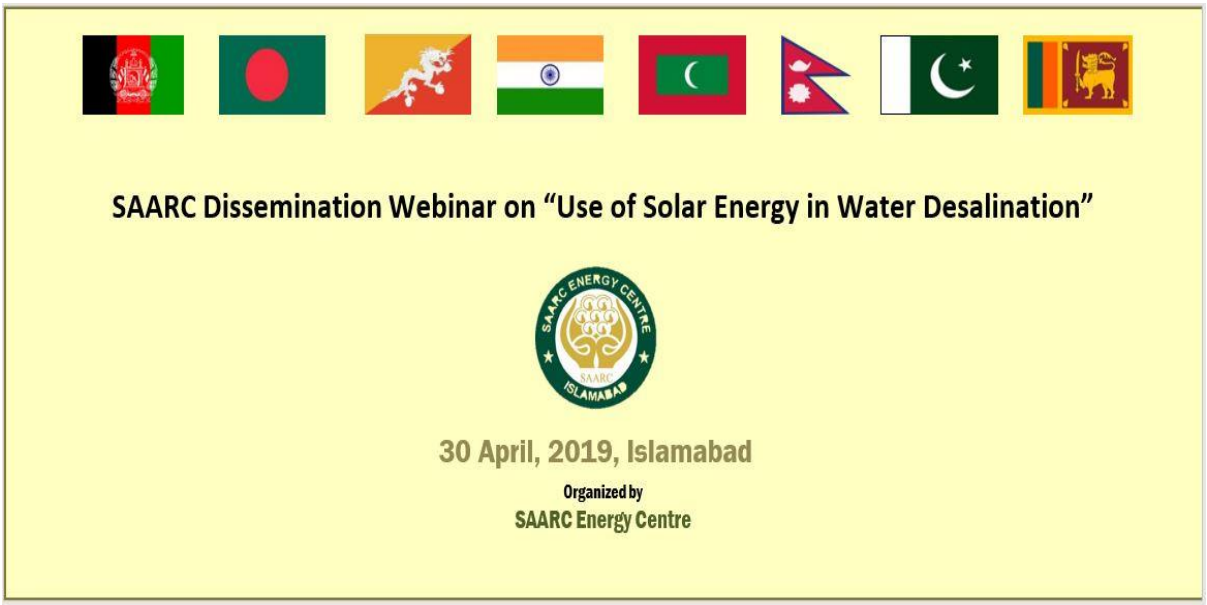
SAARC Energy Centre

THE REPORT



April 30, 2019

SAARC Energy Centre
697, Street 43, Sector E-11/4 (NPF),
Islamabad, Pakistan
www.saarcenergy.org

Introduction

SAARC Energy Centre, Islamabad under its approved programme activity for the year 2019 had successfully conducted a SAARC Webinar on "Use of Solar Energy in Water Desalination" on Tuesday, April 30, 2019. Webinar Agenda is available at Annexure I.

2. The Webinar educated the energy and water sector professionals from SAARC region about the technology options, opportunities and challenges linked with the use of solar thermal desalination/purification. Moreover, the webinar shared available knowledge and experience of different organizations involved in the thermal desalination of sea water. As solar thermal desalination is in its early stages, with a few projects recently established, therefore the webinar not only shared theoretical knowledge, but also highlighted the important learnings from those recent projects.

Participation

3. The Webinar was attended by a total of 52 professionals that included delegates from Member States, Representatives of Regional/International organizations, Academia and private sector. The Resource Persons from SAARC Energy Center gave detailed presentations on their theoretical knowledge, successful programmes, case studies, and initiatives undertaken in the field of desalination through solar energy. The participants list is available at Annexure II.

Webinar Opening and Welcome

4. Mr. Muhammad Umar Mukhtar, the programme coordinator for this webinar welcomed all the delegates and participants for attending the webinar and showing keen interest. He also

acknowledged the commitment and contribution of SEC experts in materializing the conduct of webinar.

5. He thanked the SEC expert, Mr. Bilal Hussain, for playing key role in realizing this webinar. He remarked that this webinar is just a first step, and the centre shall continue conducting such knowledge sharing webinars. At the end, he again thanked all the participants for taking out time to attend the webinar.

Technical Proceedings

6. All the presentations delivered during the webinar are available at SEC's website www.saarcenergy.org. The Experts list is available at Annexure III and Presentations at Annexure IV. A brief information on the content of the delivered presentations is as follows:

Presentation 1 – Solar Desalination in Island States

Expert: Mr. Bilal Hussain, Research Fellow (Power), SAARC Energy Center, Pakistan

7. Mr. Hussain provided an island context to solar desalination by giving an overview of the need for fresh water in islands as well as the market and the economics of solar desalination in islands. He also provided an overview of different desalination technologies and their characteristics.

8. He mentioned that due to limited freshwater resources in islands, those islands face the options of either expensive water import or the use of fossil fuels for water desalination. He pointed out that in this context, use of solar energy for water desalination has economic benefits in the form of reduced fuel usage and security of water supply.

9. Mr. Durrani explained the currently, the desalination market is dominated by fossil powered plants, majority of which are Reverse Osmosis (RO) plants. He also explained technologically viable combinations of solar energy for water desalination.

10. At the end, he discussed economics of multiple renewable energy desalination options by comparing their levelized cost of water desalination, and pointed out that PV based RO system had the least cost among other RE options, and this cost was comparable to fossil based RO plants if the RO plant size is bigger and if it operates on low temperature waste heat.

Presentation 2 – An overview of Current solar Desalination Technologies

Expert: Mr. Muhammad Umar Mukhtar, Research Fellow (Energy, Transport & Environment, SAARC Energy Center, Pakistan

11. Mr. Mukhtar started his presentation by highlighting the worldwide water crisis and mentioning the world regions that are deeply affected by lack of freshwater. He stated that around 770 million people in the world lack access to fresh water, and pointed out that this problem could be solved by desalination of brackish and saline water. He stressed the importance

of brackish water as it is significantly cheaper and easier to desalinate due to its smaller concentrations of TDS (total dissolved solids).

12. He then explained the current global status of desalination, and stated that out of the total desalination capacity of 92.5 million cubic meters per day, the MENA (Middle East and North Africa) region accounts for 44% of global desalination.

13. Mr. Mukhtar then explained the small-scale desalination solutions for single and multi-family rural households. These solutions mostly consisted of different variations of solar stills. He then explained large scale solar desalination methods in great detail, and reviewed each technology, its technical process, pros and cons one by one.

14. He then discussed the implementation of solar energy in desalination and analyzed the comparative cost for each solar desalination technology. He presented the result of that analysis by stating that the production cost varies between 1-2 USD/m^3, and that solar powered MSF has higher capital cost, while solar powered RO technology has higher operations and maintenance cost.

