AN OVERVIEW OF CURRENT SOLAR DESALINATION TECHNOLOGIES

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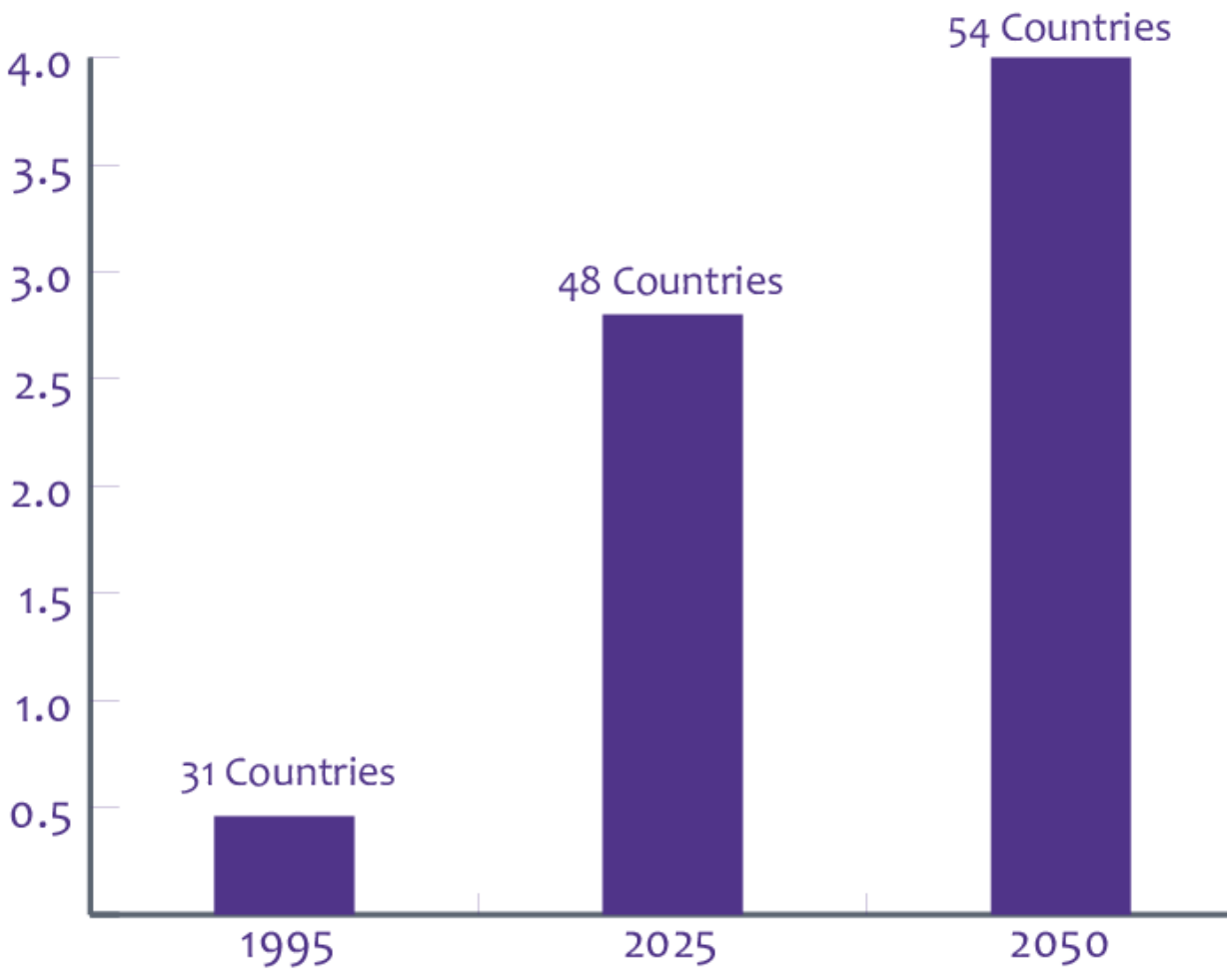
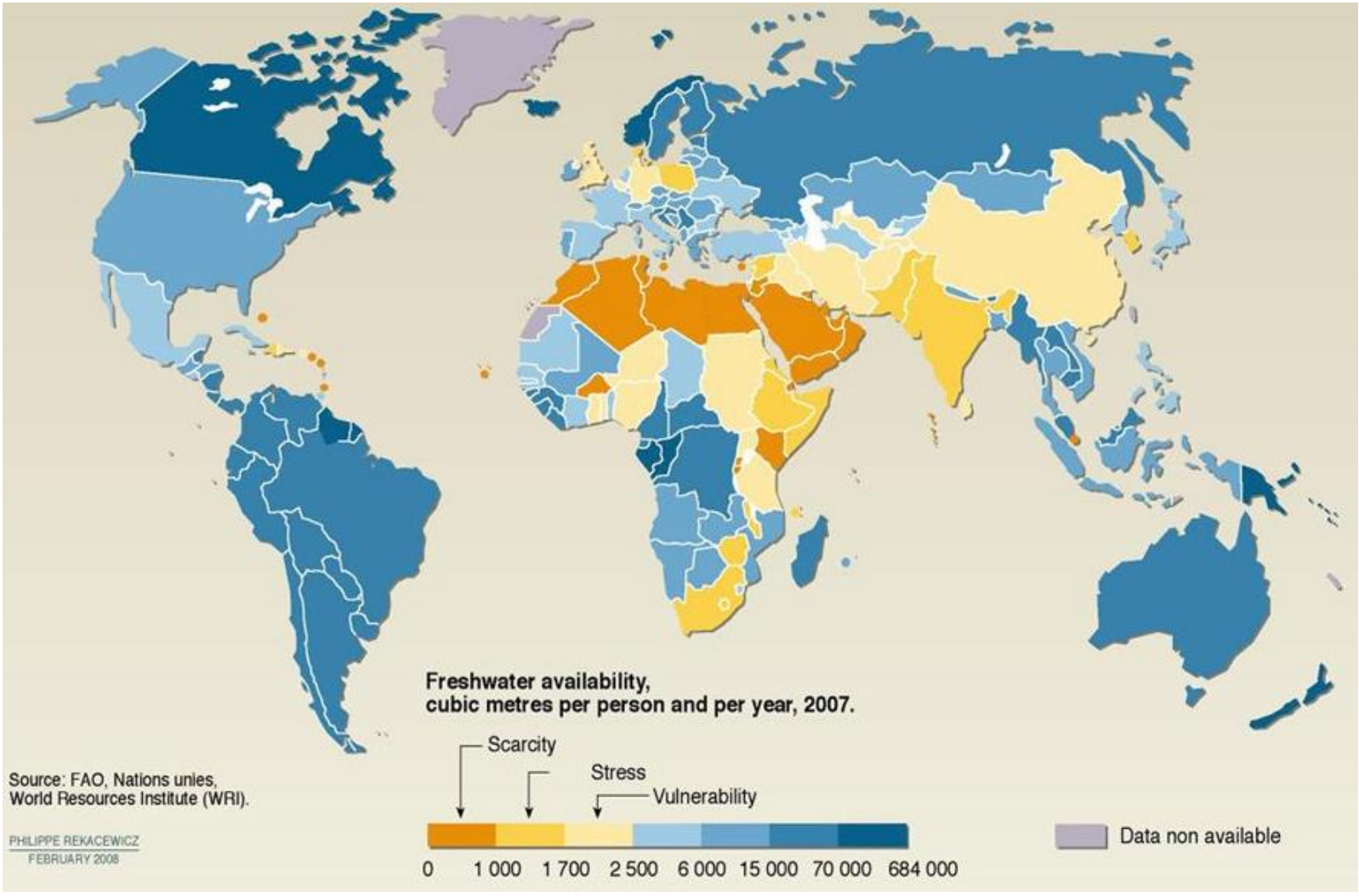
WORLDWIDE WATER CRISIS

