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 Almeria (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 Andalucia 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 Almeria 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.


PowerPoint Presentation http://wrri.nmsu.edu/publish/watcon/proc56/Zaragoza.pdf
GUILLERMO ZARAGOZA, PLATAFORMA SOLAR DE ALMERIA

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.

PLATAFORMA SOLAR (PSA)

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

PSA R&D INSTALLATIONS

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

CIEMAT SITES

NAVARRA (Scale model)
CIEMAT – El Bierzo
CIEMAT - Extremadura
CIEMAT - Barcelona
CIEMAT – Soria
CIEMAT – Madrid
CIEMAT – Almeria

CIEMAT RESEARCH PROGRAM

ENVIRONMENTAL APPLICATIONS OF SOLAR ENERGY

CATALYST

PHOTONS

REACTION

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.....
Promotion of Renewable Energies for Water Production through Desalination

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

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.

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

Conversations with Fraunhofer Institut for the evaluation of their modules
Promotion of Renewable Energies for Water Production through Desalination

3.6 million people die each year from water-related diseases.
Approximately one in eight people lack access to safe water supplies.
Half the world’s people do not have sanitation systems as good as in Ancient Rome.

United Nations report:
By 2025, 1.8 billion people will live in countries or regions with absolute water scarcity.
As of the beginning of 2011, more than 12,000 desalination plants are in operation throughout the world producing about 40 million cubic meters (roughly 10 billion US gallons) of water per day.

The desalination market is predicted to grow by 12% per year to 2015. Capacity is expected to reach 64 million m^3/day by 2015.

Desalination plant sizes and designs range from more than 1,000,000 m^3/day to 20 to 100 m^3/day.

Energy consumption of RO desalination

Data source: GWI DesalData Market Forecast 2010

The energy factor:
- Increment from 2005 to 2006 = 0.41 TW → 410 GW = 410 Power Plants of 1.0 GW producing the whole year
- Increment from 2006 to 2007 = 0.38 TW → 380 GW = 380 Power Plants of 1.0 GW producing the whole year

Data source: Key World Energy Statistics (IEA, 2005-2010)
**ProDes: Main facts**

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

**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

**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
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

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

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.
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.

PRODES

Introducing RE-desal to higher education

The course ([http://prodeslearning.com](http://prodeslearning.com)) is developed into 38 chapters (1 theoretical + 3 practical units) with several interactive questions for the evaluation.

1. Basic concepts on Desalination and Renewable Energies.
2. Desalination by Membrane Processes (ED, MED).
3. Desalination by Distillation Processes (MSF, MWW, VMD, MGD).
4. Solar Thermal Energy and MED.
5. Solar thermal energy coupled with MSF or MED.
7. Wind energy powered RO systems.
8. Other technologies.
10. Practical exercises: Four different cases but only one is mandatory:
    - Case 1: PO, ED system
    - Case 2: Solar-MSF system
    - Case 3: Solar-MED system
    - Case 4: MED-RO system

Introducing RE-desal to higher education

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 processes. More specifically, the course will instruct students in the basic principles of desalination using solar energy, the state of the art and the most promising technologies and the experiences acquired so far. There’s also time set aside for networking and exchange of experiences with visits to the best facilities of Plataforma Solar de Almería specializing in solar power production and desalination, which are the most advanced in the Mediterranean area.

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.
NEW WATER NEW ENERGY: A CONFERENCE LINKING DESALINATION AND RENEWABLE ENERGY  ALAMOGORDO, NEW MEXICO 13-DEC-2011

**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

**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.

**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

**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

**Current status of the RE-desalination technology**

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

**Technological**

- Desalination development focuses on ex-ternal systems
- Lack of components appropriate for small-scale desalination plants, types of many REO combinations

### Barrier

- **Cost:**
  - 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

### Effect

- Poor reliability
- Increased water cost

### Strategy

- The pricing structures and the subsidies of water supply create unfair competition
- Investment in REO remains unprofitable even when it offers better value than the current solutions
NEW WATER NEW ENERGY: A CONFERENCE LINKING DESALINATION AND RENEWABLE ENERGY
ALAMOGORDO, NEW MEXICO  13-DEC-2011

Main barriers of the RE-desalination technology

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Effect</th>
<th>Strategy</th>
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<tr>
<td>Institutional and Social</td>
<td></td>
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<tr>
<td>Negative perception of desalination by the population</td>
<td>Opposition of local communities to installation</td>
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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

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 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.

