The Regional capacity building workshop on "Water - Energy Nexus Operational Toolkit: Renewable Energy":

Renewable Desalination in the MENA region

Dr. Jauad EL KHARRAZ, MEDRC Head of Research
11/07/2017, UN House - ESCWA, Beirut, Lebanon

Outline

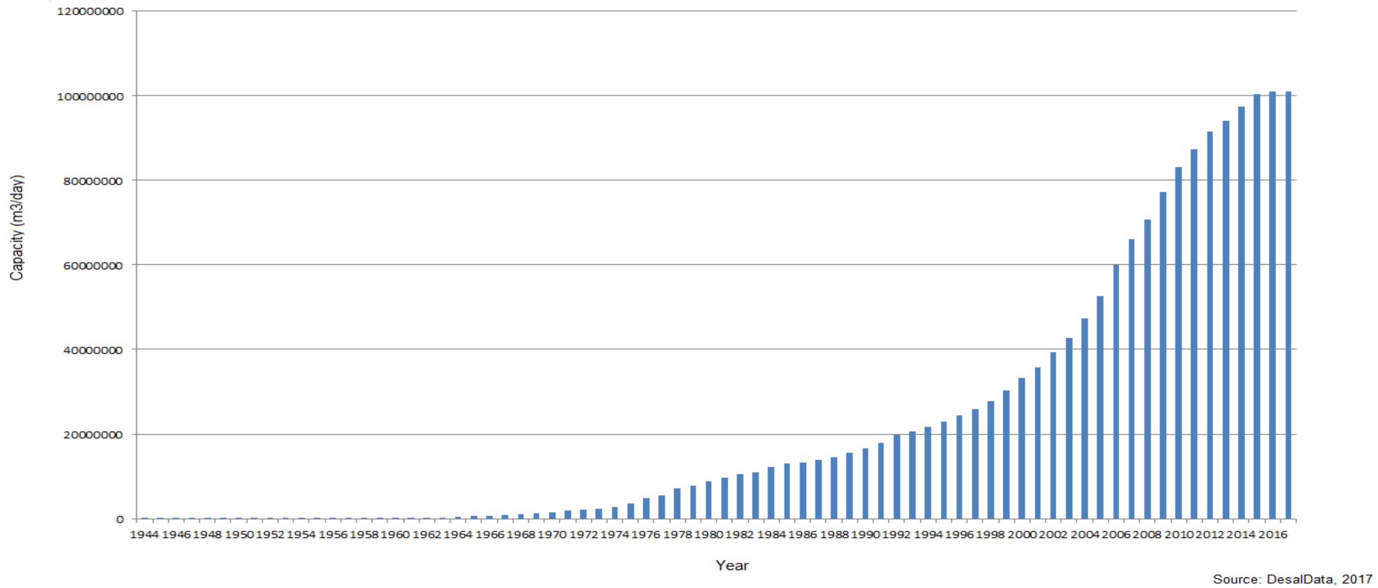
MEDRC

1. Desalination in the MENA region
2. Water supply in the MENA region
3. Energy demand for water
4. Water-Energy nexus
5. Energy demand for water
6. Desalination technologies
7. RE technologies
8. RE/Solar & wind desalination (case studies from small scale)
9. RE/Solar & wind desalination (case studies from large scale)
10. Technology Readiness Level RE desalination
11. Comparative costs
12. Conclusions

Desalination in the MENA region

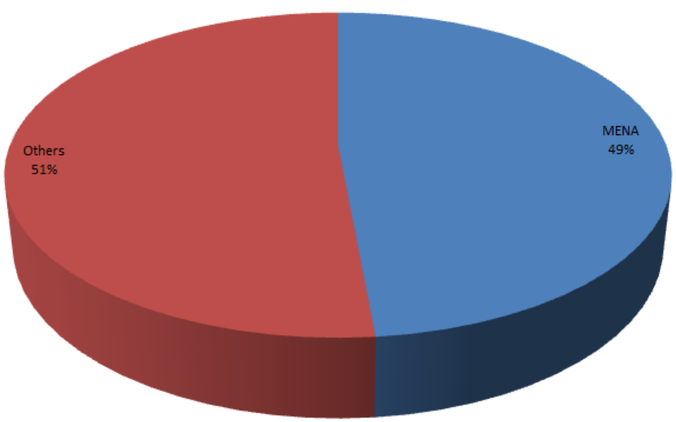
MEDRC

Total Global Cumulative Contracted Capacity of Desalination Plants since 1944 in m3 /day



Source: DesalData, 2017

MENA region occupies nearly half of the global desalination activity in 2017 with a cumulative total contracted capacity equal to 48,972,069 m3 /day and a global cumulative contracted capacity of 100,949,442 m3 /day.