- 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

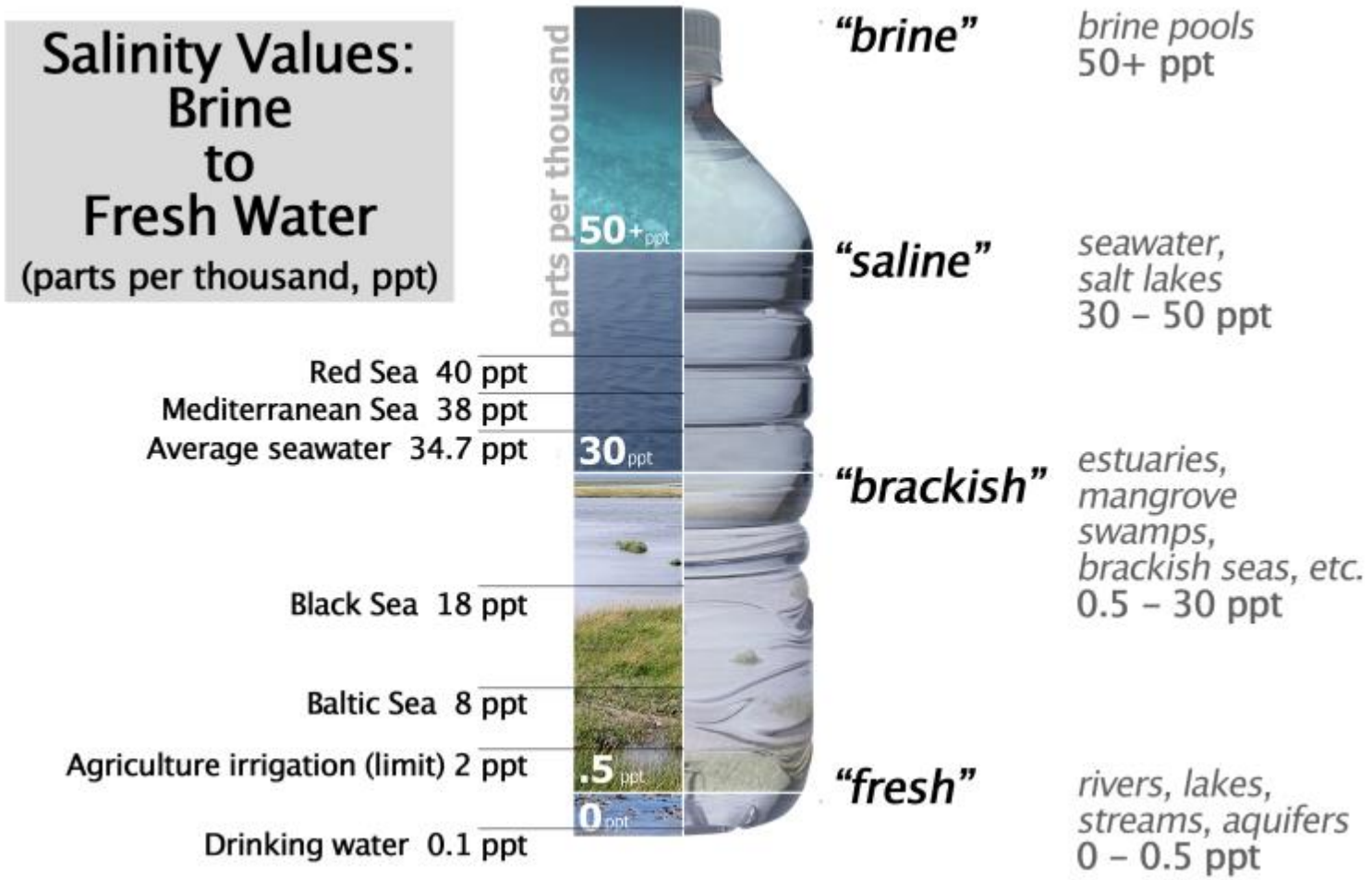


ADDRESSING THE PROBLEM AND FINDING A SOLUTION: DESALINATION

- 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



