New and Emerging Technologies for Water Desalination

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Water Desalination and Reuse Center

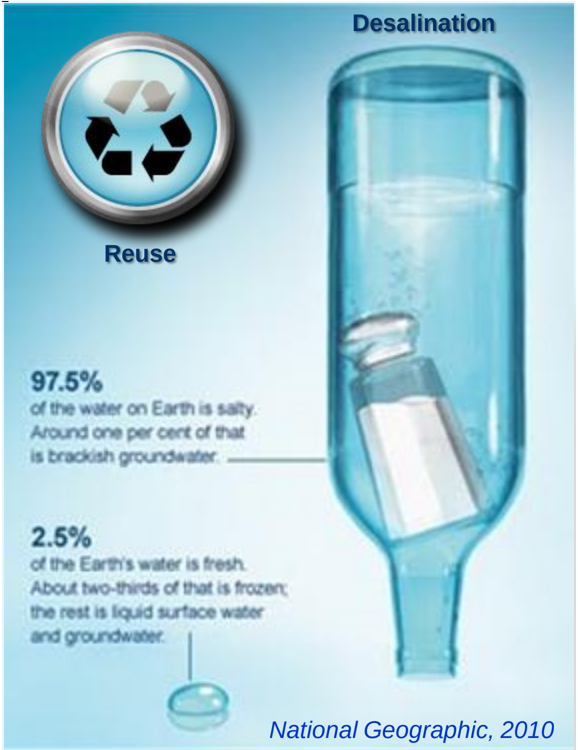
King Abdullah University of Science & Technology

Water Desalination and Reuse Center (WDRC) at KAUST




WDRC Mission

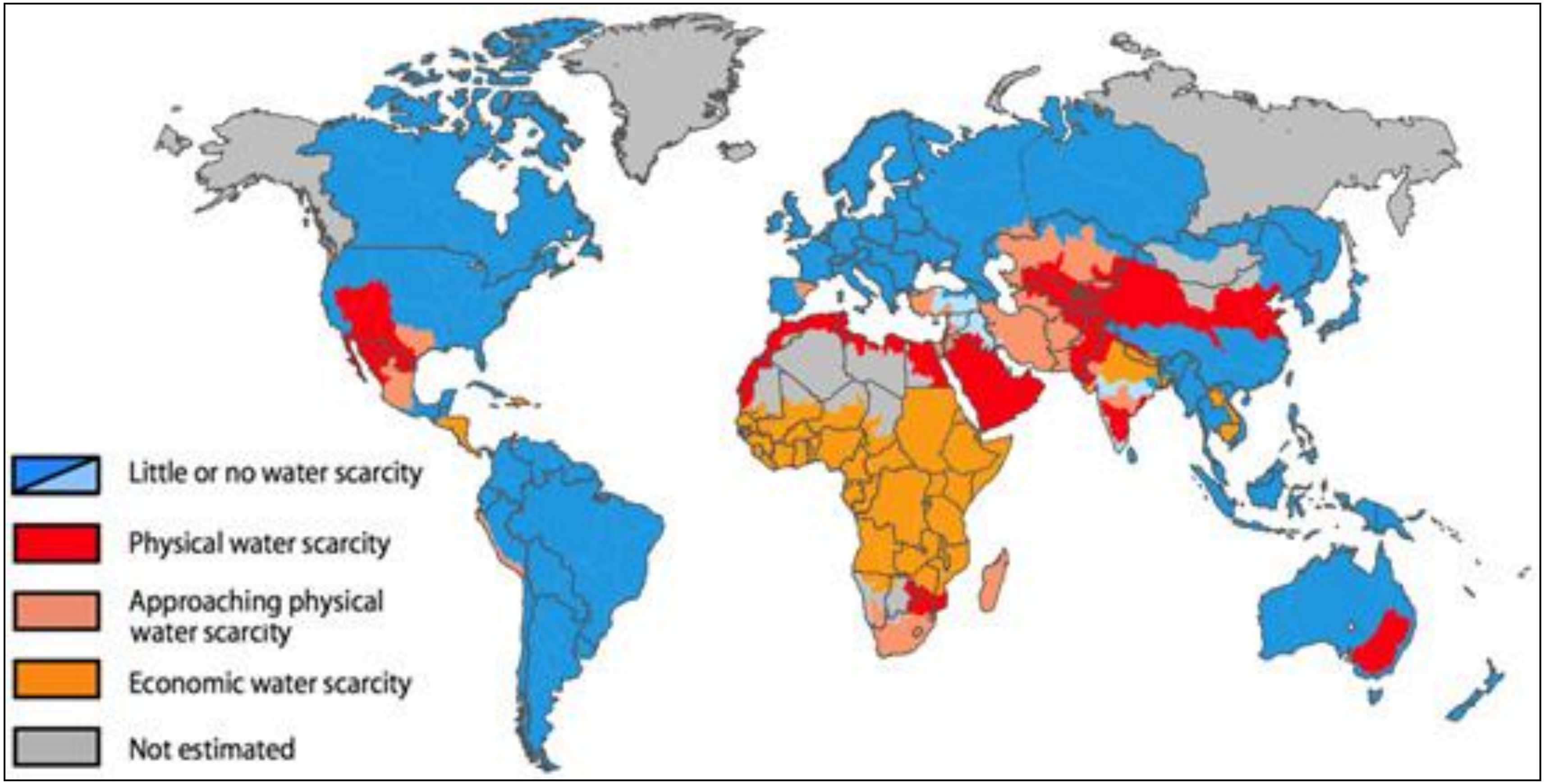
- **Sustainable exploitation:** Increase sustainable exploitation of impaired water quality sources, such as *seawater, brackish water, wastewater (effluent) and urban runoff* – as water resources
- **Greener Desalination**: Development of greener desalination technologies – lower energy use (and lower cost), Lower GHG emission, lower chemical utilization, lower wastes
- **Technology development** for the KSA, GCC/ MENA, and other water-scarce global regions
    - Optimization of existing technologies, development of robust, multi-contaminant technologies and commercialization of new technologies