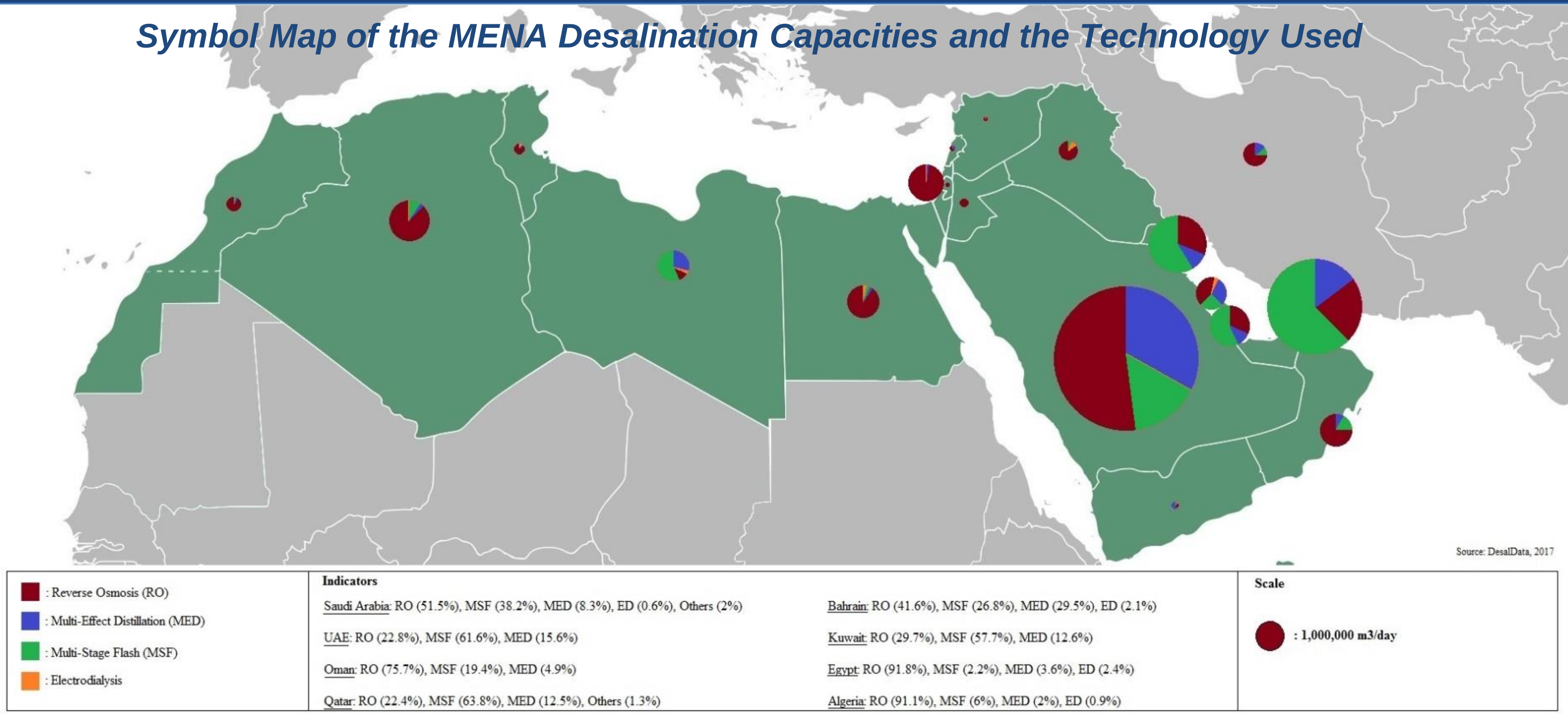


Source: DesalData, 2017

Desalination in the MENA region

MEDRC

Symbol Map of the MENA Desalination Capacities and the Technology Used

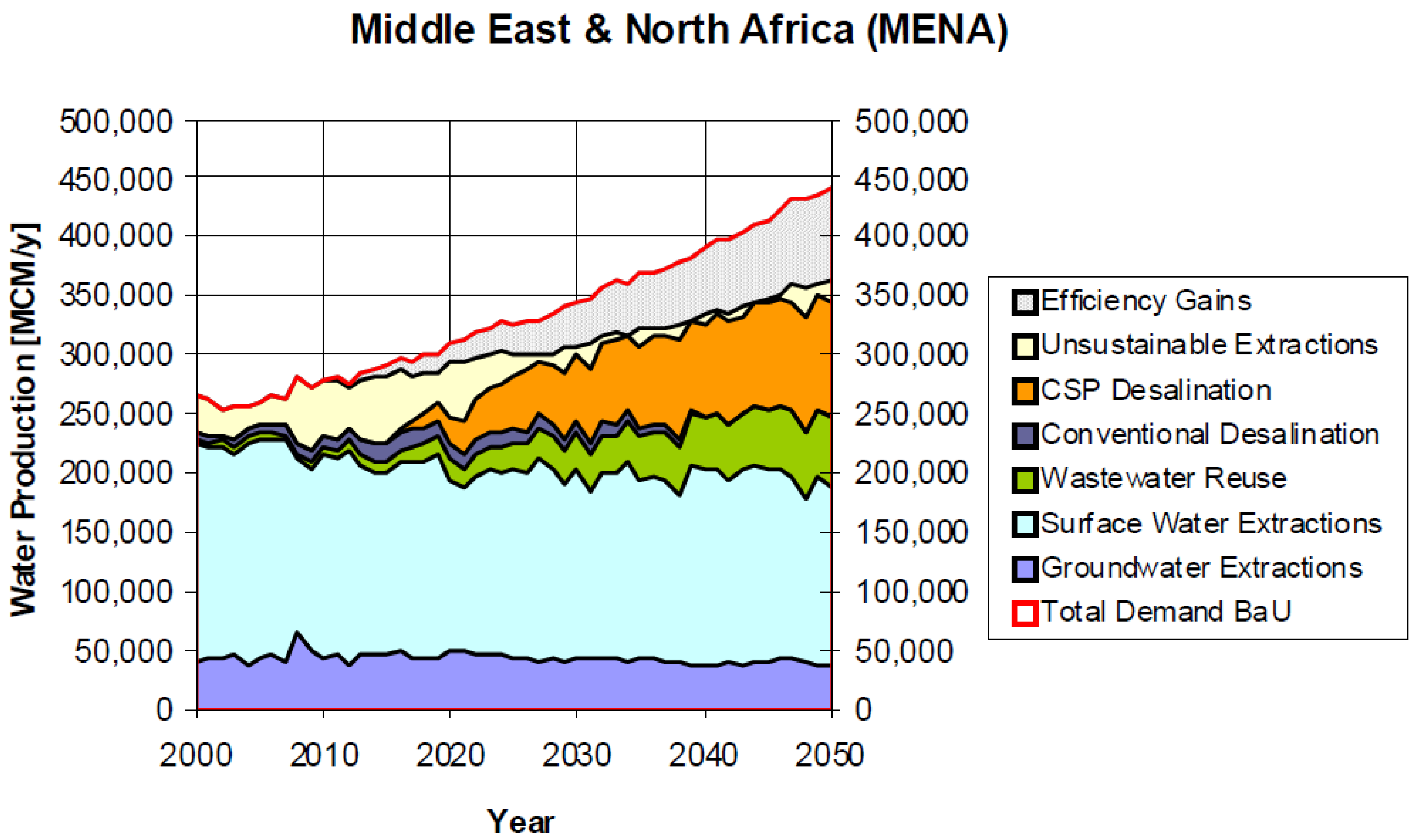


Currently, the MENA market is led by Saudi Arabia with a total cumulative capacity of 15,378,543 m3/day followed by the United Arab Emirates with 10,721,554 m3/day.