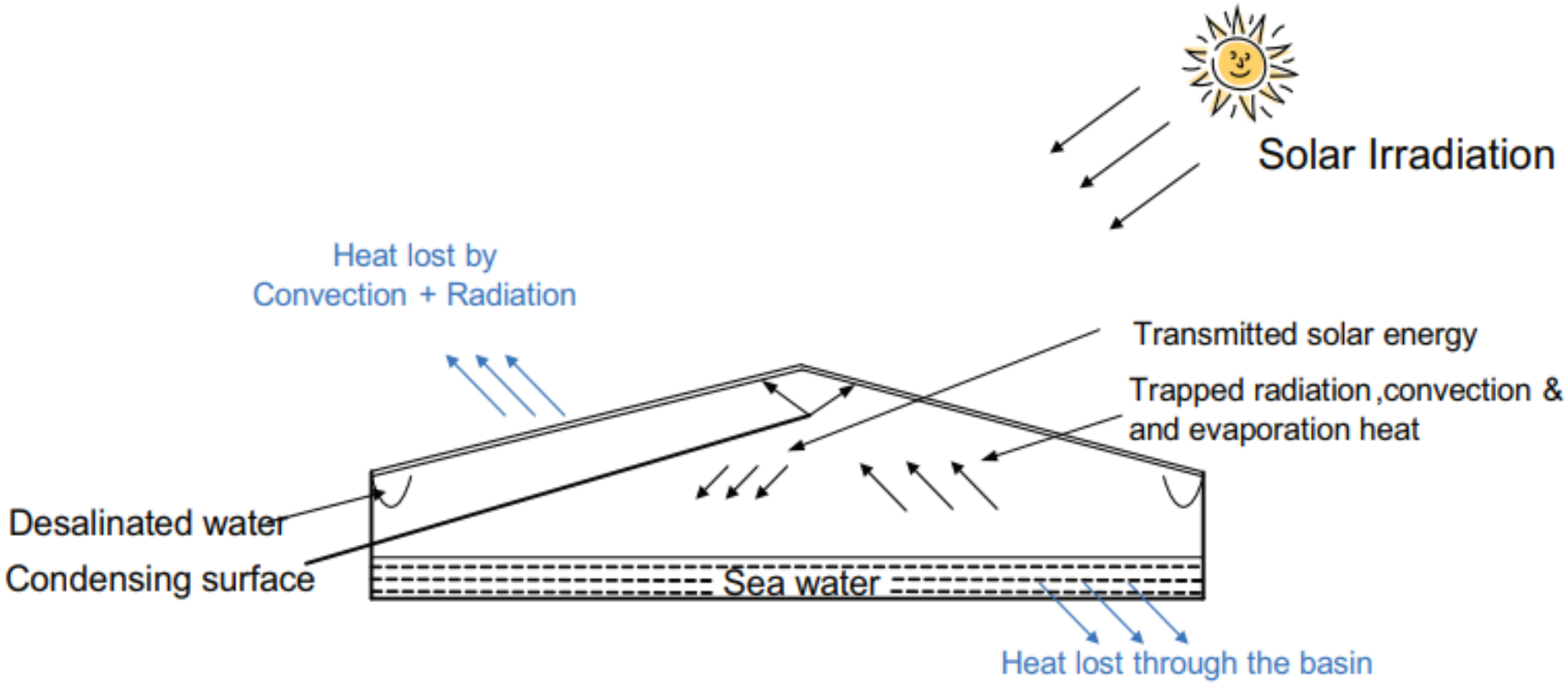
STATUS OF DESALINATION

- 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:

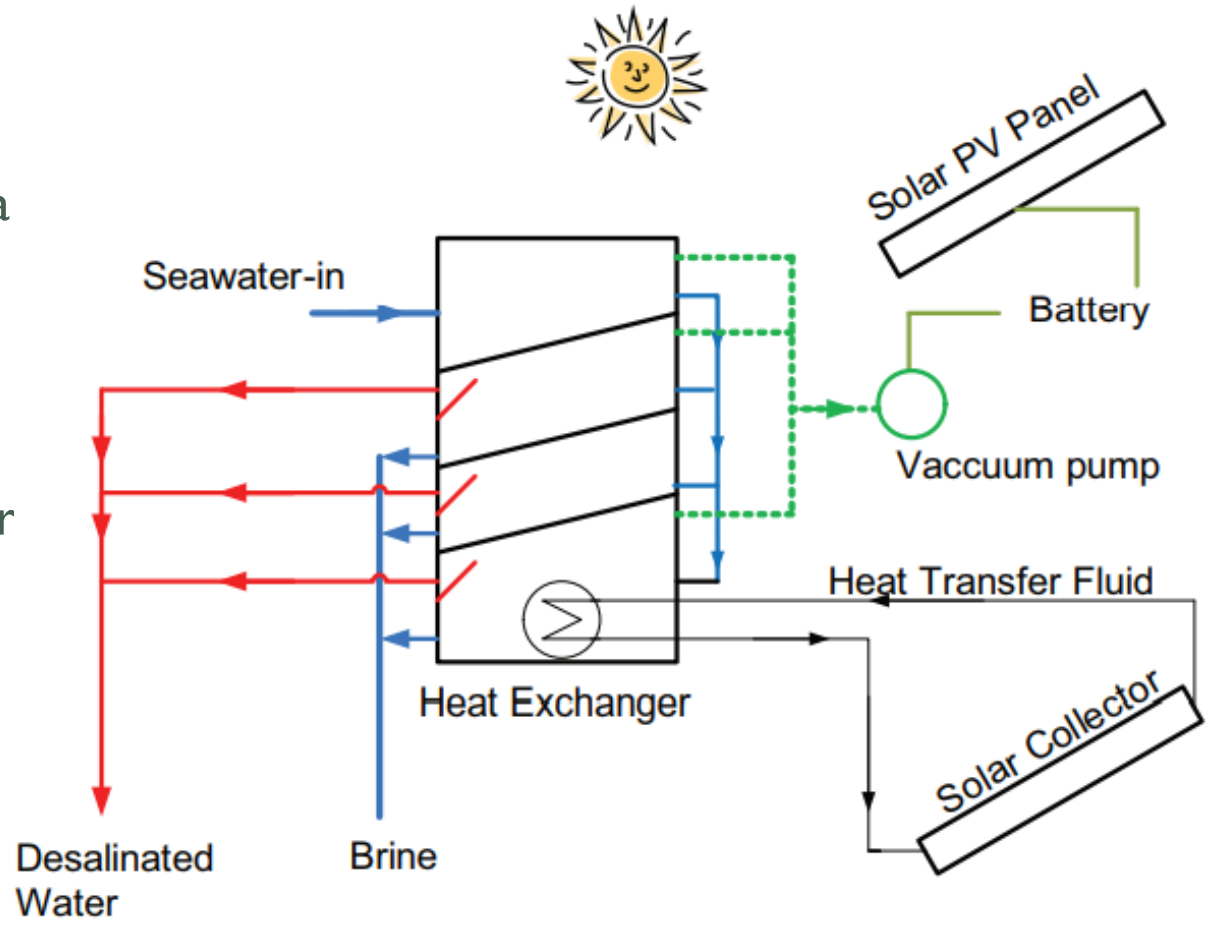
- Low Cost
- Easy to build
- No additional chemicals needed to treat water