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.
REW -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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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.


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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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Renewable Energy

Renewable energy resource: illimitably available and not generate pollution

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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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www.prodes-project.org

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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)

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 Photovoltaic
- Solar Thermal electricity
- Wind Power
- Wave Power

Solar thermal energy

Main elements of a solar collector
- Cover (C)
- Absorber (A)
- Reflector (R)

Optical and thermal features determine the collector efficiency (η):

\[ \eta = \frac{Q_{\text{useful}}}{Q_{\text{col}}} \]

- \( Q_{\text{useful}} \): useful power [W]
- \( Q_{\text{col}} \): available power [W x m²]
- \( A_{\text{col}} \): Area of collector
- \( G_{\text{in}} \): Solar input power per m²

Solar thermal electricity

Solar thermal collectors concentrate solar radiation into heat energy to produce steam, which then turns a turbine to produce electricity.
Promotion of Renewable Energies for Water Production through Desalination

**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.

**Wind energy**

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

**Geothermal energy**

**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

Worldwide exploitable wave energy resource estimated to be 2 TW

Intermittent and variable

**Tidal energy**

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
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**

**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**

**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

**Solar Stills**

- **Basin-type solar still**

**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.
Promotion of Renewable Energies for Water Production through Desalination

Mechanical Vapour Compression

Membrane Distillation

Desalination demands

Renewable Energy for Desalination

Mechanical processes

- MVC:
  - Mechanical power: 7 - 15 kWh/m³ produced water
  - Sea water intake from 3 to 5 times produced water

- RO:
  - Mechanical power: 4 - 7 kWh/m³ produced water
  - Sea water intake from 2 to 4 times produced water

Thermal processes

- MED:
  - Low pressure steam (0.8 bar) in a rate of 8 to 12 % of product water
  - Electric power: 1.5 - 3 kWh/m³ product water
  - Sea water intake from 5 to 6 times product water

- MSF:
  - Low pressure steam (2 bar) at a rate of 10 to 12 % of product water
  - Electric power: 2.5 - 4 kWh/m³ product water
  - Sea water intake from 3 to 9 times product water

Renewable Energy sources

- Geothermal Energy
- Solar Energy
- Wind & Tidal Energy

Power production

- MED: Multiple Effects Distillation
- MSF: Multi Stage Flash
- TVC: Thermal Vapour Compression
- MVC: Mechanical Vap. Comp.
Current status of the RE-desalination technology

MAGE WATER MANAGEMENT GmbH - Watercone®

Type: Solar still
Location: Yemen
Capacity: 1.5 ml/s
Year of installation: 2007
Still in operation: yes

Type: Solar still
Location: Yemen
Capacity: 1.5 ml/s
Year of installation: 2007
Still in operation: yes

Current status of the RE-desalination technology

RSD Solar - Rosendahl Systems

Type: FL 6 modules 1.25 x 1.25 m²
Location: Alexandria, Egypt
Capacity: average ca. 100 l/h
Year of installation: 2004
Still in operation: yes
Usage: drinking water for a family

Current status of the RE-desalination technology

SOLAR DEW INTERNATIONAL

Type: Solar Dew Twin - Household application
Location: Desert development
Capacity: 5.5 - 5.8 l/day
Year of installation: 2004
Usage: household tap water

Type: Solar Dew One
Location: South China Sea
Capacity: 7.5 - 8.3 l/day
Year of installation: 2009
Usage: drinking water production

Current status of the RE-desalination technology

RSD Solar - Rosendahl Systems

Current status of the RE-desalination technology

SOLAR DEW INTERNATIONAL

Current status of the RE-desalination technology
Promotion of Renewable Energies for Water Production through Desalination