15. Finally, Mr. Mukhtar highlighted technical challenges to solar desalination and presented a case study solar water desalination in Al-Khafji, Saudi Arabia, which is one of the largest solar desalination plants in the world with a capacity of 3 million cubic meters per day.

Conclusion and Closing of Webinar

Mr. Muhammad Umar Mukhtar, Research Fellow (Energy, Transport & Environment), SAARC Energy Centre

16. Mr. Muhammad Umar Mukhtar, Research Fellow (ETE) informed all the participants that the presentations will be available on SAARC Energy Centre's website (www.saarcenergy.org). He requested the participants to submit suggestions and comments to SEC for any further improvement, plus they may suggest and submit any topics of their interest to SEC for arranging future webinars. The webinar was closed with a thank you note to everyone attending the Webinar

Annexure-I

Agenda

SAARC Webinar on "Use of Solar Energy in Water Desalination"

Tuesday, April 30, 2019; 1100–1300 hrs Pakistan Standard time (PKT)

1100 – 1110	Welcome and Introduction *Mr. Muhammad Umar Mukhtar, Research Fellow (Energy, Transport & Environment), SAARC Energy Centre*
1110 – 1145	Topic: Solar Desalination in Island States *Presenter: Mr. Bilal Hussain, (Research Fellow – Power, SAARC Energy Center)*
1145 – 1155	Q&A Session
1200 – 1245	Topic: An overview of Current solar Desalination Technologies *Presenter: Mr. Muhammad Umar Mukhtar (Research Fellow – Energy, Transport & Environment, SAARC Energy Center)*
1245 – 1250	Q&A Session
1250 – 1300	Conclusions, Recommendations and Closing of Webinar *Mr. Muhammad Umar Mukhtar*

Information for the participants:

1. All times mentioned in agenda are according to Pakistan Standard Time (PKT). The participants from other Member States of SAARC and Australia may attend Webinar by following their own national time. The time conversion for all countries is given below for reference:

Country	Afghanistan	Bangladesh	Bhutan	India	Maldives	Nepal	Sri Lanka	Australia
Conversion Time	(PKT-00:30)	(PKT+01:00)	(PKT+01:00)	(PKT+00:30)	PKT	(PKT+00:45)	(PKT+00:30)	(PKT+06:00)

2. The participants can ask questions to presenters by typing questions or clicking to the raised hand option into the Attendees pane of the main window of GotoWebinar software. You may send in your questions at any time during the presentations; we will collect these and address them during the Q & A session at the end of each presentation. You may also discuss your queries during the knowledge sharing session of webinar.

3. All participants can also submit comments/views and/or observations on the webinar to SAARC Energy Centre through email to Mr. Muhammad Umar Mukhtar, Research Fellow (ETE) (rfete@saarcenergy.org) by 3rd May, 2019.

List of Participants

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Annexure-II

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Annexure-III

List of Experts

Sr. No.	Name	Designation	Organization	Email address
1.	Mr. Bilal Hussain	Research Fellow (Power)	SEC	rfpower@saarcenergy.org
2.	Mr. Muhammad Umar Mukhtar	Research Fellow (Energy, Transport & Environment)	SEC	rfete@saarcenergy.org

Presentations Delivered During the Webinar

Presentation on "Solar Desalination in Island States" by Mr. Bilal Hussain

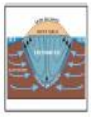
Solar Desalination in Island States

BILAL HUSSAIN
RESEARCH FELLOW POWER
SAARC ENERGY CENTER
30-04-2019

Contents

- Island Context
- Desalination Technologies and Characteristics
- Renewable Desalination Market
- Economics of RE Desalination
- Outlook and Take aways

Island Context


Limited natural freshwater resources (lenses, lakes)


Isolation from larger inhabited areas


Limited surface area for water collection or retention possibilities


Sensitive to natural disasters (cyclones, erosion, climate change)


Supply demand mismatches (dry or tourist seasons)

- Main Drivers for Renewable Energy Based Desalination
  - ✓ Expensive Water Imports
  - ✓ Fossil Fuel Imports for Water Desalination

Island Context

Benefits of Renewable Energy Based Desalination

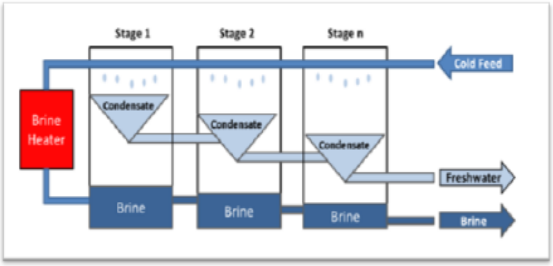

Fuel costs: reducing the cost burden of a clean and reliable water supply → **Economic Development:** facilitates the growth and deployment of economic activities

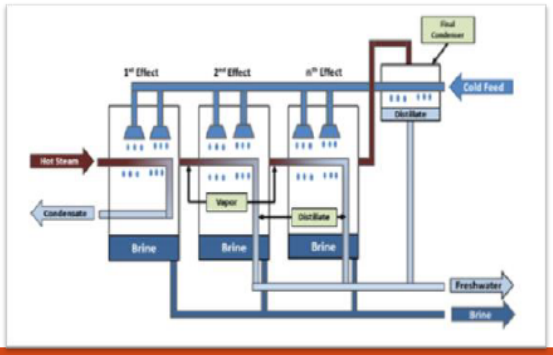

Reduced imports: reduces the need for fuel or water imports → **Security of Supply:** increases independence

Desalination Technologies and Characteristics

Thermal Driven

- **Multi Stage Flash (MSF)**
  - ✓Motive Steam for Brine Heater
  - ✓Top brine temperature around 112°C
  - ✓Qualifies for CSP steam feed
- **Multi Effect Desalination (MED)**
  - ✓Motive steam for evaporator tube
  - ✓Requires medium operating temperatures of around 70 °C
  - ✓Qualifies for low grade waste heat from CSP

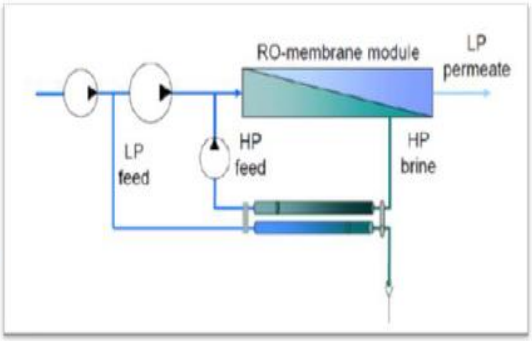


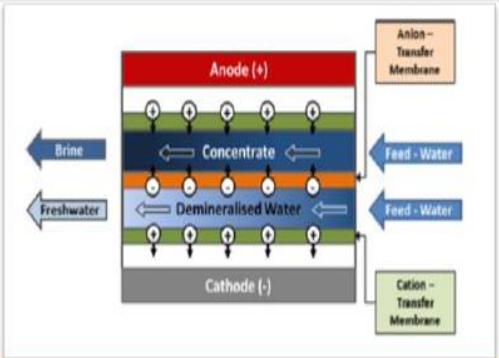


Desalination Technologies and Characteristics

Electricity Driven

- **Reverse Osmosis (RO)**
  - ✓80% electricity consumed for pumping
  - ✓Pressure requirements proportional to water salinity
  - ✓Sensitive to fluctuations
- **Electrodialysis (ED)**
  - ✓Operates on DC supply
  - ✓Limited to small scale brackish water applications