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

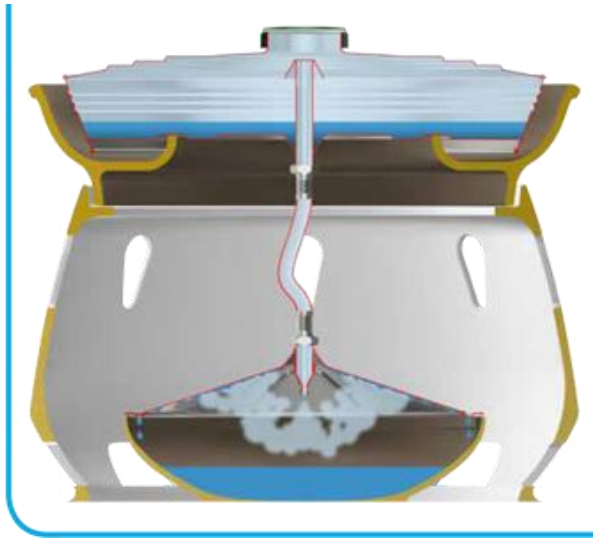
- Active or passive solar still
- Geometry: single slope, double slope, vertical, conica etc.
- Cover: glass or other transparent materials, with different glosses
- Additives: brine or another substance to aid in water absorption
- Spout run-off: Putting solar still output through a variety of run-off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



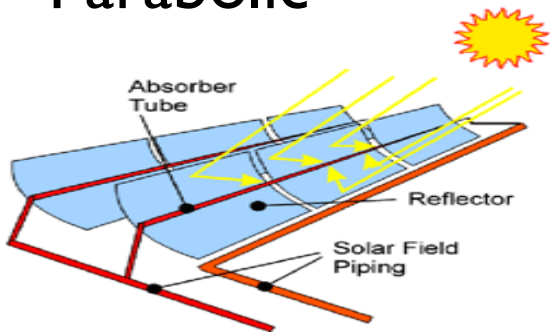
- Ceramic pot that utilizes basic concept of boiling
- Sun heats black boiler on top, turning it into steam which is forced down an expansion nozzle where it condenses against the lid
- Yields 5 L/day
- Estimated cost $50

SOLAR CONCENTRATOR

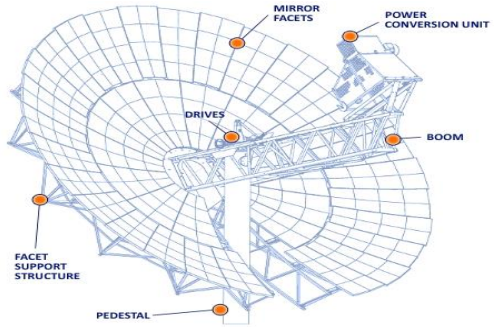
- Depending on the need, 3 types of concentrators exist (least efficient to most efficient): flat (stationary), parabolic (tracking), and dish (tracking)
- Desalination application: (1) the concentrated solar energy can either directly heat the water to temperatures adequate enough to remove impurities,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