Current status of the RE-desalination technology

SOLAR SPRING - Oryx 150

Canary Islands Institute of Technology (ITC) – DESSOL®

Current status of the RE-desalination technology

ENERCON GmbH – Wind RO

Current status of the RE-desalination technology

WME – Wind driven vapour compression

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

Type: PV-RO for brackish water
Location: Morocco
Capacity: 3,300 m³/yr
Year of installation: 2009
Still in operation: yes
Usage: supply industrial people

Type: PV-RO for brackish water
Location: Italy
Capacity: 2,300 m³/yr
Year of installation: 2009
Still in operation: yes
Usage: supply industrial people

Type: Solar Desalination System
Location: Almeria, Spain
Capacity: 50,000 m³/day
Year of installation: 2004
Still in operation: yes, full 2004
Usage: Public water supply

Type: WME – Wind driven vapour compression

Type: MEM-brane distillation
Location: Tenerife, Spain
Capacity: 15 m³/yr
Year of installation: 2006
Still in operation: yes
Usage: drinking water

Type: 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
Current status of the RE-desalination technology

PV energy

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

PV energy

Functional principle of a silicon solar cell

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

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

PV energy

Two technologies currently dominate the PV market

Single Crystalline:
- highest efficiency
- slow process
- high costs.

Poly (multi) crystalline:
- low cost
- fast process
- lower efficiency.

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 Pmax or reference values.

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

Fmax = maximum (peak) power

Isc = current at peak power

Voc = voltage at peak power

PV energy

Current status of the RE-desalination technology

PV energy

PV energy

PV energy

December 13-14, 2011
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.

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

**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

**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
**Coupling of PV with RO desalination**

**RO unit. Basic diagram**

- Water demand: 250 gallons x 50 l / p d = 12,500 l / d = 12.5 m³ / d
- Product water flow (Qp):
  - 12.5 m³/d / 7.5 h = 1.7 m³ / h
- Feed water flow (Qf):
  - Qf = Qp / r = 1.7 / 0.4 = 4.2 m³ / h

**Energy demanded by the system**

<table>
<thead>
<tr>
<th>Element</th>
<th>Operation time (h)</th>
<th>Power (W)</th>
<th>Energy (Wh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed pump</td>
<td>7.5</td>
<td>1,167</td>
<td>8,752</td>
</tr>
<tr>
<td>HP pump</td>
<td>7.5</td>
<td>8,750</td>
<td>65,625</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>74,377</strong></td>
</tr>
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</table>

**Energy storage calculation**

The autonomous electric system must have 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

**Capacity of batteries**

Data | Value
--- | ---
Operation voltage (Vb) | 40V 10k
Number of autonomy days (N) | 1 day
Discharge depth (Pd) | 20%
Unitary voltage of one vessel | 5V 10k

- Useful capacity:
  - C0 = E0 / (Vb x N) = 106,253 Wh / 10 = 10,625 Ah
- Nominal capacity (manufacturer)
  - Cn = C0 / Pd = 2,164 Ah / 0.8 = 2,688 Ah
- Number of vessels connected in serial: 48 / 2 = 24

**PV modules**

- Efficiency of charge controller: 90%
- Solar peak hours (SPH): 3.5
- Power of one module (P): 125 W

Solar peak hours is a parameter that means the number of solar hours with a radiation of 1,000 W/m² (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: E0 = E0 / 0.9 = 106,253 / 0.9 = 118,059 Wh
- Number of panels: Np = 118,059 / 0.9 x 125 x 3.9 = 269 modules
- Total installed PV power: Yp = 269 modules x 125 W / mod = 33,635 W
Promotion of Renewable Energies for Water Production through Desalination

**Design parameters:**
- Water consumption: 15 m³/day (summer)
- Average Global Horizontal radiation per day: 5.6 kWh/m²
- Ambient temperature: 0 – 60 ºC
- Salinity of brackish water: 3500 mg/l
- Temperature of brackish water: 28 – 35 ºC

**Equipments of the installation:**
- Photovoltaic field (10.5 kWp)
- Batteries (660 Ah C10 of capacity at 120VDC, 79.2 KWh)
- Charger- Inverter (10 kW)
- Desalination plant 50 m³/day (2.1 m³/h)
- Recovery: 70%