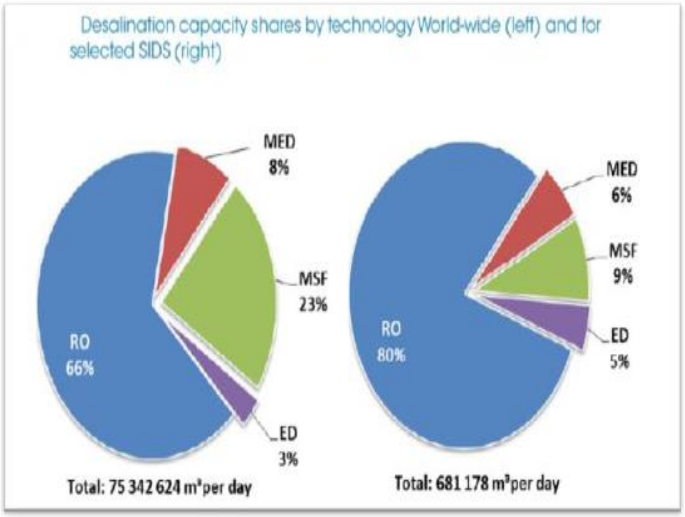
Desalination Technologies and Characteristics

Other Solutions

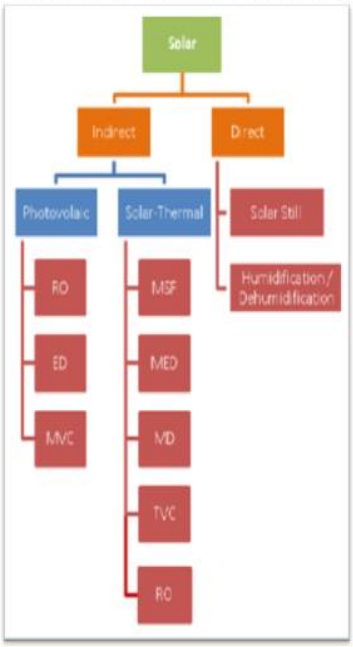
- Mechanical or Thermal Vapor Compression (MVC / TVC)
- Membrane Distillation(MD)
- Open Cycle OTEC Desalination
- Freezing

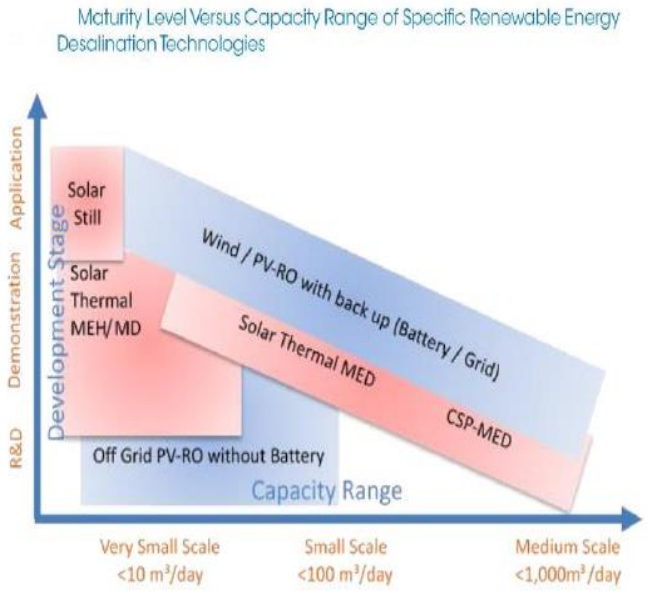
Desalination Market

- Mostly Fossil powered
- 200-20,000 Cubic Meter/Day
- RO Plants are most dominant



Renewable Desalination
Potential Combinations





Renewable Desalination
Technologically Viable Combinations

- **Photovoltaic Reverse Osmosis**
  - ✓ Low cost of water
  - ✓ Commercial plants & pilots already running
  - ✓ Storage required to avoid supply fluctuations

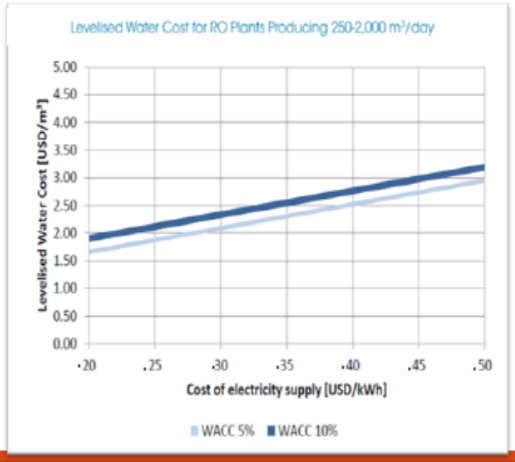
- **CSP Reverse Osmosis**
  - ✓ More Efficient that CSP-MED
  - ✓ More suitable for large RO plants
  - ✓ In R&D and demonstration phase

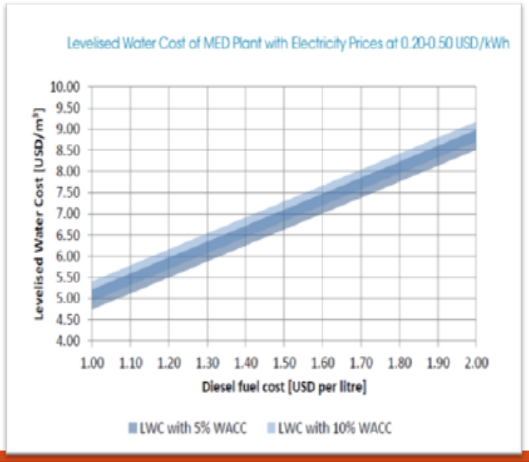
- **CSP Multi-Effect Distillation**
  - ✓ Favorability increases when salinity is high
  - ✓ Provides flexibility bonus
  - ✓ Simultaneous heat and electricity utilization

Economics of Renewable Desalination

IRENA assessment report on SIDs 2015

- Report compared RE desalination solutions with fossil powered desalination
- Comparison was done for levelized cost of water (LWC) for 250-2,000 Cubic Meter/Day plant size range

