Offshore Wind Energy and Water

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Water or Energy?
Outline

- Water Security
- Desalination
- Desalination technologies
- Economics of desalination
- Renewable energy in desalination
- Future Work
Water Security and Conflicts

- Famine
- Inequality
- Poverty
- Disease

Water
Water Security and Conflicts

Brazil drought

Water Security and Conflicts

California drought

Source: California Department of Water Resources, 2014
Water used for electricity

### Water Consumption in the Electricity Industry Value Chain

<table>
<thead>
<tr>
<th>Source</th>
<th>Raw Materials</th>
<th>Transformation</th>
<th>Delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>20–270</td>
<td>Thermoelectric generation with closed loop cooling: 720–2,700</td>
<td>Minimal</td>
</tr>
<tr>
<td>Oil or natural gas</td>
<td>See Table 4</td>
<td></td>
<td>Minimal</td>
</tr>
<tr>
<td>Uranium</td>
<td>170–570</td>
<td></td>
<td>Minimal</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td></td>
<td>Evaporation losses: 17,000</td>
<td>Minimal</td>
</tr>
<tr>
<td>Geothermal</td>
<td>5,300</td>
<td></td>
<td>Minimal</td>
</tr>
<tr>
<td>Solar</td>
<td></td>
<td>Concentrating solar: 2,800–3,500</td>
<td>Minimal</td>
</tr>
<tr>
<td>Wind</td>
<td></td>
<td></td>
<td>Minimal</td>
</tr>
</tbody>
</table>

Energy used in the provision of water

<table>
<thead>
<tr>
<th>Source</th>
<th>Raw Materials</th>
<th>Transformation</th>
<th>Delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface water</td>
<td>0–2,400</td>
<td>Treatment: varies with raw water quality</td>
<td>Depends on distance and elevation: 290</td>
</tr>
<tr>
<td>Groundwater</td>
<td>40 meters: 150, 120 meters: 520</td>
<td>High-quality groundwater: 26, Brackish water: 300–1,400</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Seawater desalinization: 3,600–4,500</td>
</tr>
<tr>
<td>Municipal wastewater</td>
<td>660</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Desalination
Water desalination

Countries using desalination

Desalination capacity
Thousand of cubic metres per day

United States

Saudi Arabia

Note: only countries with more than 70,000 cubic metres per day are shown.

Countries using desalination

Top 10 countries by total installed membrane capacity since 1945

Top 10 countries by total installed thermal capacity since 1945

Source: IDA Desalination Yearbook 2011  DesalData.com
Global desalination capacity and trends

Total worldwide installed capacity by user type

- Municipal: 63%
- Industry: 25.8%
- Power stations: 5.8%
- Irrigation: 1.9%
- Tourism: 1.9%
- Military: 1.1%
- Demonstration/other: 0.7%

Installed capacity: 66.4 million m³/d

Total worldwide installed capacity by feed water category

- Seawater: 60.0%
- Brackish water: 21.5%
- River water: 8.3%
- Wastewater: 5.7%
- Pure water: 4.3%
- Brine: 0.2%

Installed capacity: 65.2 million m³/d

Source: IDA Desalination Yearbook 2011 DesalData.com
Global desalination capacity and trends

Top 12 plants by capacity

Shoaiba Power and Desalination Plant 3.6 million m³ of water per day

Source: IDA Desalination Yearbook 2011  DesalData.com
Global desalination capacity and trends

Installed membrane and thermal capacity, 1980-2010 (cumulative)

Total worldwide installed capacity by technology

Source: IDA Desalination Yearbook 2011  DesalData.com
Desalination technologies

Schematic diagrams for major desalination technologies.