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

**PV-RO: CASES OF STUDY. DESSOL®**

**Coupling of PV with RO desalination**

Seawater PV desalination unit (since 1999) in Canary Islands

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

- RO unit 400 l/h (9.6 m³/d)
- 5.5 kWh/m³
- Also tested a battery-less PV-RO system
- Average operation 8 h/d (summer); 6 h/d (winter)

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

**PV-RO: CASES OF STUDY. DESSOL®**

**Coupling of PV with RO desalination**

- 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 m³/h (30 m³/d)
- 2.54 kWh/m³.
- Average operation 8 h/d

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

**PV-RO: CASES OF STUDY. DESSOL®**

**Coupling of PV with RO desalination**

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

- Advantages:
  - Easy to operate
  - Modularly RO can adapt to energy available
- Disadvantages:
  - High investment cost due to photovoltaic
  - Brackish water: 4.5 €/m³ produced

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

**PV-RO: CASES OF STUDY. DESSOL®**

**Coupling of PV with RO desalination**

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

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

**PV-RO: CASES OF STUDY. DESSOL®**

**Coupling of PV with RO desalination**

- Cooperation project. Autonomous PV-RO unit in Tunisia (since 2006)
- The village of Ksar Ghilène 1st 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 ºC)
- PV power 10.5 kWp (~ 85 m²).
- Operating more than 3,100 h producing 8,000 m³ of drinking water in 27 months.
- Raw water salinity 3.5 g/l.
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 €/m³, SW: from 9 to 12 €/m³).

Conclusions

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).

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 m³/h – 4 kWp).
- CRES.

Installed equipment:

- PV field (4 kWp ≈ 36 m²).

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.

Hybrid Wind & PV-RO: Cases of Study. Morena

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 m² divided into 3 zones: one for the desalination unit and ERD, the battery bank and the electrical acquisition panels.

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 m³/h – 4 kWp – 900 W).
- CRES.

Installed equipment:

- Photovoltaic field (36 modules; 4 kWp).
- Wind turbine (900 W).
- Batteries (capacity 1,800 Ah C100 24VDC).
- 2 Regulator-Inverter of 1.5 y 3.0 kW.
- RO desalination plant of 3.2 m³/d (recovery rate 20%).

Source: ADU-RES
Coupling of PV and Wind with RO desalination

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

<table>
<thead>
<tr>
<th>Location</th>
<th>RO: capacity (m³/day)</th>
<th>Electricity supply</th>
<th>Year of installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ra de Plantier, France</td>
<td>0.5</td>
<td>4 kW W/T, no batteries</td>
<td>1992</td>
</tr>
<tr>
<td>Island of Sducnog, Germany</td>
<td>0.25 + 0.37</td>
<td>5 kW W/T, no batteries</td>
<td>1993</td>
</tr>
<tr>
<td>Pezzi Ippolito, Sicilia</td>
<td>8 x 1.0</td>
<td>2 x 1.0 kW W/T, no batteries</td>
<td>1995</td>
</tr>
<tr>
<td>Tenerife, Spain; JOULE</td>
<td>3.5 - 4.5</td>
<td>50 kW W/T, no batteries</td>
<td>1985</td>
</tr>
<tr>
<td>Lowestborough Univ/UK</td>
<td>0.6</td>
<td>2.5 kW W/T, no batteries</td>
<td>2001/2</td>
</tr>
<tr>
<td>Delf Univ., The Netherlands</td>
<td>0.2 - 0.4</td>
<td>WindsWatt, no batteries</td>
<td>2007/2008</td>
</tr>
<tr>
<td>Thessali island, APSIRIENA</td>
<td>0.2</td>
<td>15 kW W/T, 440Ah batteries</td>
<td>1995/6</td>
</tr>
<tr>
<td>Kerata, Greece EAFIT Project</td>
<td>0.13</td>
<td>900W W/T, 4 kWp PV, batteries</td>
<td>2001/2</td>
</tr>
<tr>
<td>Pezzi Ippolito, Sicilia</td>
<td>0.80</td>
<td>18 kWp W/T, 190Ah batteries</td>
<td>2005/6</td>
</tr>
<tr>
<td>Heraklio island, Greece CPC programme</td>
<td>3.3</td>
<td>30 kW W/T, off shore, batteries</td>
<td>2007</td>
</tr>
<tr>
<td>Island of Helifiandia, Germany</td>
<td>49</td>
<td>1.2 MW W/T, diesel</td>
<td>1986</td>
</tr>
<tr>
<td>Fuerteventura, Spain</td>
<td>2.3</td>
<td>225 kW W/T + 160 kVA diesel</td>
<td>1998</td>
</tr>
<tr>
<td>Syros Island, Greece; JOULE</td>
<td>2.0 + 37.5</td>
<td>500 kW W/T, grid connected</td>
<td>1998</td>
</tr>
<tr>
<td>Milos Island, Greece CPC programme</td>
<td>2 x 42</td>
<td>808 kW W/T, grid connected</td>
<td>2007</td>
</tr>
</tbody>
</table>