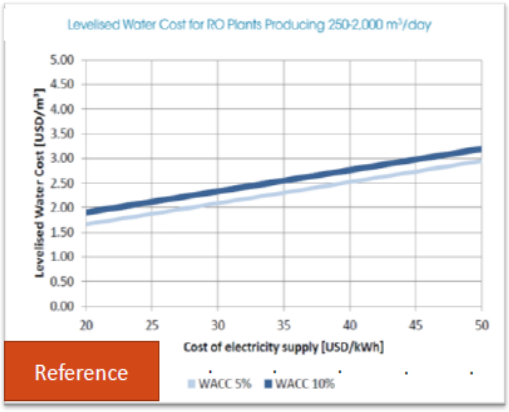


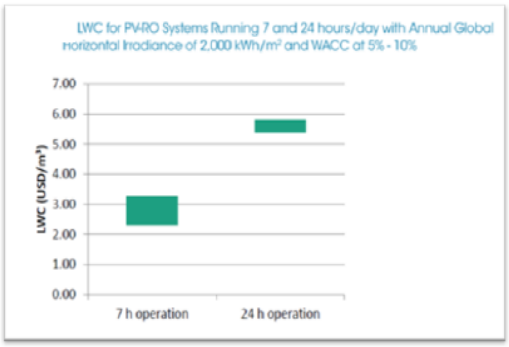


Economics of RE Desalination

IRENA assessment report on SIDs 2015

Comparison of Grid Connected PV-Reverse Osmosis

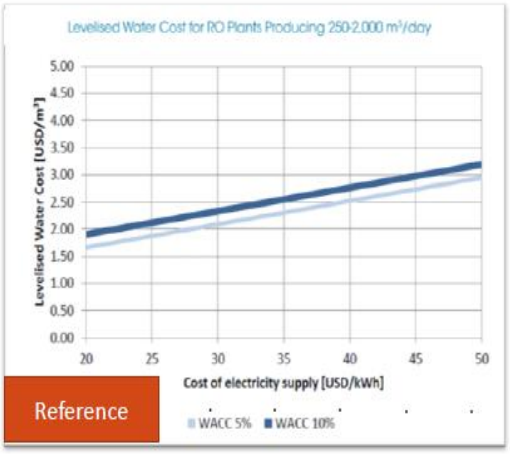


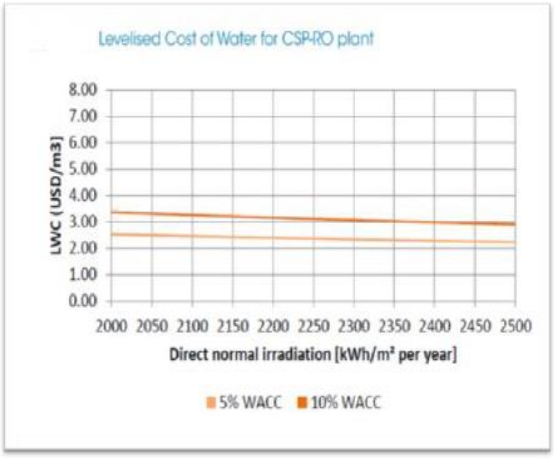


Economics of RE Desalination

IRENA assessment report on SIDs 2015

Comparison of CSP-Reverse Osmosis

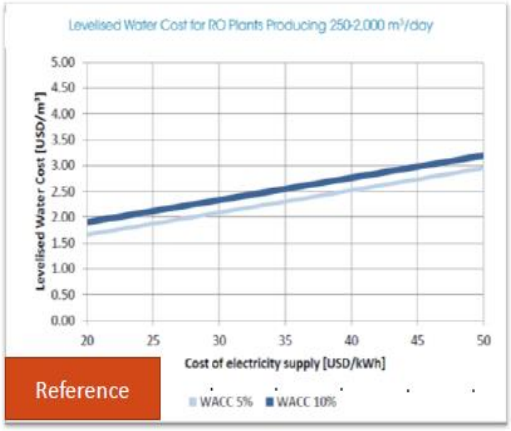


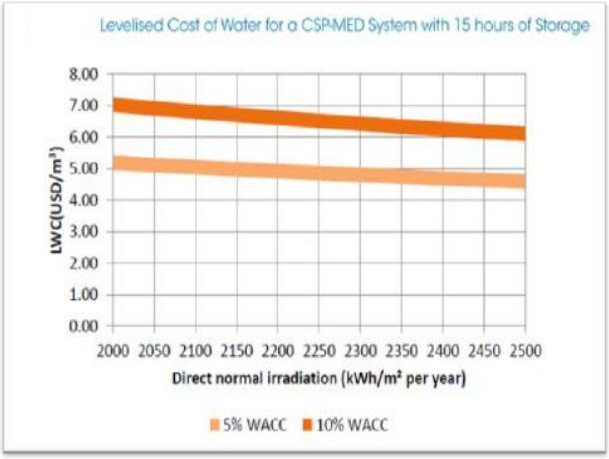


Economics of RE Desalination

IRENA assessment report on SIDs 2015

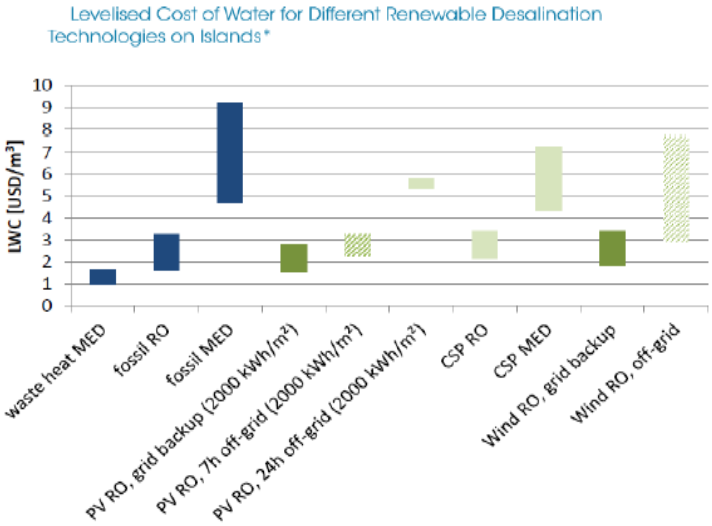
Comparison of CSP-Multi Effect Distillation (MED)





Economics of RE Desalination
IRENA assessment report on SIDs 2015

Summary Results



Outlook & Take Aways

- Declining energy storage costs will favor RE desalination in Future
- In Future, flexible RO desalination plants will attract more investors and energy companies
- Refilling the overexploited ground water lenses/aquifers with desalinated water is an interesting area to explore favorability of commercial RE desalination solutions
- Bigger size RE desalination plants are cost effective especially when operating on low temperature waste heat
- Asides the maturing technology options, expansion of RE desalination solutions requires better training and education facilities, information sharing on best practices and functioning supply chains