Source: Water in the energy industry: An introduction (BP), 2013
Desalination: Membrane (Reverse Osmosis)

Reverse Osmosis

Desalination: Membrane (Reverse Osmosis)

- Seawater intake
- Pretreatment
- High pressure pumping unit
- Membrane element assembly unit
- Energy Recovery Device
- Permeate treatment
- Storage tank*

Schematic diagram of a typical SWRO desalination process

Source: Membrane Desalination Technology; Mark Wilf, 2007
Diagram: Overview of systems engineering approaches for a large-scale seawater desalination plant with a reverse osmosis network  Joon Ha Kim, 2008
Desalination: Distillation (MED)

Desalination: Distillation (MSF)

Desalination: Distillation (VC)

Vapor compression unit

Source: University of Wisconsin-Eau Claire. Course ENPH 441: Water and Wastewater [link]
# Desalination: Energy Requirements

<table>
<thead>
<tr>
<th>Process/energy type</th>
<th>MED</th>
<th>MSF</th>
<th>VC</th>
<th>RO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric energy equivalent, kWh/m3</td>
<td>4.5</td>
<td>14.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Electric consumption, kWh/m3</td>
<td>1.2-2.0</td>
<td>3.0-4.0</td>
<td>8.5</td>
<td>3-5</td>
</tr>
<tr>
<td>Total electric energy equivalent, kWh/m3</td>
<td>5.7-6.5</td>
<td>17-18</td>
<td>8.5</td>
<td>3-5</td>
</tr>
</tbody>
</table>
Hybrid Systems

Schematic diagram of commercially available simple hybrid desalination plants.

Source: Overview of hybrid desalination systems — current status and future prospects (Osman A. Hamed, 2005)
Types of Hybrid Systems

• Simple hybrid: combined with new or existing desalination process
• Integrated hybrid: application in new desalination complexes.
• Power/water hybrid:
  ▪ Seasonal demands of electricity and water
  ▪ Power-to-water ratio
  ▪ Minimization of fuel consumption and increase in the power plant efficiency
  ▪ Minimization of environmental impact of CO2
Desalination: Economics

“The cost of desalinated seawater has fallen below US$0.50/m for a large scale seawater reverse osmosis plant at a specific location and conditions while in other locations the cost is 50% higher (US$1.00/m3) for a similar facility.” (Ghaffour, et. al, 2012)

Unit water cost trends by SWRO and MSF processes.

Investment costs in RO processes vs. capacity

Source: Technical review and evaluation of the economics of water desalination: Current and future challenges for better water supply sustainability. (Noreddine Ghaffour, 2012)
Renewable Energy Powered Desalination

Global Renewable Energy Desalination by Energy Source, 2009 (percent)

Possible technological combinations of the main renewable energies and desalination methods.

Source: Overview of hybrid desalination systems — current status and future prospects (Osman A. Hamed, 2005)
Renewable Energy Powered Desalination


Source: Fichtner and DLR 2011.
Renewable Energy Powered Desalination

<table>
<thead>
<tr>
<th>RE source</th>
<th>Solar heat</th>
<th>PV</th>
<th>Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desalination technology</td>
<td>CSP-MED</td>
<td>MEH</td>
<td>Stills</td>
</tr>
<tr>
<td>Production (m³/day)</td>
<td>&gt;5,000</td>
<td>1–100</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Cost (€/m³)</td>
<td>1.8–2.2</td>
<td>2–5</td>
<td>1–15</td>
</tr>
<tr>
<td>RO</td>
<td></td>
<td></td>
<td>Small</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td></td>
<td>1,000</td>
</tr>
<tr>
<td></td>
<td>5–7</td>
<td></td>
<td>1.5–4.0</td>
</tr>
</tbody>
</table>

Source: After ProDes 2010, table 1.2.
Note: €1.0 = US$1.40; EDR = electrodialysis reverse; MEH = multi-effect humidification; MVC = mechanical vapor compression.

Cost of Desalinated Seawater from Renewable Energy Alternatives

Schematic diagram of commercially available simple hybrid desalination plants.

Source: Overview of hybrid desalination systems — current status and future prospects (Osman A. Hamed, 2005)
Research Questions and Future Work

- What is the desalinate water cost with offshore wind energy?
- Benefits of offshore wind in desalination industry and possible markets
- Technical aspects of this integration
- Backup system (grid, storage or other energy source) to be coupled with offshore wind in desalination system.
- Modeling optimization in the integration of offshore wind energy with desalination systems
- Case Study (Caribbean?)
Thank You!