National Geographic, 2010

- Thrust KAUST and the KSA to **the global forefront** of water desalination/wastewater reuse technology research, development, adaptation, and dissemination

Water Scarce Region



- The MENA/GCC is one of the driest with water scarcity region of the World
- Low rainfall, high evaporation rate, little natural recharge, excessive population growth– are causing water scarcity for the region

Annual Water Consumption - KSA

2009

6%

Less Energy Intensive
Desalination

14%

Renewable water:
2.7 x 10^9 m^3/yr.
(i.e., groundwater/surface water)

80%

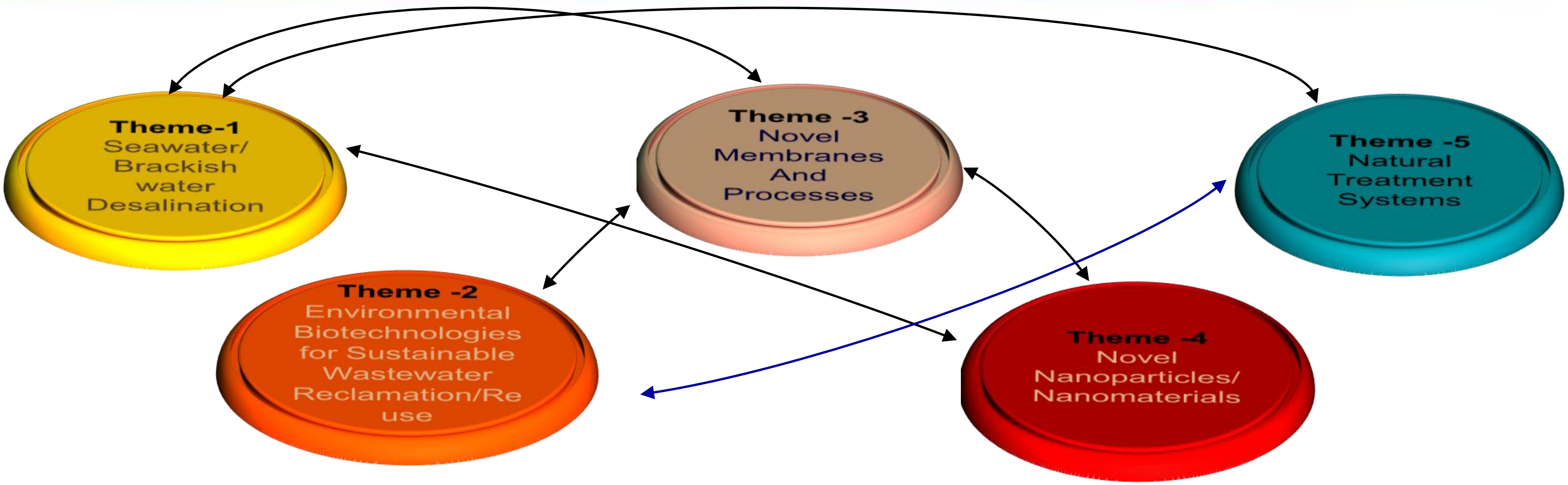
Preserve **Non-Renewable**
resources for future generation by promoting water Reuse