Thank you…

Presentation on "An overview of Current Solar Desalination Technologies" by Mr. Muhammad Umar Mukhtar

AN OVERVIEW OF CURRENT SOLAR DESALINATION TECHNOLOGIES

PRESENTED BY: **MUHAMMAD UMAR MUKHTAR**

RESEARCH FELLOW – ENERGY, TRANSPORT & ENVIRONMENT

SAARC ENERGY CENTER

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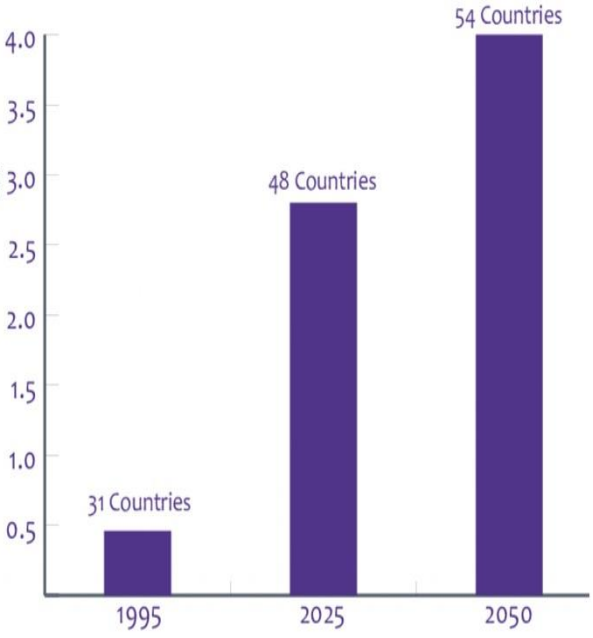
TABLE OF CONTENTS (CONTINUED)

Solar Energy Sources for Desalination

- Implementation of Solar Energy in Desalination
- Comparative cost analysis
- Technical Challenges
- Solar Ponds
- Case Study
- Conclusion

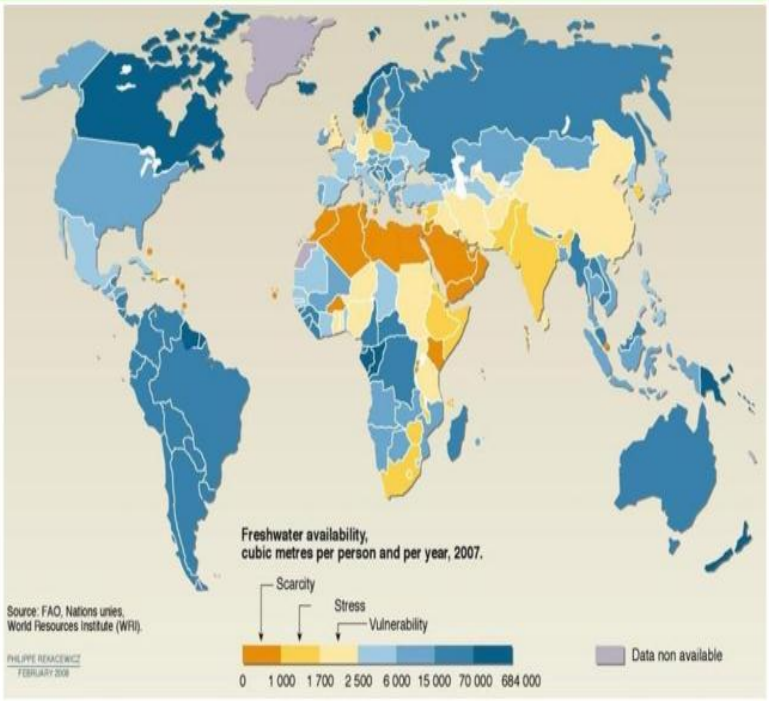
WORLDWIDE WATER CRISIS

- 1 out of 11 people lack access to clean water
- 2/3 of the worlds population → water stressed conditions (by 2025)
- 1.8 billion people → absolute water scarcity (by 2025
- Unsustainable rate of withdrawal
- Costly water drilling and poor quality water near surface
- Poor quality water health impacts
  - 3.4 million people die every year form water related diseases.
- Increased population → increase in water scarcity
- Global warming



WORLD REGIONS DEEPLY AFFECTED

- 358 million people in Africa
- 180 million people in South, West and Central Asia
- 186 million people in South East, East Asia and Oceania
- Overall around 770 million people lack fresh water access



ADDRESSING THE PROBLEM AND FINDING A SOLUTION: DESALINATION

- Definition: Removal of salts and dissolved solids from water in order to produce water suitable either for human consumption or agricultural purposes and industrial processes
- Varying degrees of salinity in water. Desalination used for both sea water and brackish water
- Solar desalination

A COMPARISON OF DESALINATION FOR SEAWATER AND BRACKISH WATER

- The concentration of total dissolved solids (TDS) in Seawater is 3.5 to 35 times greater than concentration in brackish water
  - Brackish water: 1,000 -10,000 mg/L TDS
  - Salt water from the ocean: ~35,000 mg/L TDS
- Brackish water is significantly cheaper and easier to desalinate due to its smaller concentrations of TDS
- Brackish water is readily available in many nations

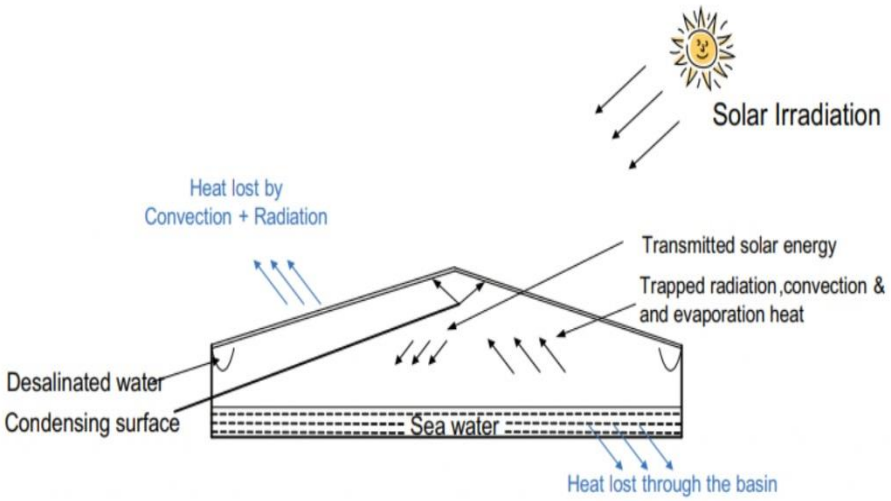
STATUS OF DESALINATION

- 18,436 desalination plants
- Total Desalination capacity → 92.5 million m3/day
- MENA Region → 44% of global desalination
- Gulf region average water availability → less than 300m3 per capita per year
- Desalination more practical in seas because of lower salinity than the oceans, leading to lower energy consumption requirement.

