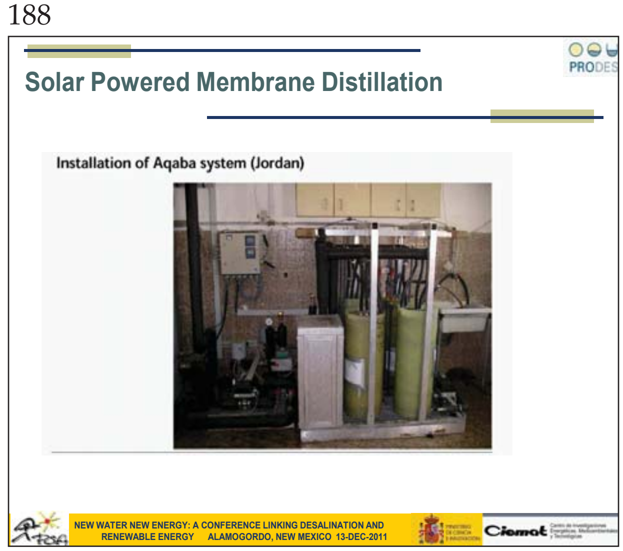

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THANK YOU
Vicente Subiela and Baltasar Peñate (Instituto Tecnológico de Canarias, Spain)
Andrea Cipollina and Giorgio Micale (University of Palermo, Italy)
Eftihia Tzen (CRES, Greece)
Marcel Wieghaus and Joachim Koschikowski (Fraunhofer Institute, Germany)
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