Total Water Annual Consumption: 19.2 x10^9 m^3/yr

(Al-Saud, 2010)

Current practice is not sustainable, require better management/technologies

WDRC Strategic Research Agenda



Theme-1

- SWRO pretreatment
- Environmental impact (intake/outfalls)
- Integrated Membrane System (IMS)
- Thermal desalination
- **Adsorption Desalination**
- **Microbial desalination cells (MDCs)**
- Partial seawater desalination for aquaculture/agriculture

Theme-2

- Hybrid biotechnologies for water reuse (hybrid MBRs)
- Biotechnologies for sustainable wastewater treatment and desalination (MFC & MDC)
- Biofouling in membrane systems

Theme-3

- Ceramic membranes
- Inorganic-organic composites
- **Forward osmosis (FO)**
- **Membrane distillation (MD)**
- **Membrane hybrids**

Theme-4

- **Adsorbents**
- **Catalysts**
- Contaminant Sensors
- Membrane modifications
- Material-Based Disinfectants

Theme-5

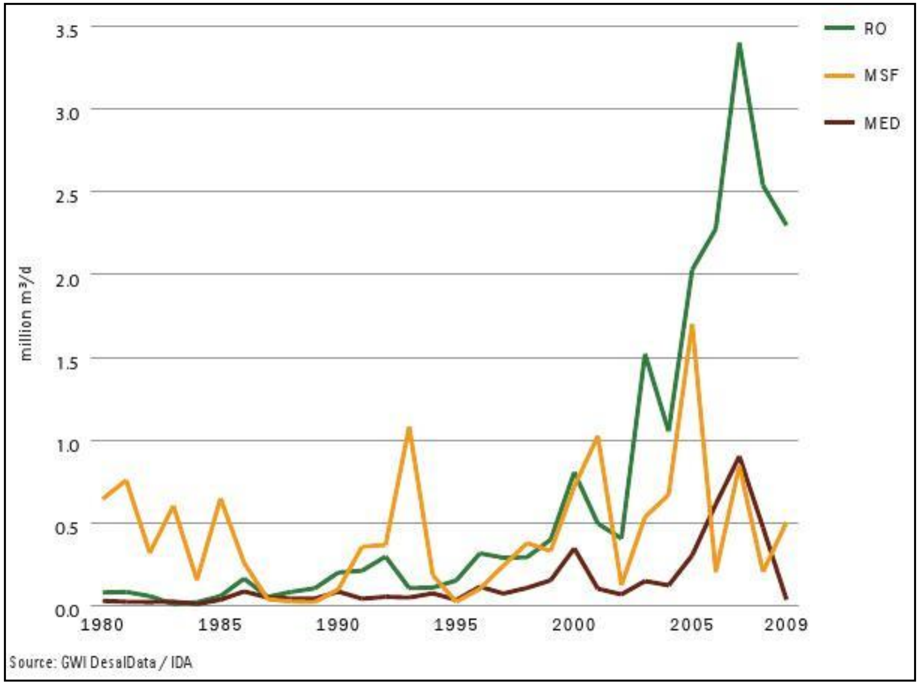
- Aquifer recharge and recovery (ARR)
- Subsurface intakes (beach wells)
- Oxidation hybrids
- Membrane hybrids
- Arid-land constructed wetlands (CW)
- CW-ARR hybrids

