The Regional capacity building workshop on “Water - Energy Nexus Operational Toolkit: Renewable Energy”: Renewable Desalination in the MENA region

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MENA region occupies nearly half of the global desalination activity in 2017 with a cumulative total contracted capacity equal to 48,972,069 m$^3$/day and a global cumulative contracted capacity of 100,949,442 m$^3$/day.
Currently, the MENA market is led by Saudi Arabia with a total cumulative capacity of 15,378,543 m3/day followed by the United Arab Emirates with 10,721,554 m3/day.

Desalination Capacity: 12 MENA countries are in the TOP 20 globally... and the trend is projected to continue beyond 2017 with more MENA countries coming into picture!
Water supply within the average climate change scenario for MENA

[MENA Water Outlook, Task 2 Report]
**Nexus**: Higher technology to treat impaired water requires higher energy demand

**WATER**

**ENERGY**

- Membrane
  - Energy: 33%
  - Other O&M*: 33%
  - Capital: 34%

- Thermal (MED)
  - Energy: 45%
  - Other: 24%
  - Capital: 31%

* Membrane replacement, Chemicals, Labor, Maintenance
Solution: Joint technology development driving energy and cost out

The cost of desalination with membranes has fallen by more than 80% in the last two decades

Source: GE
## Energy Demand of Water

### Energy Requirements of Various Water Resource Options

<table>
<thead>
<tr>
<th>Water Supply Options</th>
<th>Energy Demand (kWhr/kgal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh Water Importation (100-300 miles)</td>
<td>10-18</td>
</tr>
<tr>
<td><strong>Seawater Desalination w/Reverse Osmosis</strong></td>
<td>12-20</td>
</tr>
<tr>
<td><strong>Brackish Groundwater Desalination</strong></td>
<td></td>
</tr>
<tr>
<td>Reverse Osmosis Treatment</td>
<td>7-9</td>
</tr>
<tr>
<td>Pumping and concentrate management</td>
<td>1-3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>8-12</td>
</tr>
<tr>
<td>Aquifer Storage and Recovery</td>
<td></td>
</tr>
<tr>
<td>Pre-treatment (as needed)</td>
<td>3-4</td>
</tr>
<tr>
<td>Post-treatment (as needed)</td>
<td>3-4</td>
</tr>
<tr>
<td>Pumping</td>
<td>2-3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5-11</td>
</tr>
</tbody>
</table>

*Source: Mike Hightower, Sandia National Laboratories*
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
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.

<table>
<thead>
<tr>
<th>Heat production RE technologies</th>
<th>Power production RE technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar thermal</td>
<td>Wind Power</td>
</tr>
<tr>
<td>Biomass</td>
<td>Wave Power</td>
</tr>
<tr>
<td>Geothermal</td>
<td>Solar Photovoltaic</td>
</tr>
</tbody>
</table>
### Possible combinations of renewable energy and desalination technologies
(Source: Al-Karaghouli et al., 2011)

<table>
<thead>
<tr>
<th>Thermal Technologies</th>
<th>Membrane Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MSF</td>
</tr>
<tr>
<td>Renewable Technologies</td>
<td>⬤</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>⬤</td>
</tr>
<tr>
<td>Solar PV</td>
<td>⬤</td>
</tr>
<tr>
<td>Wind</td>
<td>⬤</td>
</tr>
<tr>
<td>Geothermal</td>
<td>⬤</td>
</tr>
</tbody>
</table>
The main challenge of Renewable Energy Desalination is that Desalination technologies generally work in steady-state conditions but Renewable Energy sources are usually non-stationary.

→ Renewable energy generation needs adjustments for continuous supply (energy storage)

→ Desalination technologies can adapt to variable operation
When we consider the solar energy application in desalination processes, we can distinguish between two different concepts:

- **Direct solar desalination**: the desalination unit and the solar collector are integrated within an unique physical device.