SMALL SCALE DESALINATION SOLUTIONS

- Solar Still technologies – Recommended for small scale desalination in both single and multifamily rural households
  - Used where demand for fresh water is small and land is inexpensive
  - Inexpensive and require less technical knowledge to design and construct
  - Helps promote self reliance and enable communities to develop further

SOLAR STILLS



SOLAR STILLS – PROS AND CONS

Advantages:

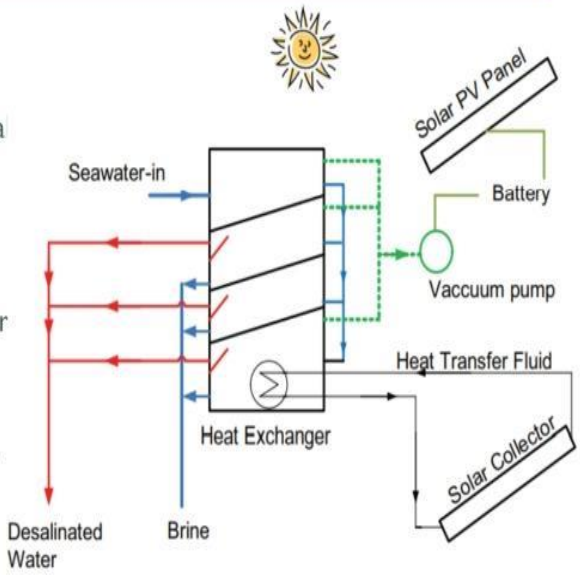
- Low Cost
- Easy to build
- No additional chemicals needed to treat water

Disadvantages

- Low production yield 2 – 7 L/M2/day
- Not economically viable for large-scale applications
- Large land requirements to scale up size of operation

SOLAR STILL VARIATIONS

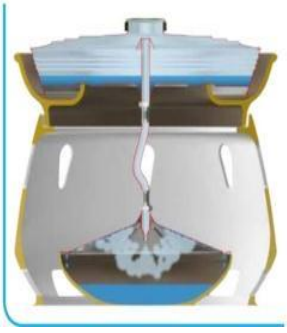
- Active or passive solar still
- Geometry: single slope, double slope, vertical, conica etc.
- Cover: glass or other transparent materials, with different glosses
- Additives: brine or another substance to aid in water absorption
- Spout run-off: Putting solar still output through a variety of run-off for further cleaning. Example: slow sand filter



AQUAMATE SOLAR STILL

- Portable variation used for seawater
- Clean water falls into the donut of the buoy and can be sucked through drinking tube
- Used by U.S. military and life-raft survival kits

ELIODOMESTICO

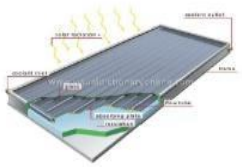


- Ceramic pot that utilizes basic concept of boiling
- Sun heats black boiler on top, turning it into steam which is forced down an expansion nozzle where it condenses against the lid
- Yields 5 L/day
- Estimated cost $50

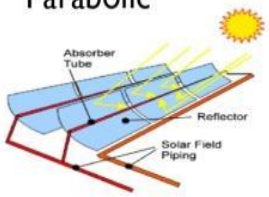
SOLAR CONCENTRATOR

- Depending on the need, 3 types of concentrators exist (least efficient to most efficient): flat (stationary), parabolic (tracking), and dish (tracking)
- Desalination application: (1) the concentrated solar energy can either directly heat the water to temperatures adequate enough to remove impurities, or (2) can focus the energy onto a plane of solar thermal collectors or photovoltaic panels that then power desalination plants

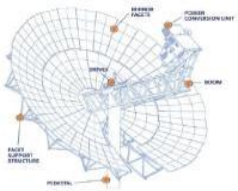
Flat



Parabolic



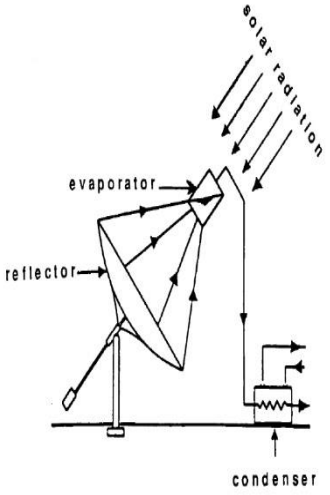
Dish



Flat solar collector merely absorbs and does not reflect rays, so it can be stationary, whereas the other two collectors must move in order to concentrate rays to a plane or point.

CONCENTRATING COLLECTOR STILL

- Combines the concept of solar collectors and solar stills.
- Solar heat is concentrated into a container of impure water, creating vapor that then runs through a tube where it is condensed. Example of heating water source directly.



Concentrating Solar Still Diagram

LARGE SCALE SOLAR DESALINATION METHODS

Two Major types of Distillation processes that can be supplemented with solar are:

- Membrane:
  - Reverse Osmosis (RO) (~ 60% of global desalination capacity)
  - Electro-dialysis (ED)
- Thermal:
  - Multi-Effect Distillation (MED)
  - Multi-Stage Flash (MSF) (~26.8% of global capacity)

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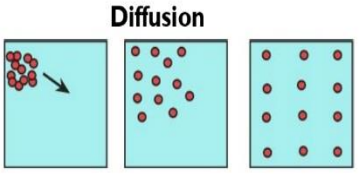
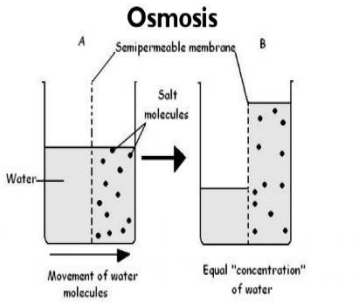
REVIEW OF MEMBRANE METHODS: REVERSE OSMOSIS (RO)