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 in the MENA region

MEDRC



Water supply within the average climate change scenario for MENA [MENA Water Outlook, Task 2 Report]

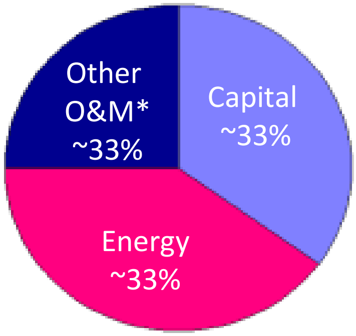
Nexus: Higher technology to treat impaired water requires higher energy demand

MEDRC

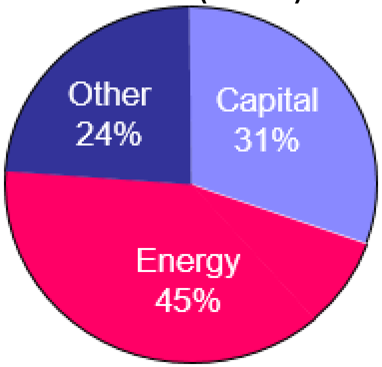
WATER

ENERGY

Membrane



Thermal (MED)

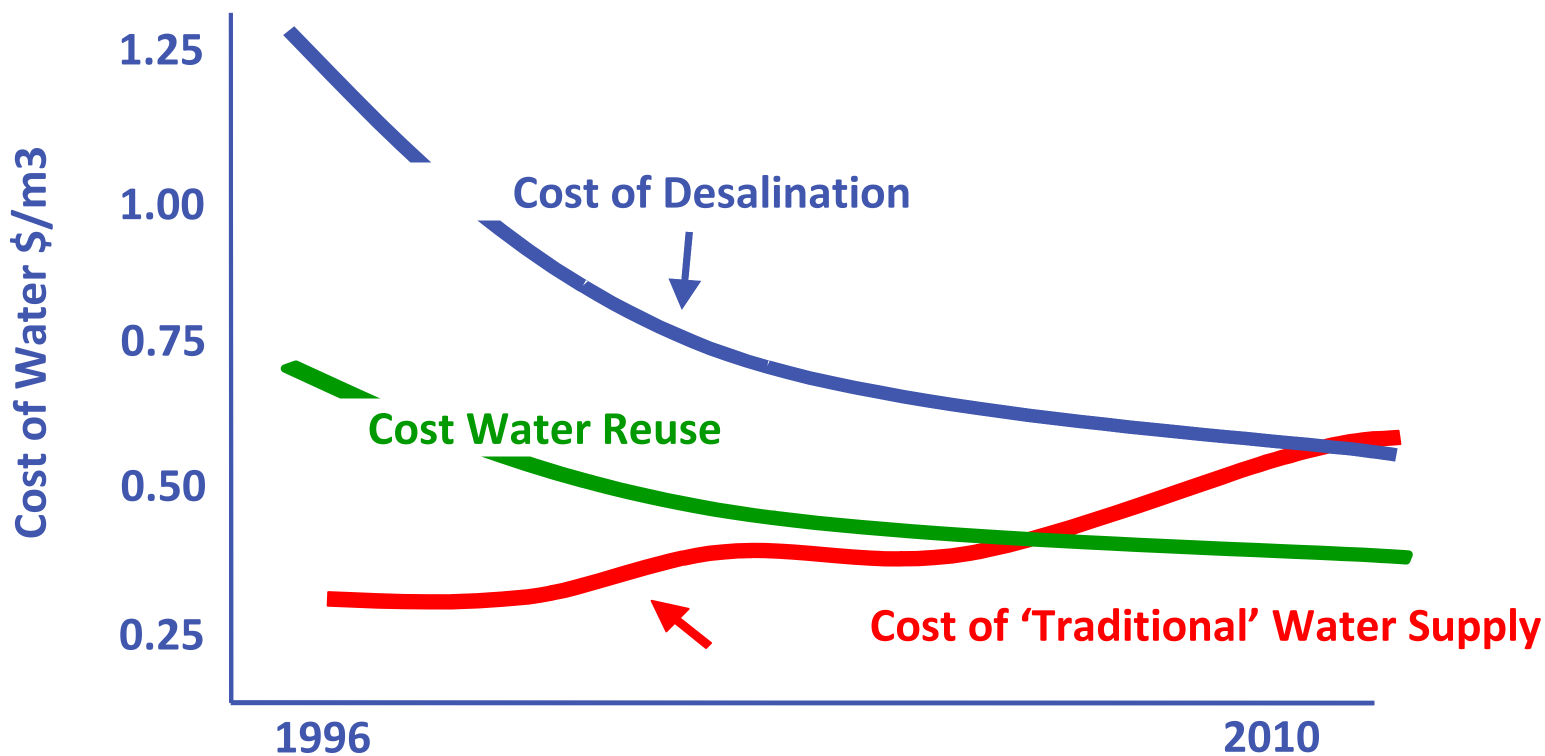


*** Membrane replacement, Chemicals, Labor, Maintenance**

Solution: Joint technology development driving energy and cost out

MEDRC

WATER = ENERGY



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

Source: GE

Energy Demand of Water

MEDRC

Energy Requirements of Various Water Resource Options

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

Source: Mike Hightower, Sandia National Laboratories

Desalination technologies

MEDRC

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.

heat-driven and power-driven processes

- Mechanical Vapour Compression

power-driven processes

- Reverse Osmosis
- Electro Dialysis

RE technologies

MEDRC

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

heat and power production: Solar Thermal electricity

power production RE technologies

- Wind Power
- Wave Power
- Solar Photovoltaic

RE technologies

MEDRC

Possible combinations of renewable energy and desalination technologies *(Source: Al-Karaghouli et al., 2011)*

Thermal Technologies	Membrane Technologies				
	MSF	MED	VC	RO	ED
Renewable Technologies	●	●	●	●	●
Solar thermal			●	●	●
Solar PV			●	●	●
Wind	●	●	●	●	●
Geothermal	●	●	●	●	●

RE technologies

MEDRC

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)

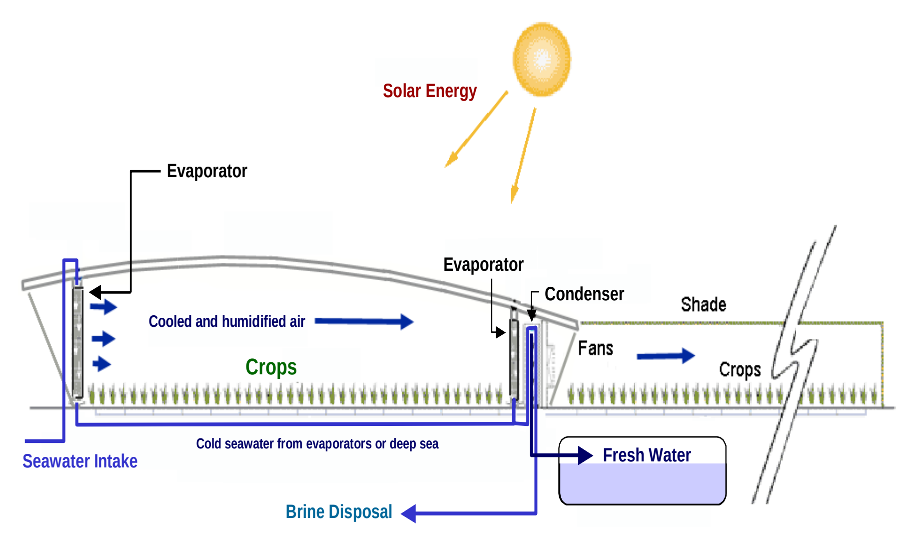
→ Desalination technologies can adapt to variable operation