- **Indirect solar desalination**: in this case, a conventional desalination system is coupled to a solar collector field, which provides the energy (power or thermal energy) required by the desalination process.
Solar desalination

Solar Energy

Direct
- Solar Stills

Indirect
- Solar Collector
- Photovoltaic Cells
- Energy Storage
  - Tower Turbin
  - Wind

Hot Water
- Electric Current
  - Thermal Desalination
    - MSF, MED
  - RO, MVC and pumping power for thermal desalination

Sensible Heat
- Phase Change
- Batteries

Source: Ettouney & Rizzuti (2007)
Solar desalination

Commercial desalination and CSP technologies prior to model set-up

Source: MENA Regional Water Outlook, Dr. Fulya Verdier/ FICHNER
Solar desalination

Large-scale solar desalination
(> 10,000 m³/day)

Small-scale solar Desalination
(< 100 m³/day)
PV-RO Desalination
Small scale

Optimal combination?
Variables of design optimization
- # of PV panels, inverter capacity,
- # of RO membrane elements, # of vessels, feed pressure, feed flow, energy recovery device,
- (capacity of battery)

Solar Photovoltaic Energy  Reverse Osmosis Desalination

PV panels  Brine

High Salinity Seawater  Fresh Water

High pressure pump

RO membrane elements

PV-Smart RO (SSD - Smart Solar Desalination) process

BiSoN Bi-facial Tracker
### Solar desal plants in the MENA region

### Status | Plant/Project Name | Country | Capacity (m³/d) | Contract Year | Online Year | Technology | EPC Contractors
--- | --- | --- | --- | --- | --- | --- | ---
- | Ben Guerdane solar-powered BWRO | Tunisia | 1,800 | 2012 | 2013 | RO | Suidco Kiko Kaisha Ltd.
- | Al Khafji solar-powered SWRO | Saudi Arabia | 60,000 | 2015 | 2017 | RO | Abengoa
- | Hassi R'mel solar thermal plant | Algeria | 1,577 | 2008 | 2011 | RO | Grupo SETA, S.L.
- | Qatar Solar Technologies Polysilicon Project, Ras Laffan | Qatar | 12,000 | 2012 | 2013 | RO | VA Tech Wabag Ltd.

### Notes

- **Ben Guerdane solar-powered BWRO**
  - Status: Online
  - Award date: 2010
  - Online date: 2013
  - Capacity: 1,800 m³/d
  - Location: Ben Guerdane, Tunisia
  - Technology: RO (Reverse Osmosis)
  - Membrane type: Spiral Wound

- **Al Khafji solar-powered SWRO**
  - Status: Online
  - Award date: 2015
  - Online date: 2017
  - Capacity: 60,000 m³/d
  - Location: Al Khafji, Saudi Arabia
  - Technology: RO (Reverse Osmosis)
  - Feed water type: Desalination Plant

- **Hassi R'mel solar thermal plant**
  - Status: Construction
  - Award date: 2015
  - Online date: 2017
  - Capacity: 1577 m³/d
  - Location: Hassi R'mel, Algeria
  - Technology: RO (Reverse Osmosis)
  - Feed water type: Desalination Plant

- **Qatar Solar Technologies Polysilicon Project, Ras Laffan**
  - Status: Online
  - Award date: 2012
  - Online date: 2013
  - Capacity: 12,000 m³/d
  - Location: Ras Laffan, Qatar
  - Technology: RO (Reverse Osmosis)
  - Feed water type: Desalination Plant

### Additional Information

- **Qatar Solar Technologies Polysilicon Project, Ras Laffan**
  - Location: Doha, Qatar
  - Technology: RO (Reverse Osmosis)
  - Feed water type: Desalination Plant

- **Ben Guerdane solar-powered BWRO**
  - Location: Ben Guerdane, Tunisia
  - Technology: RO (Reverse Osmosis)
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Case study 1: Morocco
Project involving MEDRC

**Autonomous Desalination System Concepts for Sea Water and Brackish Water in Rural Areas with Renewable Energies – ADIRA**

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

5 m³ freshwater per day: Sufficient for 100 people → Covering food & sanitation

Site parameters:
- Water production capacity of 1 m³/h
- Energy consumption: 4 kWh / m³
- PV capacity: 8 kWp
→ Capital cost: 70,000 Euro
→ Cost of water: 3 – 6 Euro / m³
Case study 2: Tunisia

Autonomous PV-RO unit in Tunisia (since 2006)
The village of Ksar Ghilène first 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 $T > 50 \, ^\circ\text{C}$), PV power 10.5 kWp.

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

Prototype designed and tested as a technical solution to water shortage in low water demand isolated areas with no electric grid.