Flat

Parabolic



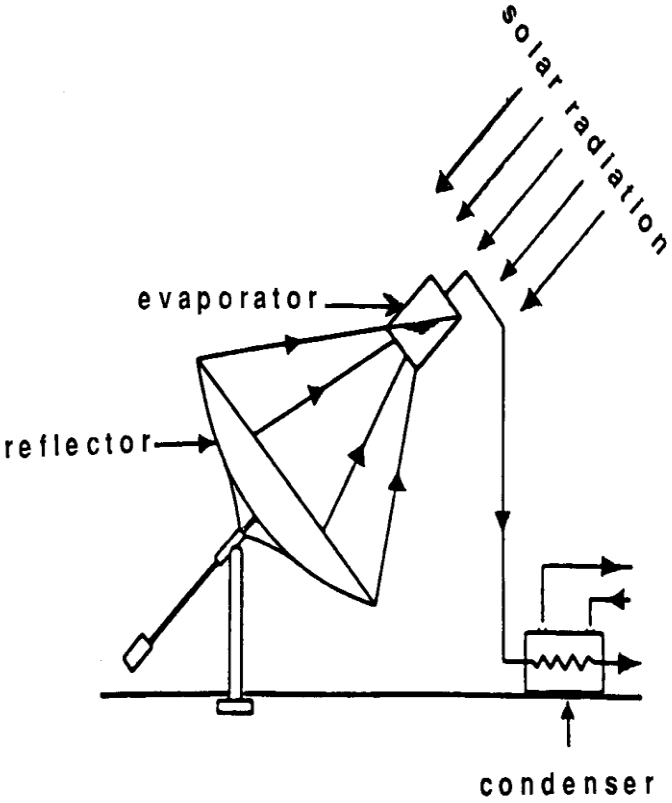
Dish



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

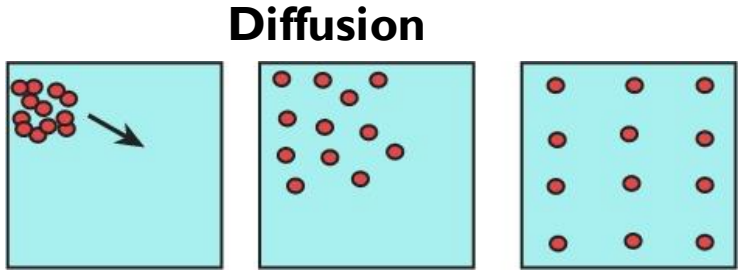
LARGE SCALE SOLAR DESALINATION METHODS

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

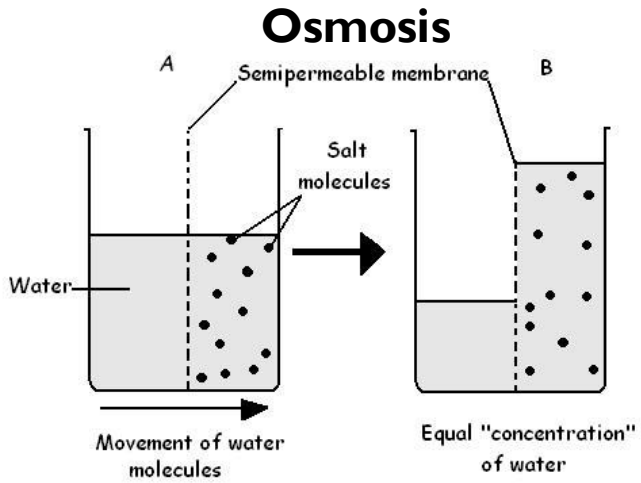
- Membrane:
  - Reverse Osmosis (RO) (~ 60% of global desalination capacity)
  - Electro-dialysis (ED)
- Thermal:
  - Multi-Effect Distillation (MED)
  - Multi-Stage Flash (MSF) (~26.8% of global capacity)

REVIEW OF MEMBRANE METHODS: REVERSE OSMOSIS (RO)

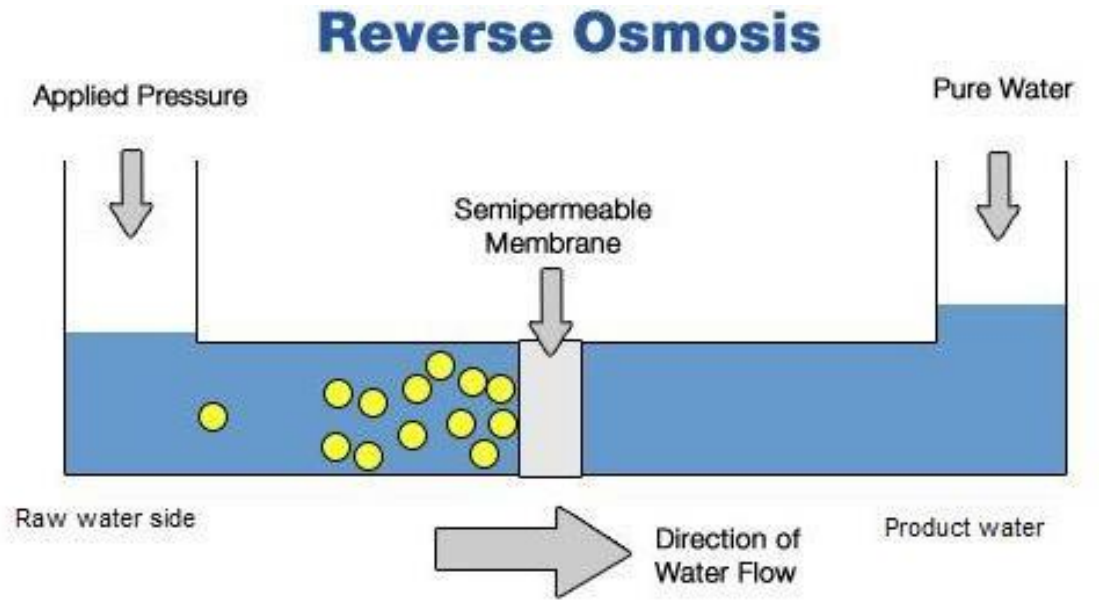
- Osmosis – a type of diffusion
- Two solutions with different concentrations are separated by a semi-permeable membrane
- Solvent from low concentration side moves to high concentration side through the membrane.
- Osmotic pressure when equilibrium is achieved