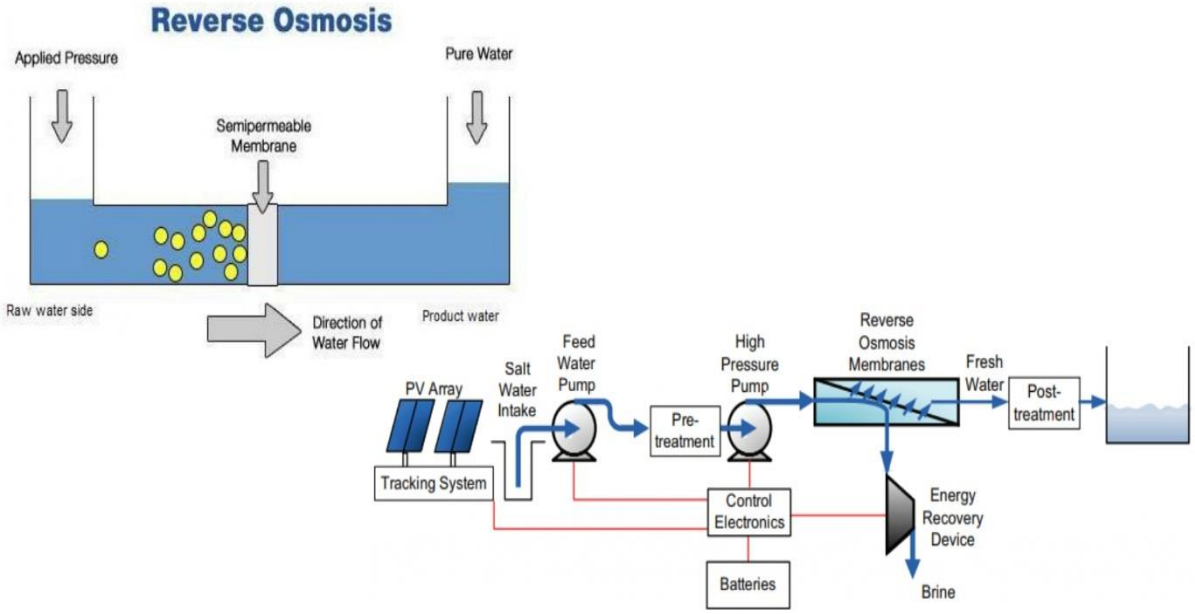
- Osmosis – a type of diffusion
- Two solutions with different concentrations are separated by a semi-permeable membrane
- Solvent from low concentration side moves to high concentration side through the membrane.
- Osmotic pressure when equilibrium is achieved



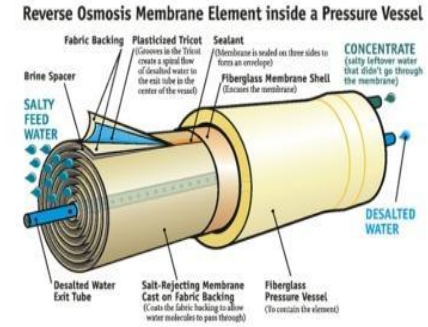
Process of diffusion over time



SOLAR POWERED RO PROCESS EXPLAINED

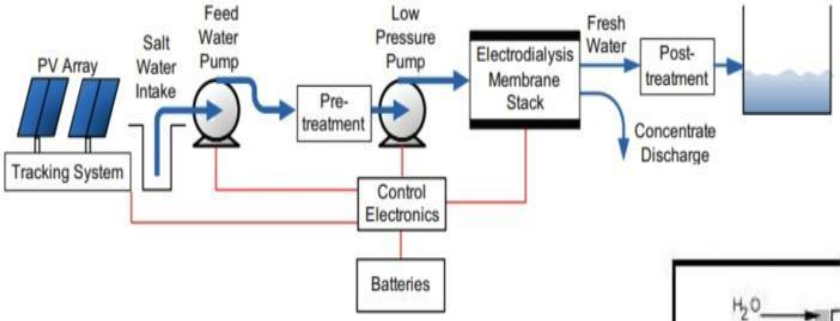


REVERSE OSMOSIS – KEY FEATURES

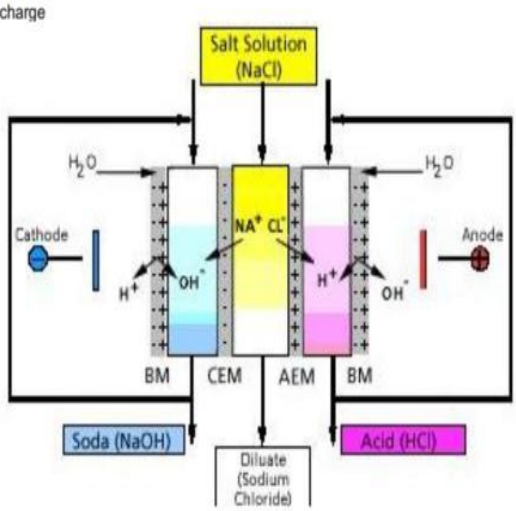


- Most common method
- Easy to use, even for small scale applications
- Produces 55-65 liters of fresh water for 100 liters of seawater through multiple stages
- Low Energy Consumption 3.5-5.0 kWh of electricity / m3
- Use of ultrafiltration membranes and renewable energy is making this technology more suitable
- Suitable for seawater of 35,000 ppm.
- Consistent water quality is required to increase the lifespan of the membranes therefore pretreatment of the salt water is required

REVIEW OF MEMBRANE METHODS: ELECTRO-DIALYSIS (ED)

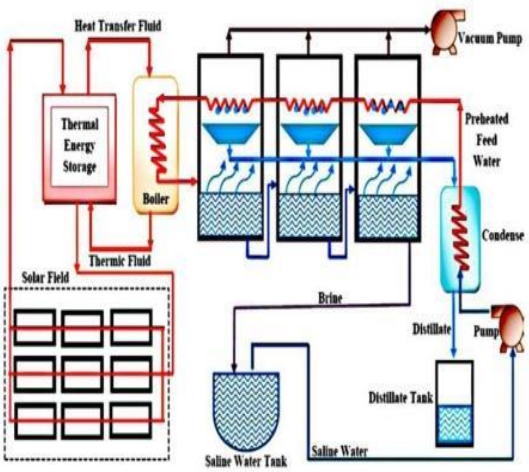


- A series of ionic and anionic membranes are lined up between two electrodes and a low DC voltage is applied causing the ions in the brackish water to migrate to the electrodes.