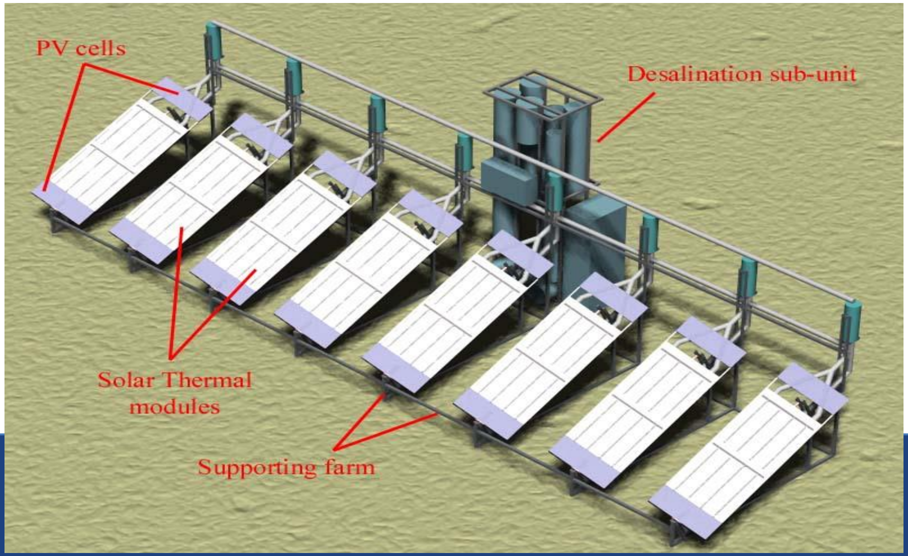
Solar desalination

MEDRC

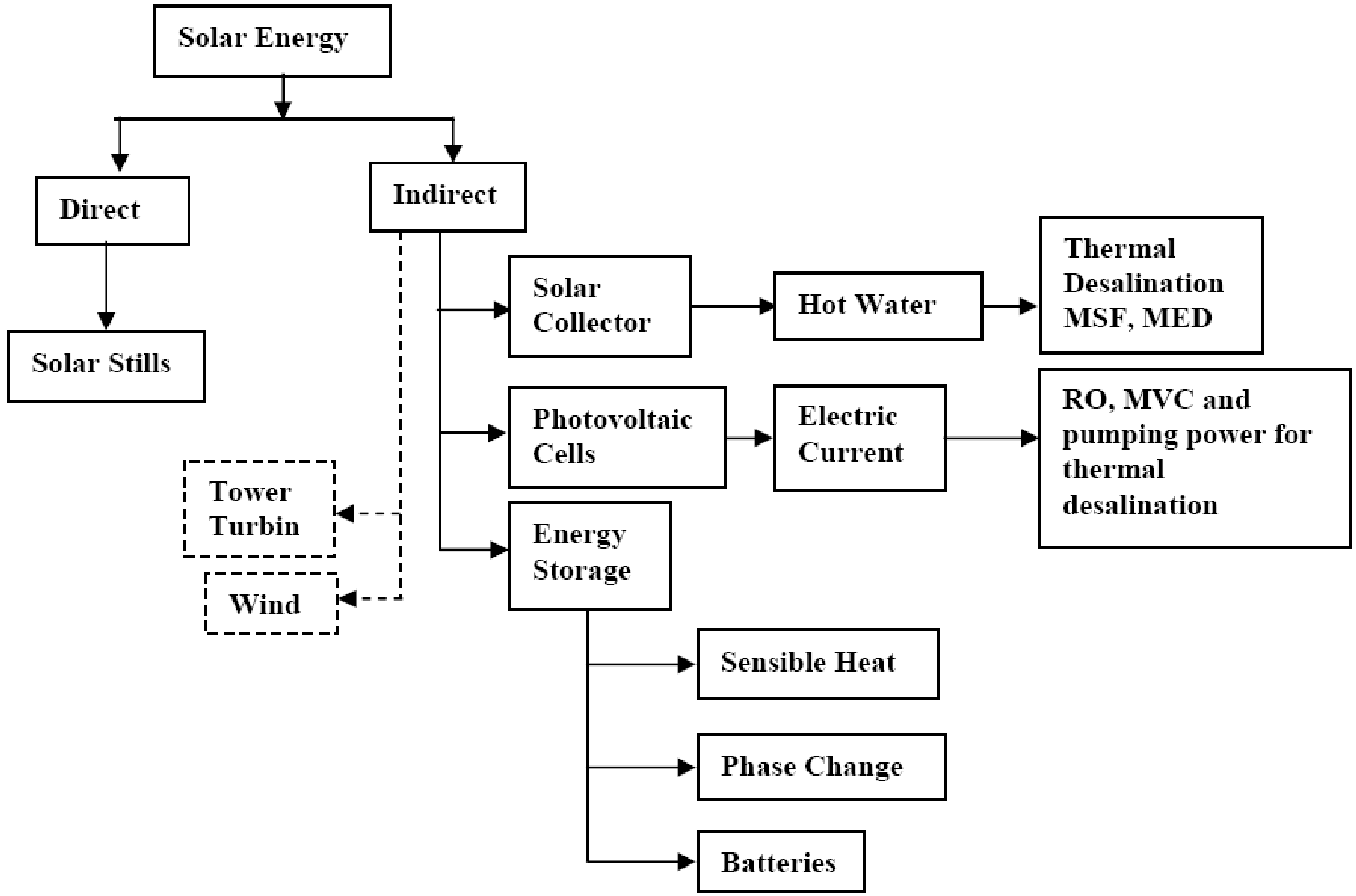
When we consider the solar energy application in desalination processes, we can distinguish between two different concepts:

- **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.