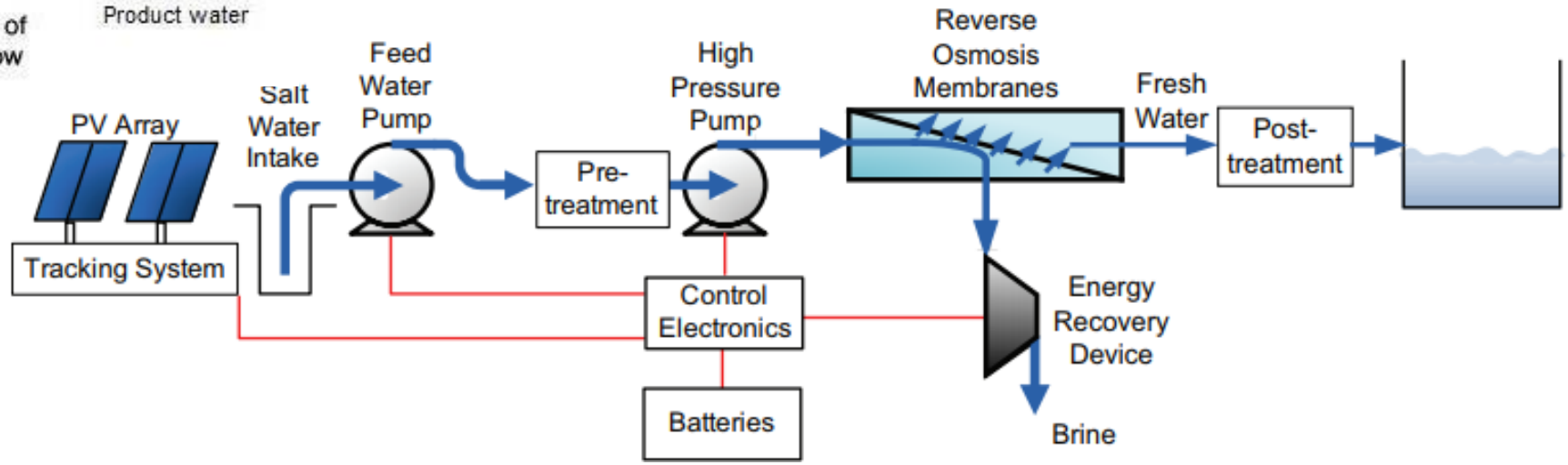


Process of diffusion over time

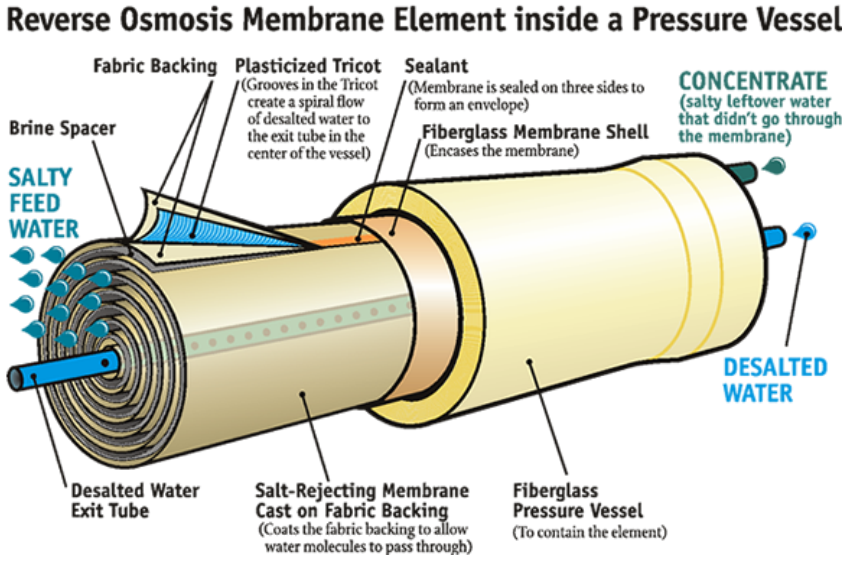


SOLAR POWERED RO PROCESS EXPLAINED



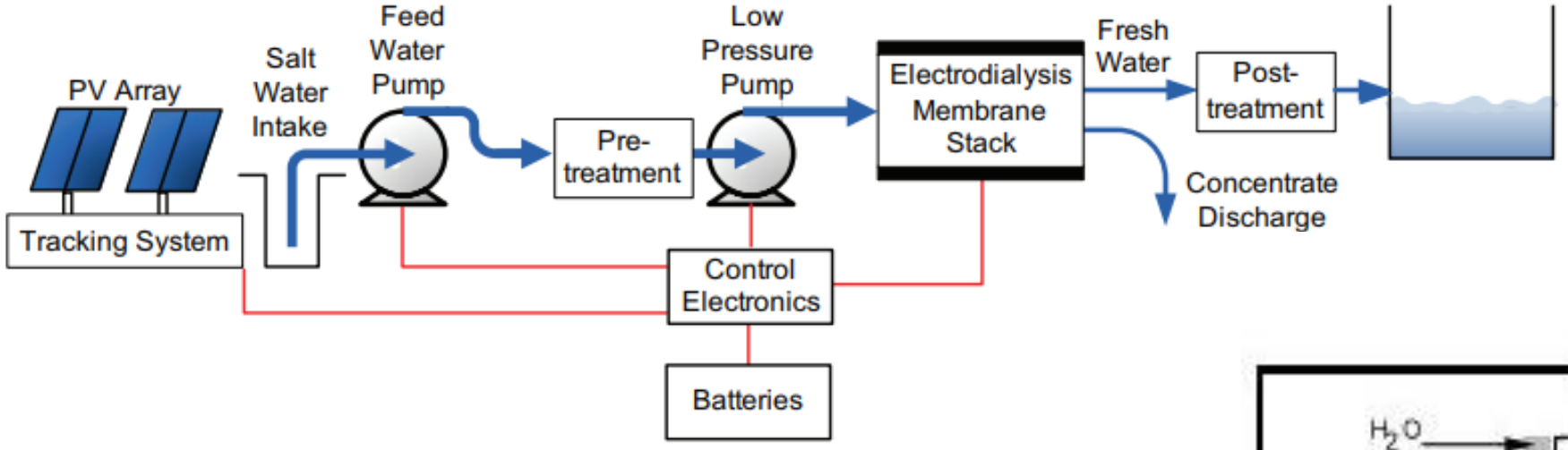


REVERSE OSMOSIS – KEY FEATURES

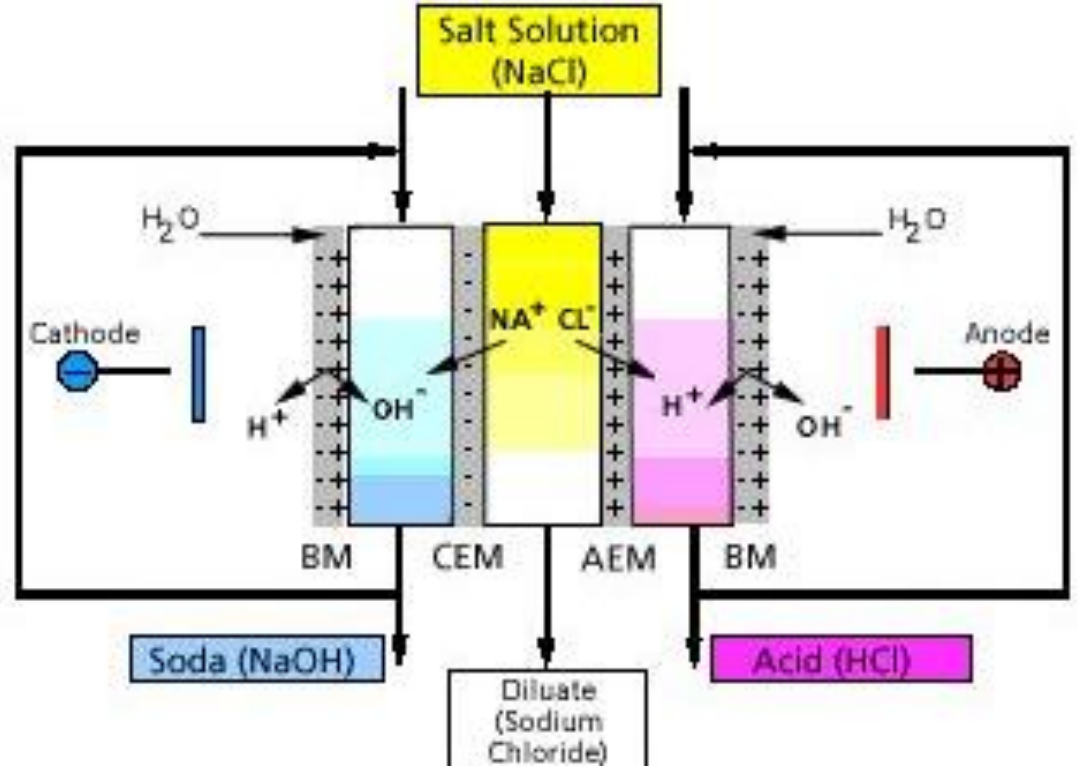


- Most common method
- Easy to use, even for small scale applications
- Produces 55-65 liters of fresh water for 100 liters of seawater through multiple stages
- Low Energy Consumption 3.5-5.0 kWh of electricity / m3
- Use of ultrafiltration membranes and renewable energy is making this technology more 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)