35 Research projects underway; 25 more planned

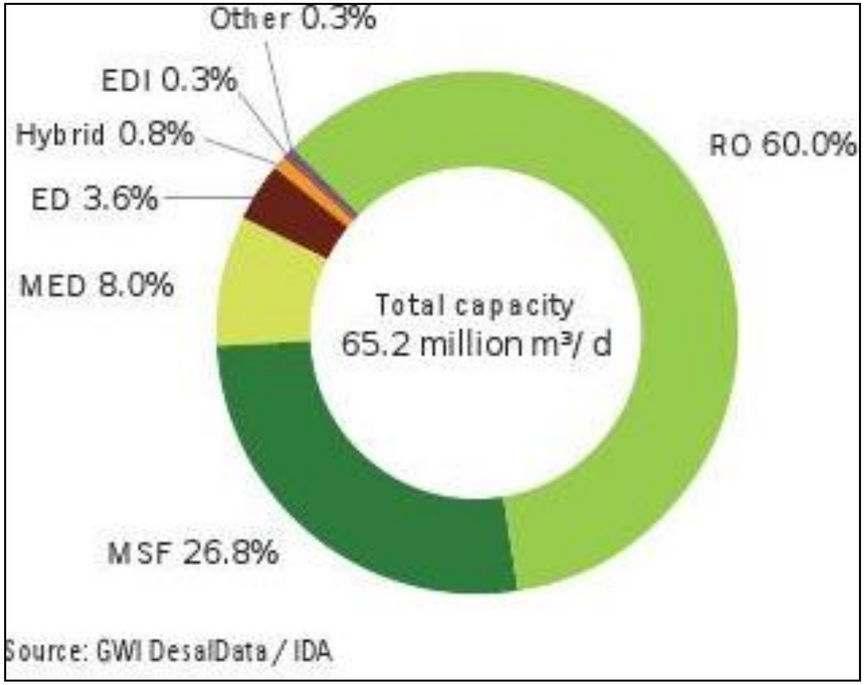
Desalination Trends: Technologies, Energy, Costs

Historical Water Desalination Trends

Annual new contracted seawater desalination capacity by technology, 1980 - 2009



Total worldwide installed capacity by technology



- Membrane based desalination is growing rapidly to thermal based desalination
- Thermal based desalination still growing, but at slower pace, especially in the Arabian Gulf regions (*with highest level of salinity)*

Trends in Desalination Water Costs

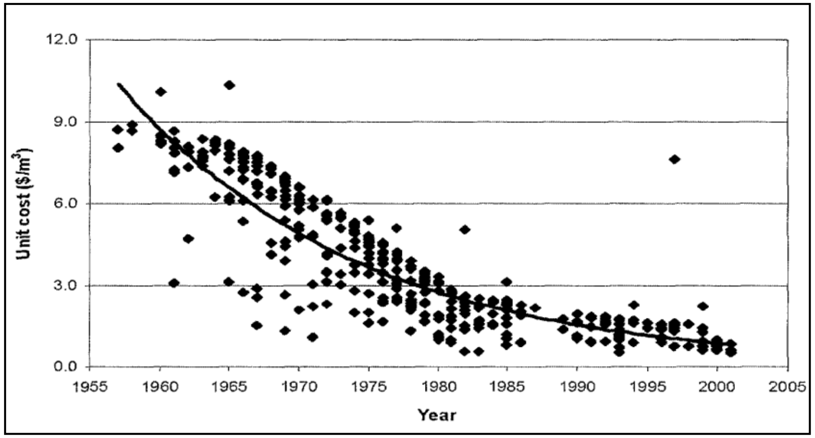
Trends in Thermal Costs

- Thermal cost is reducing
- Due to technological maturity and various developments as well as transparency and competition

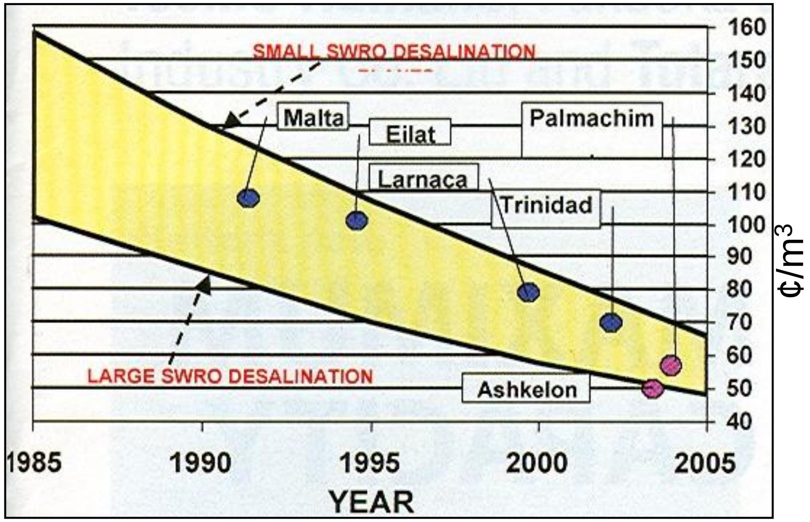
Trends in RO Costs

- RO Costs has declined significantly
- Costs reduced to a level to compete with traditional/ conventional water treatment option