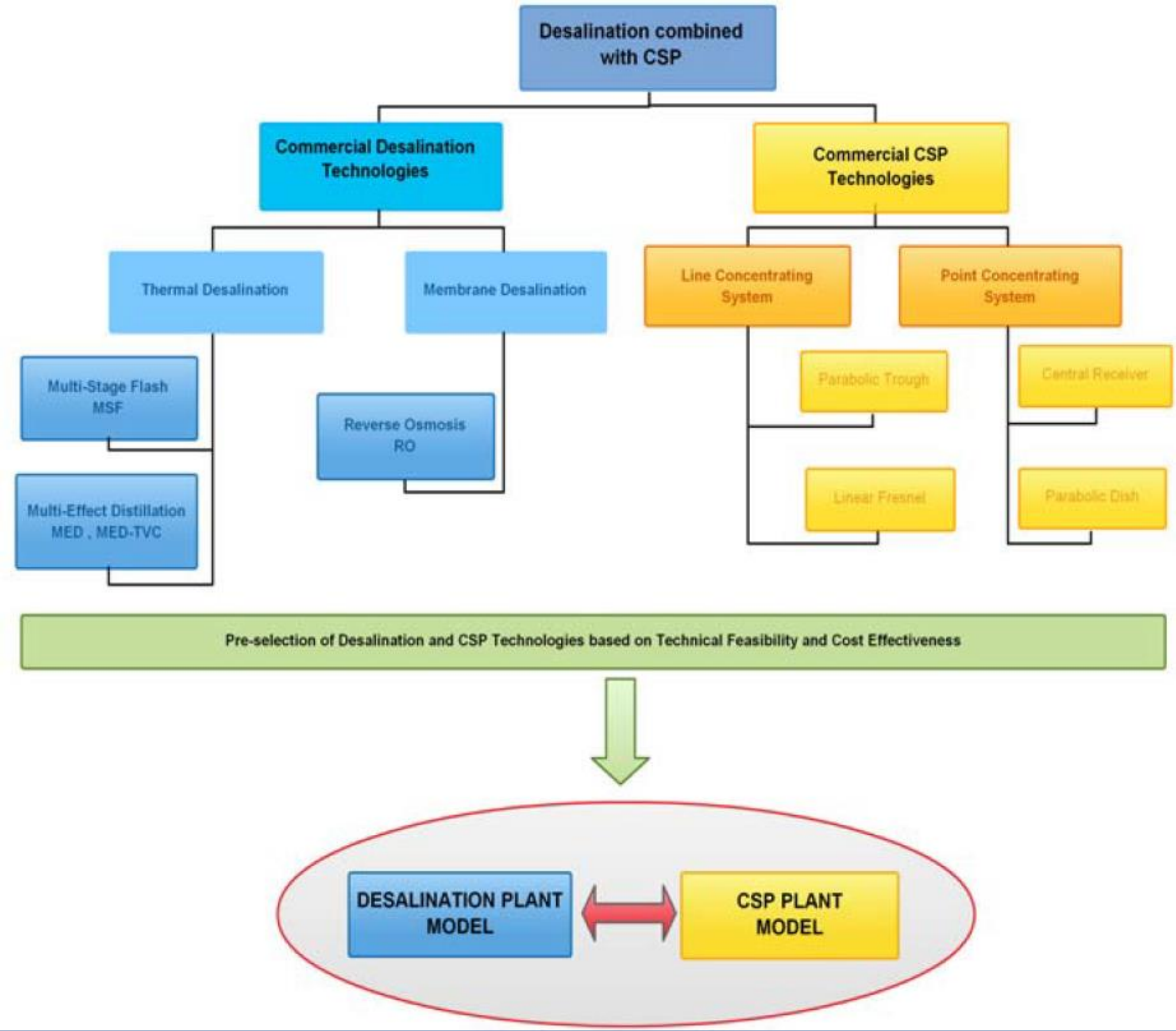


Solar desalination



Source: Ettouney & Rizzuti (2007)

Solar desalination



Commercial desalination and CSP technologies prior to model set-up

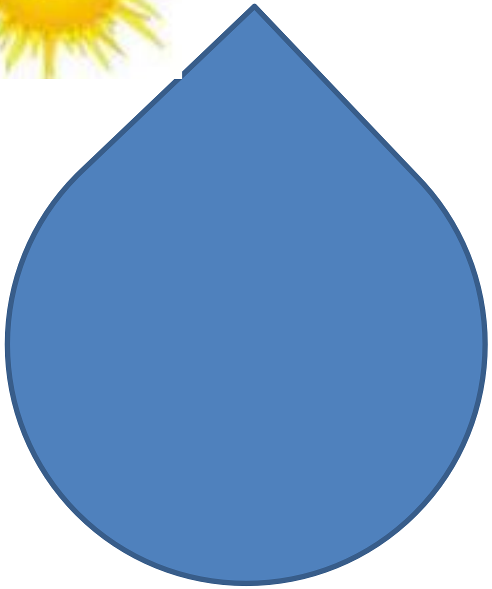
Source: MENA Regional Water Outlook, Dr. Fulya Verdier/ FICHNER

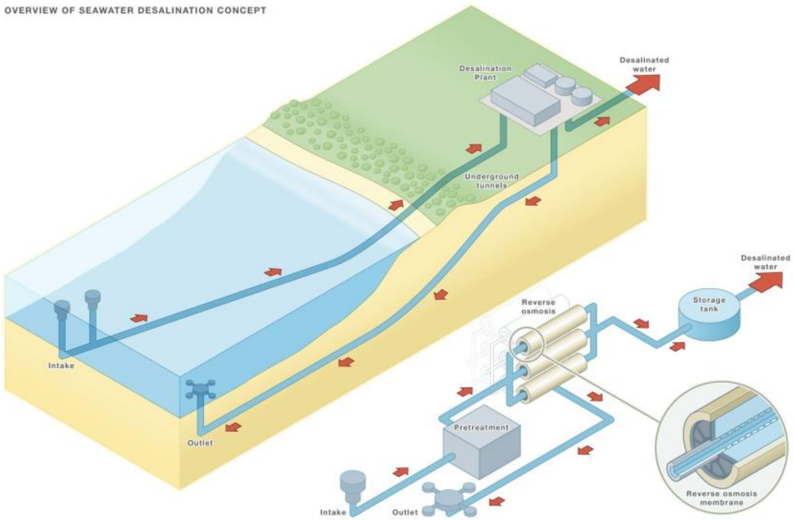
Solar desalination

MEDRC

Large-scale solar desalination

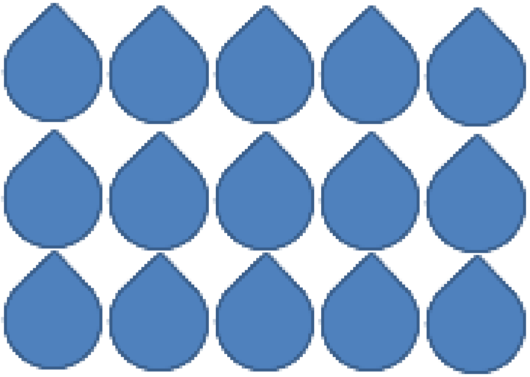
(> 10,000 m^3/day)