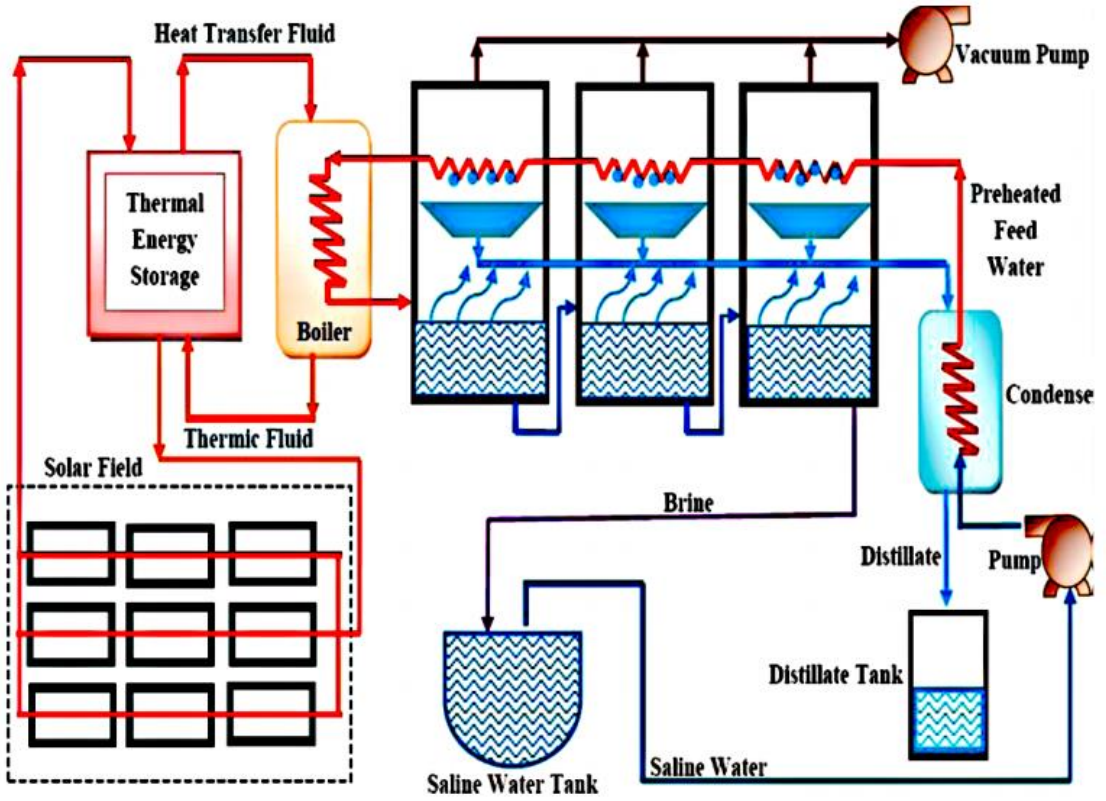


- A series of ionic and anionic membranes are lined up between two electrodes and a low DC voltage is applied causing the ions in the brackish water to migrate to the electrodes.



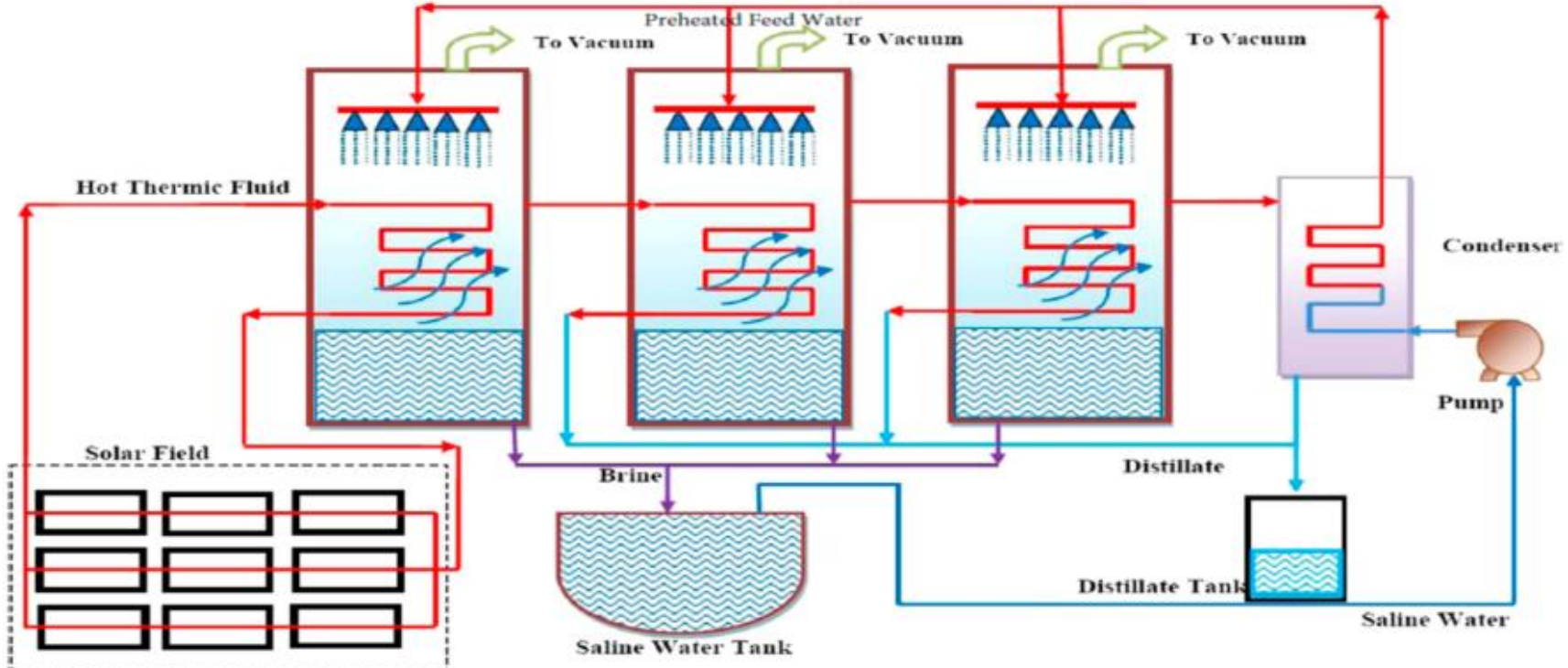
REVIEW OF THERMAL METHODS: MULTI STAGE FLASH (MSF)