Thermal (MSF) Costs Trends



RO Costs Trends



(Source: Ghaffour, 2011)

Total Energy Requirements of Desalination

Process	Total Energy (kW-h/m3)	Capital Cost ($/m3/d)	Unit Water ($/m3)
MSF (without waste heat)	55-57	-	-
MSF (with waste heat)	**10 - 16**	1000 - 1500	0.8 -1.0
MED (without waste heat)	40-43	-	-
MED (with waste heat)	**6 - 9**	900 - 1200	0.6 – 0.8
SWRO	3 - 6	800 - 1000	0.5 – 0.8
SWRO (with energy Recovery)	**2 - 3**	< 800	0.45 – 0.6
BWRO	**0.5 – 2.5**	< 800	0.1 – 0.3
Innovative Technology/Hybridization	**< 2.0 ***	< 800	<0.5

** Thermodynamically minimum energy requirement for desalination 0.75 kWh/m3; <2.0 kWh/m3 attained by improving efficiency/hybridization*

(Source: Ghaffour and Ng, 2011)

Energy Requirements

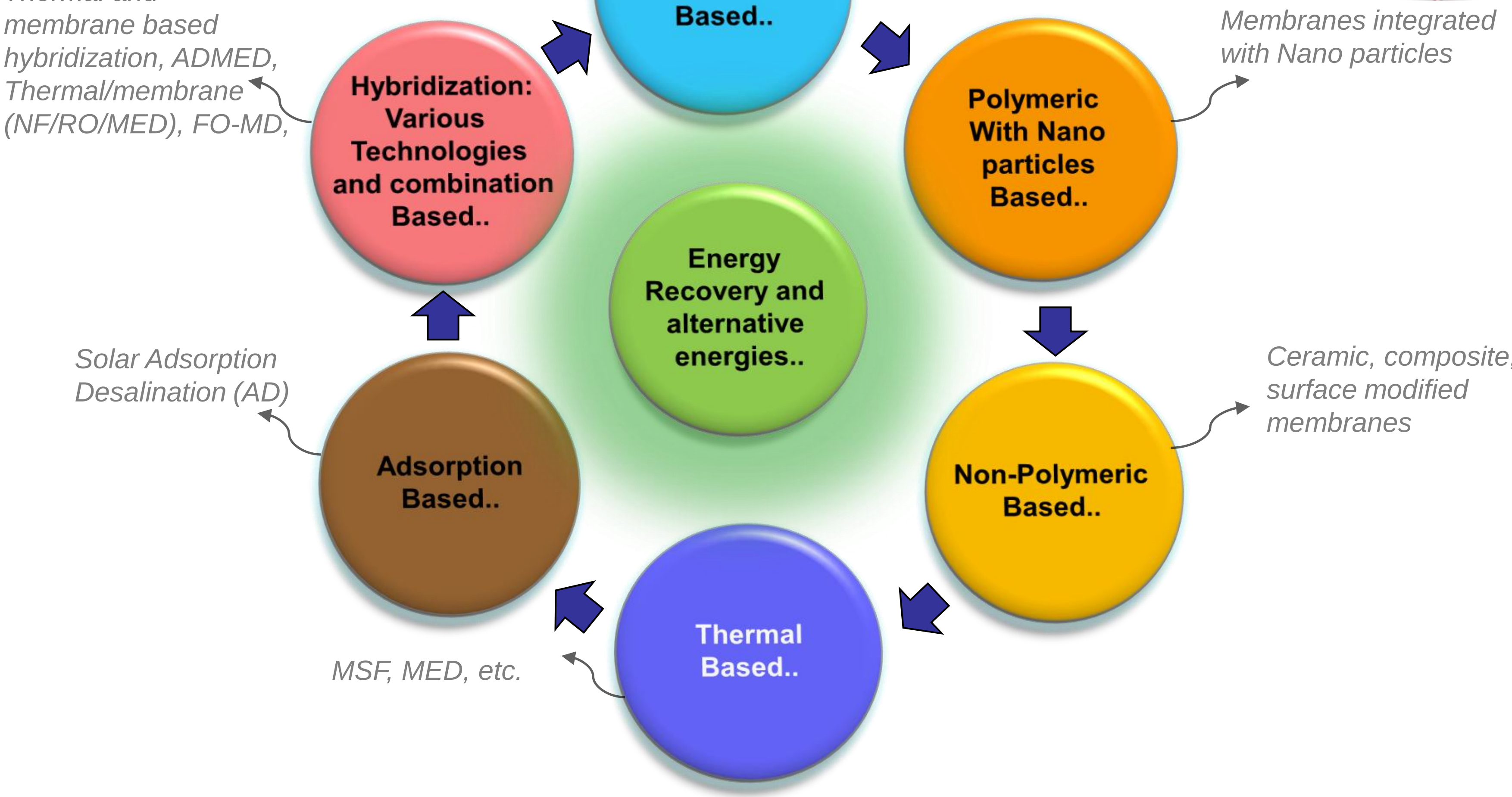
- Minimize energy requirements by using waste heat and/or energy recovery
- Thermal desalination energy reduction by co-location with power plant