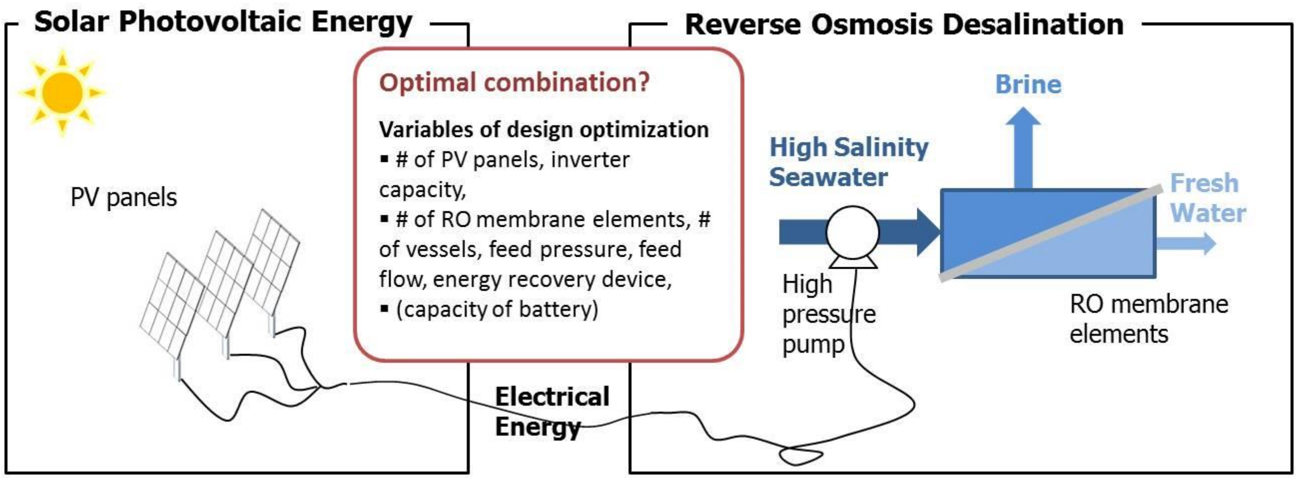


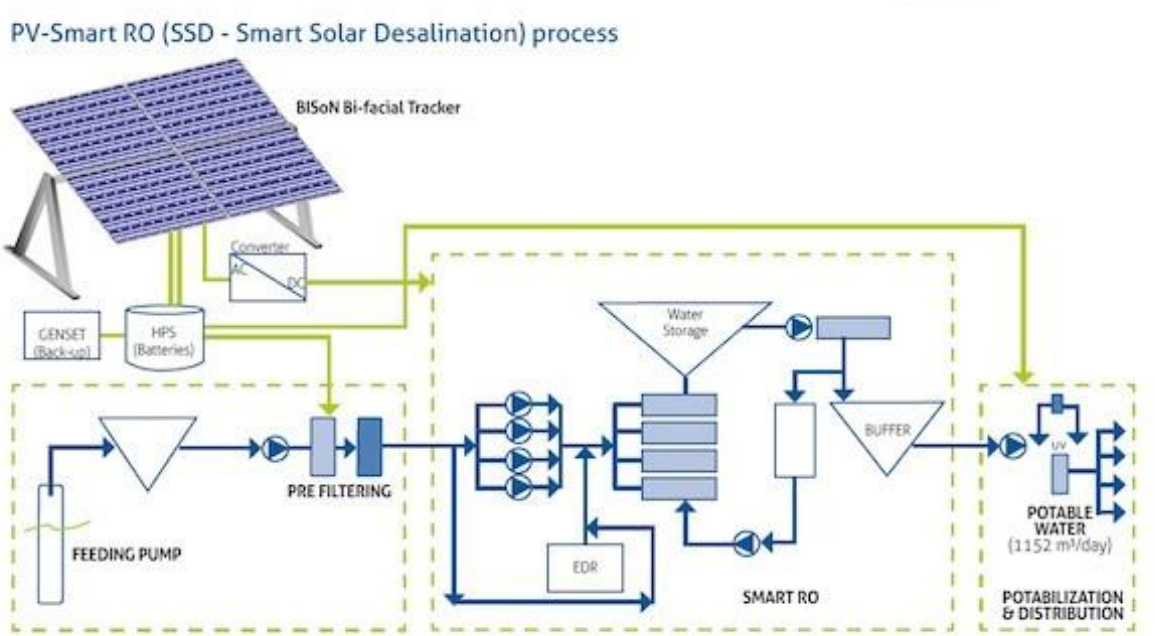
Small-scale solar Desalination

(< 100 m^3/day)



PV-RO Desalination Small scale





Solar desal plants in the MENA region

MEDRC

Status	Plant/Project Name	Country	Capacity (m^3/d)	Contract Year	Online Year	Technology	EPC Contractors
	Ben Guerdane solar-powered BWRO	Tunisia	1,800	2012	2013	RO	Suido 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.