- 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



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

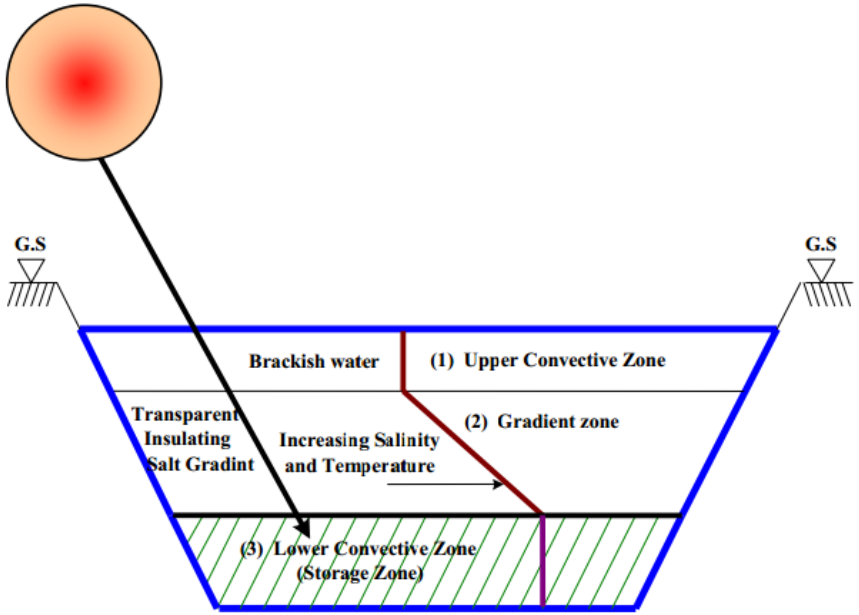
	Technical Capacity	Energy Demand (kWh/m^3)	Water Cost (USD/m^3)	Development Stage
Solar stills	< 0.1m^3/d	Solar passive	1.3–6.5	Application
Solar-Multiple Effect Humidification	1–100 m^3/d	thermal: 100 electrical: 1.5	2.6–6.5	R&D Application
Solar- Membrane Distillation	0.15–10 m^3/d	thermal: 150–200	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



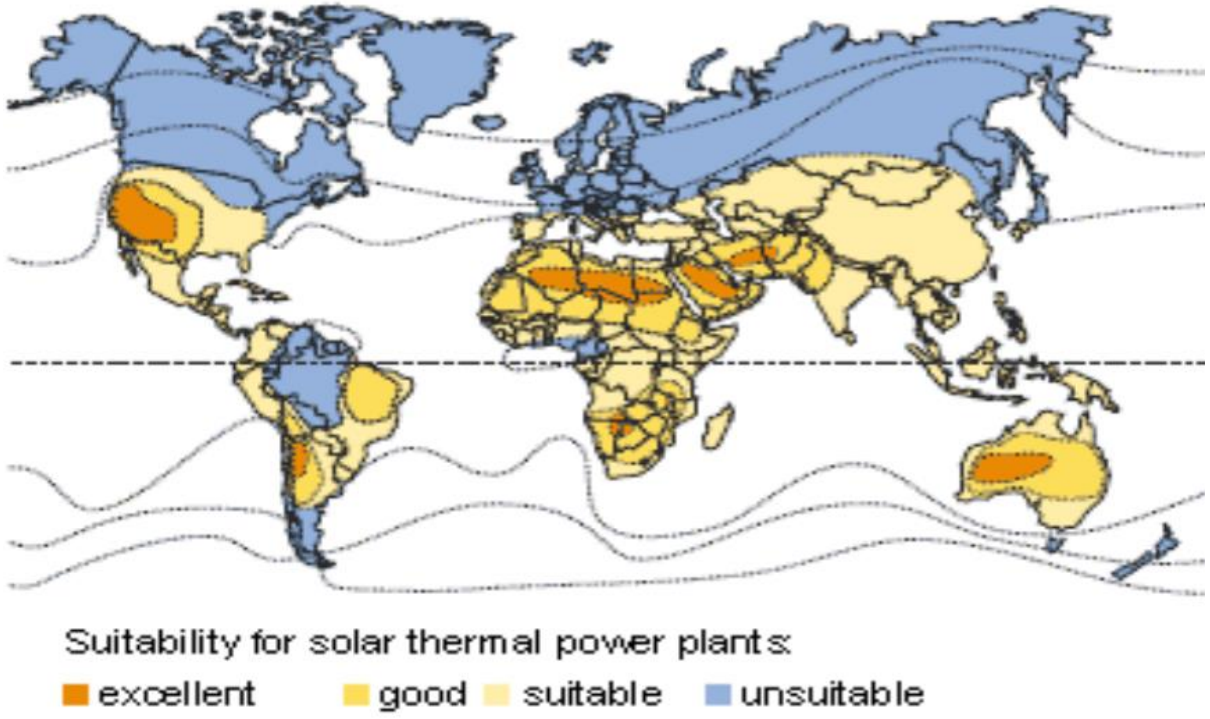
Solar Pond

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



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