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Coupling of Wind energy with RO desalination

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

CRES, Keratea, Greece, seawater, stand-alone
Desalination: 3 m³/day RO plant
Power Supply: 1 kW W/T, 4 kWp PV, 1850 Ah/100h
Year of installation/operation: 2001
Unit Water Cost: >10 €/m³

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Coupling of PV and Wind with RO desalination

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

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

- The German companies provide to the market compact Wind-RO solutions for brackish and SW desalination, in the range of 175 to 2000 m³/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 3000 m³/day.

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Coupling of Wind energy with RO desalination

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

CRES, Keratea, Greece, seawater, stand-alone
Desalination: 3 m³/day RO plant
Power Supply: 1 kW W/T, 4 kWp PV, 1850 Ah/100h
Year of installation/operation: 2001
Unit Water Cost: >10 €/m³

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.

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.

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.

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.

\[
\begin{align*}
Q_h &= h_i \left( T_h - T_1 \right) \\
Q_m &= Q_h + \lambda_{AV} N_v = k_m \left( T_1 - T_2 \right) + C_r \lambda_{AV} \left( T_1 - T_2 \right) \\
Q_c &= h_e \left( T_2 - T_c \right)
\end{align*}
\]

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Temperature Polarization in MD

\[
\begin{align*}
T_h - T_c &= \text{Total temperature difference available;} \\
P_1 - P_2 &= (T_1 - T_2) = \text{effective driving force available for vapour crossing through the membrane;} \\
T_h - T_c (\delta T) &= \text{“driving force losses” due to the Temperature Polarization;} \\
(T_1 - T_2)/(T_h - T_c) &= \text{Temperature polarization coefficient}
\end{align*}
\]

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

Membrane Distillation

Configurations of MD

- Direct Contact MD
- Air gap MD
- Membrane Distillation
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.

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.
Promotion of Renewable Energies for Water Production through Desalination

Membrane Distillation

Specific energy consumption per cubic meter distillate for a feed flow of 300 l/h depending on the evaporator inlet temperature.

Solar Powered Membrane Distillation

Sketch of compact system

1. Feed tank
2. Generator
3. Collectors
4. MD module
5. Feed pump
6. Refilling pump
7. PV panel
8. Control box
9. Floating switches
10. Distillate output
11. Feed overflow
12. Sea water feed line

Solar Powered Membrane Distillation

First compact system set up in December 2004

- Operating collector temperature up to 85°C
- 6 m² 2AR collectors
- PV-module 80W
- One membrane distillation module
- Daily capacity about 80 to 150 litres of distilled water

Solar Powered Membrane Distillation

Two system designs

Compact system

Two loop system

JUST University, Irbid (Jordan), Prof. Dr. Fawzi Banat

Production rate up to 120 litres per day measured in September

This corresponds to 20 litres per day per m² collector area.

Conductivity of distillate below 4 µS/cm
Solar Powered Membrane Distillation

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

installed in July 2005

Solar Powered Membrane Distillation

Kela system, Morocco (80 km from Marrakech)

installed in August 2005

in a village with about 560 residents

to desalinate water from a brackish well

Larger two-loop system Aqaba (Jordan)

- 72 m² flat plate collectors
- 12 m² PV modules
- 3 m³ thermal storage tank
- Titanium heat exchanger
- 4 M2 modules in parallel

December 13-14, 2011
THANK YOU

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