Hassi R'mel solar thermal plant

Specifications

Status	Online
Award date	2008
Online date	2011
Capacity	1,577 m³/d
Location	Hassi R'Mel, Algeria
Technology	RO (Reverse Osmosis)
Project scope	Desalination Plant
Contract type	EPC
Location type	Land based
User Category	Industry (TDS <10ppm)
Feed water type	Wastewater

Technical Specifications

Technology	RO (Reverse osmosis)
Output water	1,577 m³/d
No. of units	2
1st-pass RO system	
Membrane type	Spiral Wound Membrane

Ben Guerdane solar-powered BWRO

Specifications

Status	Online
Award date	2012
Online date	2013
Capacity	1,800 m³/d
Location	Ben Guerdane desalination plant, Tunisia
Technology	RO (Reverse Osmosis)
Project scope	Desalination Plant
Contract type	EPC
Plant type	Greenfield
Location type	Land based
User Category	Municipalities as drinking water (TDS 10ppm - <1000ppm)
Feed water type	Brackish water or inland water (TDS 3000ppm - <20000ppm)

Technical Specifications

Technology	RO (Reverse osmosis)
Output water	1,800 m³/d

Qatar Solar Technologies Polysilicon Project, Ras Laffan

Specifications

Status	Online
Award date	2012
Online date	2013
Capacity	12,000 m³/d
Location	Ras Laffan Desal complex, Qatar
Technology	RO (Reverse Osmosis)
Project scope	Desalination Plant
Contract type	EPC
Location type	Land based
User Category	Industry (TDS <10ppm)
Feed water type	Seawater (TDS 20000ppm - 50000ppm)

Technical Specifications

Technology	RO (Reverse osmosis)
Output water	12,000 m³/d
No. of units	3
Energy recovery	Turbo Charger
1st-pass RO system	
Membrane type	Spiral Wound Membrane

Al Khafji solar-powered SWRO

Specifications

Status	Construction
Award date	2015
Online date	2017
Capacity	60,000 m³/d
Location	Al Khafji, Saudi Arabia
Technology	RO (Reverse Osmosis)
Progress rating	5 / 5
Reality rating	10 / 10
Project scope	Desalination Plant
Contract type	DBO
Location type	Land based
User Category	Municipalities as drinking water (TDS 10ppm - <1000ppm)
Est. EPC cost	USD 130,000,000
Feed water type	Seawater (TDS 20000ppm - 50000ppm)

Technical Specifications

Technology	RO (Reverse osmosis)
Output water	60,000 m³/d

Case study 1: Morocco
Project involving MEDRC

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).

Dessol®.

5 m^3 freshwater per day: Sufficient for 100 people→ Covering food & sanitation

Site parameters:

- Water production capacity of 1 m^3/h
- Energy consumption: 4 kWh / m^3
- PV capacity: 8 kWp

→Capital cost: 70.000 Euro

→Cost of water: 3 – 6 Euro / m^3

RO unit (1 m^3/h).

PV field (4 kWp).

MEDA Water

2003-2007

Case study 2: Tunisia

MEDRC

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 ºC), PV power 10.5 kWp.

Dessol®.

BWRO plant (2.1 m^3/h).

Operating more than 3,100 h producing 6,000 m^3 of drinking water in 27 months.

Raw water salinity 3.5 g/l.

Small scale wind desal.
Case study 1: Spain

MEDRC

Small scale wind powered autonomous desalination plant (1999-2003) – Dr. Guillermo Zaragoza (CIEMAT)

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 Scale RE desalination

MEDRC

Large energy requirements → co-generation with electricity production

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

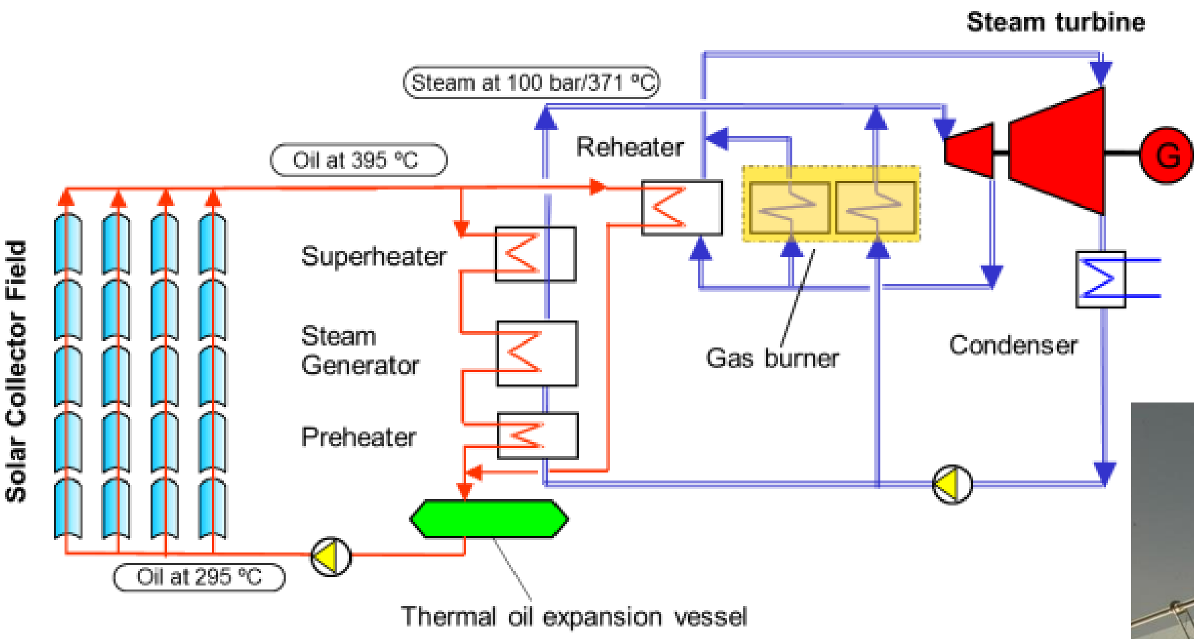
Molten salts: state of the art technology for heat storage

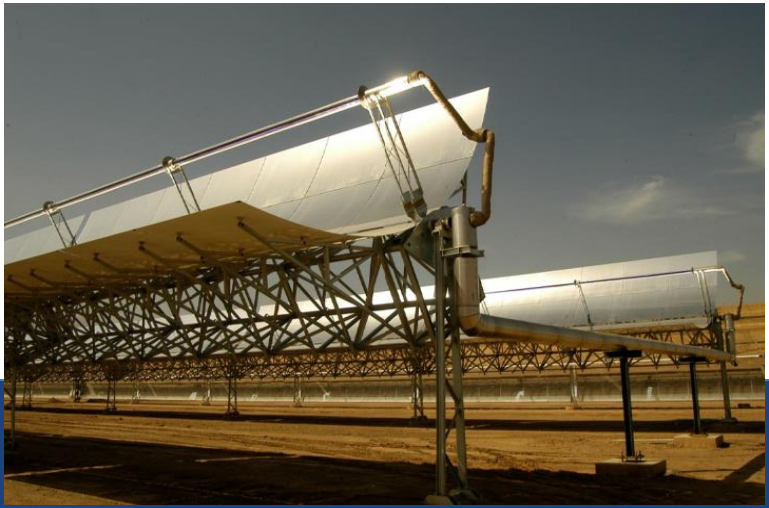
Large Scale RE desalination

MEDRC

Concentrated Solar Power (CSP) generates heat to produce steam, which then is driven into a turbine to produce electricity