RO unit 750 l/h, 8.4 kWh/m³.

Wind turbine (15kW).

Battery bank (23 kWh).

Average operation 18 h/d.
Large energy requirements $\rightarrow$ co-generation with electricity production

Solar thermal energy (Concentrated Solar Power) considered due to its dispatchability (thermal heat storage vs batteries for PV)

Molten salts: state of the art technology for heat storage
Concentrated Solar Power (CSP) generates heat to produce steam, which then is driven into a turbine to produce electricity.

Parabolic trough solar collectors (T~400°C) on a steam Rankine cycle.
Case study 1: King Abdullah Initiative for Solar desal – Saudi Arabia

• To harness solar energy for all water desalination during 2010-2019.
• The initiative is expected to reduce production costs of desalinated water from 2.5-5.5 SR/m³ to 1 -1.5 SR/m³ (1US$=4SR).
• King Abdulaziz City of Science and Technology (KASCT) is developing the world's first large-scale desalination plant to be powered by solar energy in Saudi Arabia.

1. Phase I: Construction of a solar-powered desalination plant (10 MW and RO) at Al-Khafji Town (30,000 m³/day).
2. Phase II: Construction of a another solar-powered desal. plant (300,000 m³/day)
3. Phase III: Construction of several solar plants for desalination in all parts of the kingdom.
Case study 2: Australia
Large Scale RE desalination

The first large RO seawater desalination plant in the Southern hemisphere and the first to be fed by renewable energies

- DBO Project developed by Western Australian Water Corporation in Alliance with a JV of Degrémont and Multiplex
- 143,000 m³/d Drinking Water from seawater
- Municipal Drinking Water supplying began in November 2006

The environment footprint under control
- Brine discharge
- Reduced energy consumption
- Wind farm energy
- Energy recovery

Connected to the general power grid fed by a Wind Farm 48 Turbines (80 MW) → 270 GW.h/year to the grid

200% of desalination plant energy consumption
4 areas ranked high Technology Readiness Level (TRL), high impact:
1. PV-RO,
2. Wind-RO,
3. CSP-thermal desalination hybrids, and
4. Optimized power-water cogeneration.

Source: Abdul Latif Jameel World Water and Food Security Lab, MIT
## Comparative costs for common renewable desalination

<table>
<thead>
<tr>
<th>Source: Papapetrou et al., 2010 and European Union, 2008</th>
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</thead>
<tbody>
<tr>
<td><strong>Technical Capacity</strong></td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td>Solar stills</td>
</tr>
<tr>
<td>Solar Multiple Effect Humidification</td>
</tr>
<tr>
<td>Solar Membrane Distillation</td>
</tr>
<tr>
<td>Solar/CSP Multiple Effect Distillation</td>
</tr>
<tr>
<td>Photovoltaic-Reverse Osmosis</td>
</tr>
<tr>
<td>Photovoltaic-Electrodialysis Reversed</td>
</tr>
<tr>
<td>Wind Reverse Osmosis</td>
</tr>
<tr>
<td>Wind Mechanical Vapor Compression</td>
</tr>
<tr>
<td>Wind Electro dialysis</td>
</tr>
<tr>
<td>Geothermal Multi Effect Distillation</td>
</tr>
</tbody>
</table>
Conclusions

- Current desal technologies are very energy intensive. There is an urgent need to develop low-energy driven desal processes, which could be integrated with RE.
- The coupling of solar energy with desal technologies is seen as having the potential to offer a sustainable route for increasing the supplies of desalinated water. However, the success in implementing solar desal technologies at a commercial scale depends on the improvements to convert solar energy into electrical and/or thermal energies economically.
- Decentralized solar powered water desal systems offer independence & help to avoid being taken hostage by price raises from the utility/water companies.
- The evaluation of different plant configurations point out that plant location, plant capacity, selected technology and also plant configuration such as dual purpose or standalone plant can have impacts on the design of the CSP plant as well as the cost of the two products: water and electricity.
- RE technologies suited to desal include solar thermal, PV, wind, & geothermal energy. CSP produce a large amount of heat that is suited to thermal desalination. PV and wind electricity is often combined with RO or ED. As electricity storage is still a challenge, combining power generation and water desal can also be a cost effective option for electricity storage when generation exceeds demand.