Thermal > SWRO > Innovative processes

New and Emerging Technologies for Water Desalination

Technologies

Seawater Desalination..



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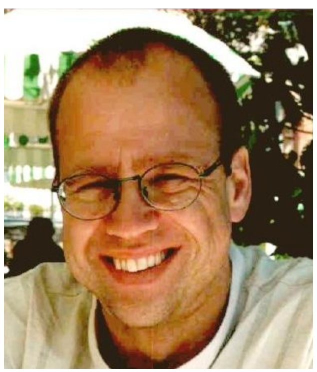

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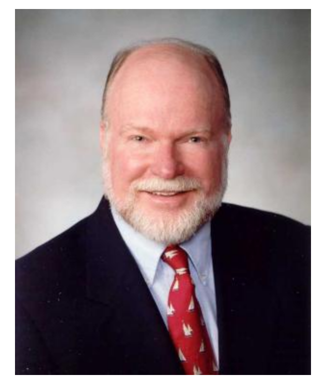

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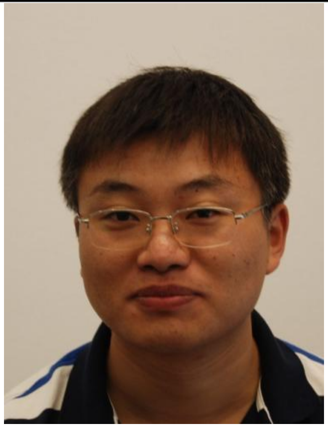

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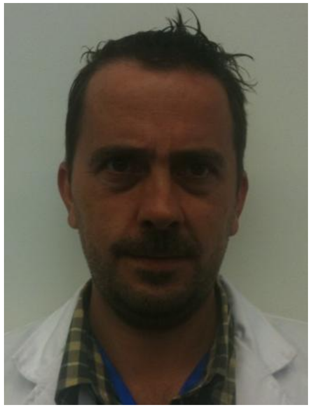

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Research Scientist
(Core Lab Liaison)

Dr. Harvey Winters
Principal Research Scientist
(Memb. Desalination Technologies)

New Membrane Based Desalination Approaches

Concept of Forward Osmosis

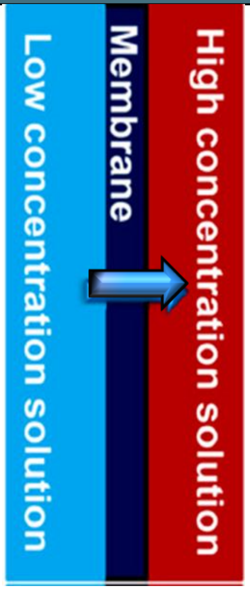
Osmosis (Forward Osmosis)

- Natural process, movement of water through a semipermeable membrane from low concentration (dilute) to more concentrated side (with more dissolved ions)
- Pressure exerted on the membrane due to flow of water is the *osmotic pressure*
- Osmosis equalizes the strength of solution on both sides of the membrane

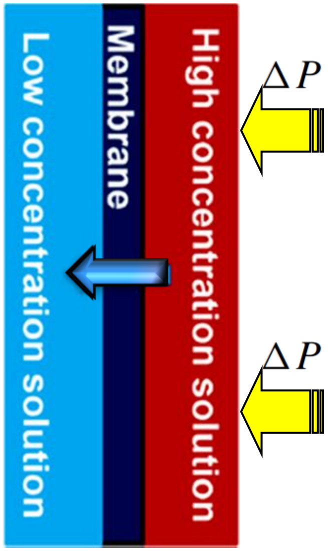
Reverse Osmosis

- In Reverse Osmosis (RO), pressure is applied (greater than *osmotic pressure*) on the high concentrated solution side, to produce and recover fresh water from concentrated water