Parabolic trough solar collectors (T~400ºC) 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

Al-Khafji sewater RO Desalination Using Solar Energy

Case study 2: Australia
Large Scale RE desalination

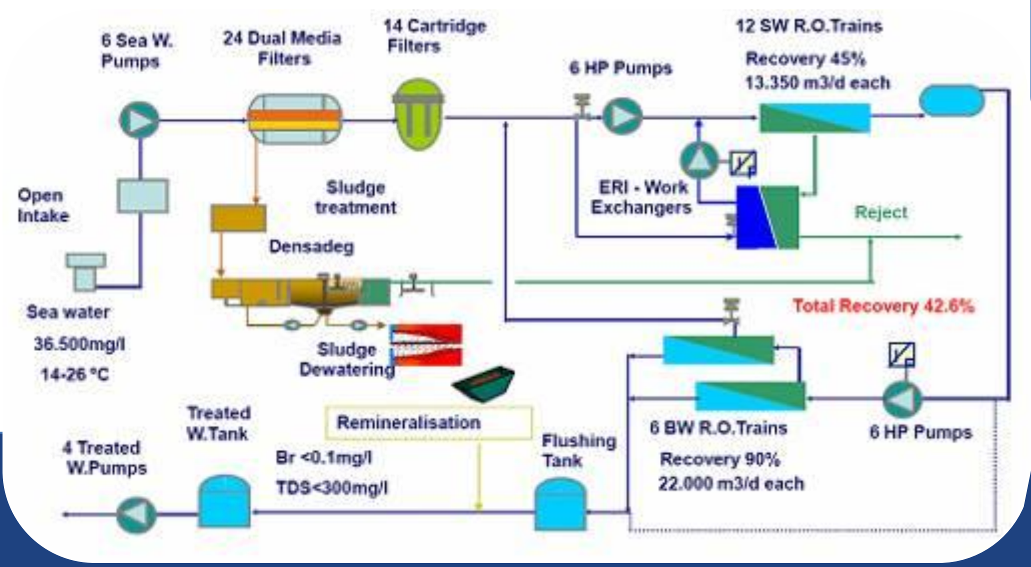
The first large RO seawater desalination plant in the Southern hemisphere and the first to be fed by renewable energies

- *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

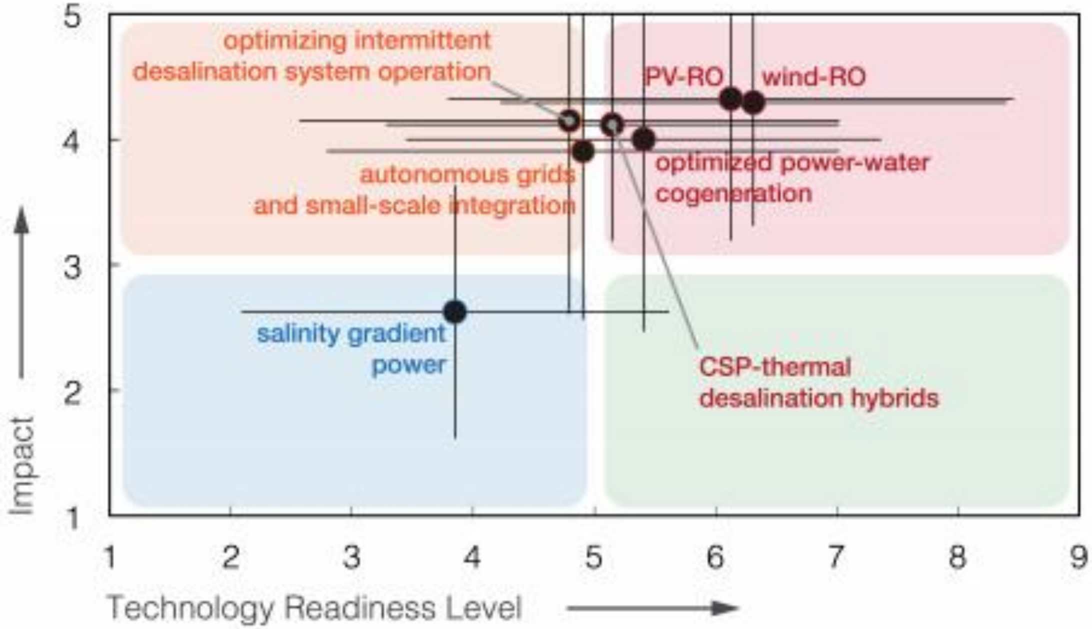
Connected to the general power grid fed by a Wind Farm **48 Turbines (80 MW)→270 GW.h/year to the grid**

200% of desalination plant energy consumption



GHG Impact versus TRL for Several Low Carbon Desalination Systems

MEDRC



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

MEDRC

	Technical Capacity	Energy Demand (kWh/m³)	Water Cost (USD/m³)	Development Stage
Solar stills	< 0.1m³/d	Solar passive	1.3–6.5	Application
Solar-Multiple Effect Humidification	1–100 m³/d	thermal: 100 electrical: 1.5	2.6–6.5	R&D Application
Solar- Membrane Distillation	0.15–10 m³/d	thermal: 150–200	10.4–19.5	R&D
Solar/CSP-Multiple Effect Distillation	> 5,000 m³/d	thermal: 60–70 electrical: 1.5–2	2.3–2.9 (possible cost)	R&D
Photovoltaic-Reverse Osmosis	< 100 m³/d	electrical: BW: 0.5–1.5 SW: 4-5	BW: 6.5–9.1 SW: 11.7–15.6	R&D Application
Photovoltaic-Electrodialysis Reversed	< 100 m³/d	electrical: only BW:3–4	BW:10.4–11.7	R&D
Wind- Reverse Osmosis	50–2,000 m³/d	electrical: BW: 0.5–1.5 SW: 4–5	Units under 100 m³/d, BW:3.9–6.5 SW:6.5–9.1 About 1,000 m³/d, 2–5.2	R&D Application
Wind- Mechanical Vapor Compression	< 100 m³/d	electrical: only SW:11–14	5.2–7.8	Basic Research
Wind- Electrodialysis	–	–	BW: 2.0–3.5	–
Geothermal- Multi Effect Distil-lation	–	–	SW: 3.8–5.7	–

Source: Papapetrou et al., 2010 and European Union, 2008

Conclusions

MEDRC

- 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.

MEDRC

elkharraz@medrc.org