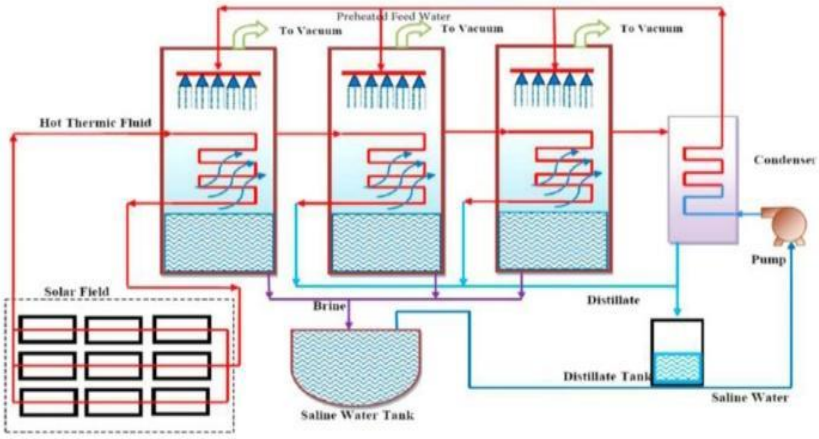
REVIEW OF THERMAL METHODS: MULTI STAGE FLASH (MSF)

- Seawater or brackish water is heated between 90-110 degrees Celsius and the tanks decrease in pressure at each stage
- The decreases in pressure allow water to flash (quickly vaporize)
- The MSF process can be powered by waste heat making it commonly used in the MENA area due to the large resources of readily available, cheap fossil fuels
- MSF process accounts for 26.8% of global desalination capacity
- Energy Consumption: ~80.6kWh of heat plus 2.5-3.5 kWH of electricity per m3 of water



REVIEW OF THERMAL METHODS: MULTIPLE EFFECT DISTILLATION (MED)

- MED accounts for 8.0% of global desalination capacity
- Consists of multiple stages ("effects") where the feed water is heated by steam in tubes. Some of the water evaporates, and the remaining steam flows into the tubes of the next stage, heating and evaporating more water. Each stage reuses the energy from the previous stage.
- Where the energy is used: heating/pressurizing the water into steam



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PROS AND CONS OF MED

- Operates at lower temperatures of approximately 70 ◦C which helps reduce tube corrosion and scaling
- Low pre-treatment and operational costs because the quality of the feed water is not as essential as is the case in the RO process
- Less Power consumption of MED as compared to MSF process
- Higher performance efficiency of MED plants as compared to MSF in regards to heat transfer and fresh water production cost

SOLAR ENERGY POTENTIAL IN DESALINATION EFFORTS

IMPLEMENTATION OF SOLAR ENERGY IN DESALINATION

- Solar energy makes desalination process more sustainable
- Forecast of increase in Fossil fuel prices and decline in solar technologies cost
- Two major ways of utilizing solar energy in desalination
  - Distillation processes driven by heat produced directly from the solar energy system
  - Membrane and distillation processes driven by electricity produced by the Solar PV system
- Solar energy sources that could be utilized in desalination efforts include:
  - Solar thermal
  - Solar Photovoltaics (PV)
  - Concentrating Solar Power (CSP)
- Solar energy can be used on a case to case basis depending on the sources of energy available in a given area

COMPARATIVE COST ANALYSIS OF COMMON METHODS OF DESALINATION USING RENEWABLE ENERGY SOURCES

- Solar desalination still expensive
- Installation in remote areas is cost effective
- MSF (higher capital cost) vs RO (higher operation & maintenance cost)
- Production cost USD 1-2 per m3
- Desalination is economically affordable only for middle to high income countries
- Cost of solar desalination likely to reduce in future

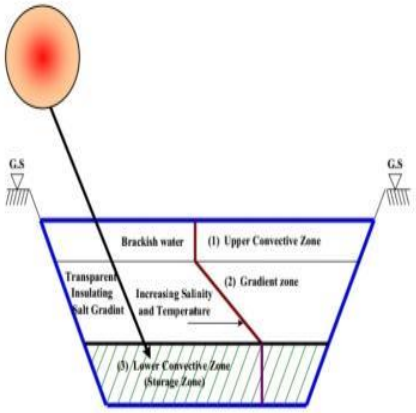
	Technical Capacity	Energy Demand (kWh/m^3)	Water Cost (USD/m^3)	Development Stage
Solar stills	< 0.1 m^3/d	Solar passive	1.3–6.5	Application
Solar-Multiple Effect Humidification	1–100 m^3/d	thermal: 100 electrical: 1.5	2.6–6.5	R&D Application
Solar- Membrane Distillation	0.15–10 m^3/d	thermal: 150–200	10.4–19.5	R&D
Solar/CSP-Multiple Effect Distillation	> 5,000 m^3/d	thermal: 60–70 electrical: 1.5–2	2.3–2.9 (possible cost)	R&D
Photovoltaic-Reverse Osmosis	< 100 m^3/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 m^3/d	electrical: only BW:3–4	BW:10.4–11.7	R&D

TECHNICAL CHALLENGES TO SOLAR DESALINATION

- Need to tailor solar power technologies to powering desalination
- Need to avoid hyperbole and face the challenge
- Need for better determination of saline and brackish water reserves

SOLAR PONDS

- Solar energy from the sun is absorbed by saltwater causing the pond to heat off
- Ambient air causes the top layer of water to cool off causing convective circulation (war water rises from the bottom and cooler water sinks from the top)
- A solar pond is designed in a way so that the top layer is less dense and therefore less saline while the bottom layer is more dense and therefore more saline
  - This design inhibits convective circulation enabling thermal energy to be stored in the bottom layer of the pond
- Thermal energy can be extracted by piping the bottom layer through a heat exchanger



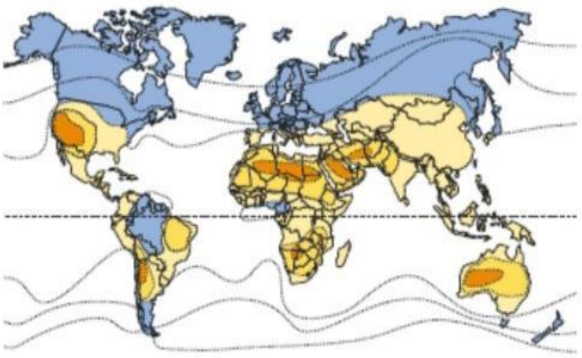
Solar Pond

CASE STUDY: SOLAR WATER DESALINATION IN AL-KHAFJI, SAUDI ARABIA

- Plant utilizes a Ultra High Concentrator Photovoltaic (UHCPV) system
- Three phase plan
  - Phase I: Construction of solar-powered desalination plant at Khafji (30,000,000 l/day)
  - Phase II: Construction of a second solar-powered desalination plant (3,000,000,000 l/day)
  - Phase III: Construction of additional solar-powered desalination plants across Saudi Arabi
- All three phases are projected to be completed by 2020

CONCLUSIONS

- Solar Thermal can either be direct or indirect
  - Direct with solar condensers and collectors integrated into one unit
  - Indirect with condensers connected externally to collectors
- Direct systems are relatively low cost and simply to construct (i.e. solar stills) but require large areas of land and have low fresh water production
- Indirect Systems (MED, MSF) are able to produce greater quantities of fresh water but have a higher capital cost



Suitability for solar thermal power plants:
excellent good suitable unsuitable

CONCLUSIONS

- Solar panels can be used to generate electrical energy which can then be used in the RO process
- Fluctuations in power generation is to be expected as the input of solar energy can change with weather
- Power fluctuations would decrease the efficiency of the RO process
  - Battery storage would be required for times where there is little or no solar energy (night time and cloudy days)

Photovoltaic Solar Array

THANK YOU