FO



RO

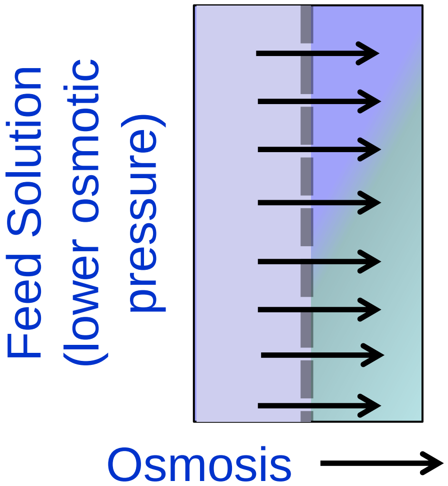


Forward Osmosis (FO)

Prof. Amy

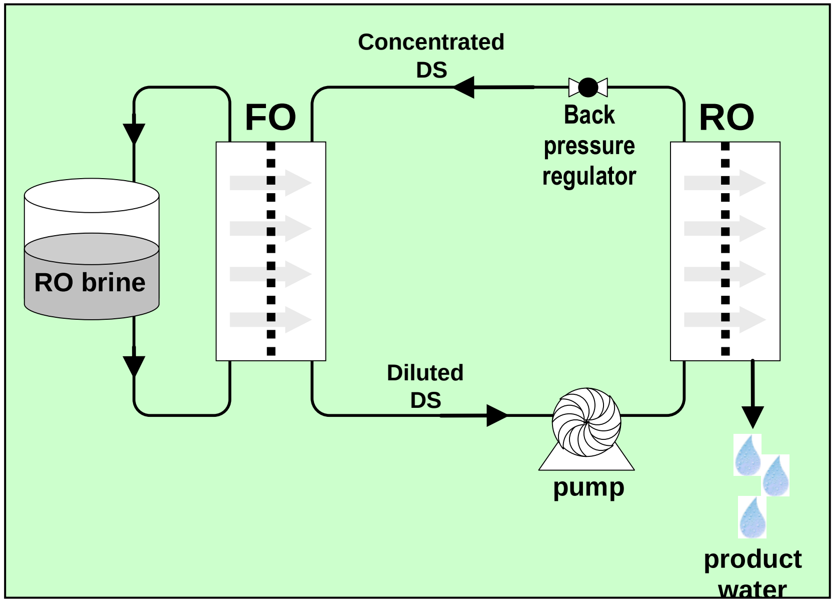
Forward Osmosis (FO)

- RO-like membrane, but osmosis- is not pressure-driven
- Low energy, low energy alternative to SWRO (energy saving)
- Feed: RO conc. or WW
- Draw: Conc. DS or Seawater



Research Needs

- New/better FO Membranes (Open support layer; thickness and porosity)
- Minimize fouling/biofouling
- Novel draw solutions (seawater vs. synthetic solutions)

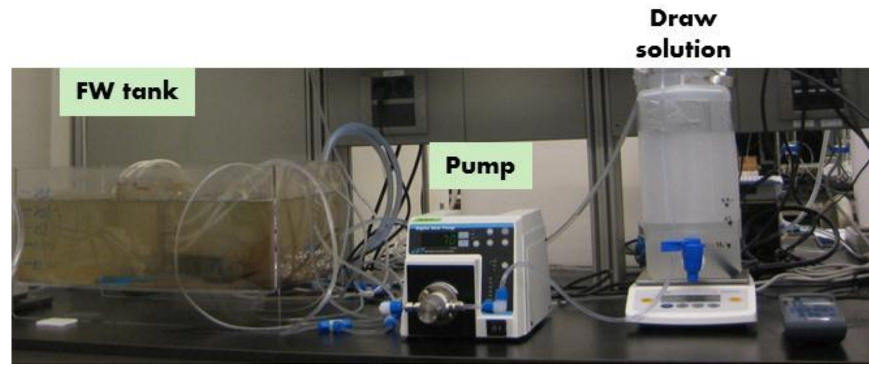


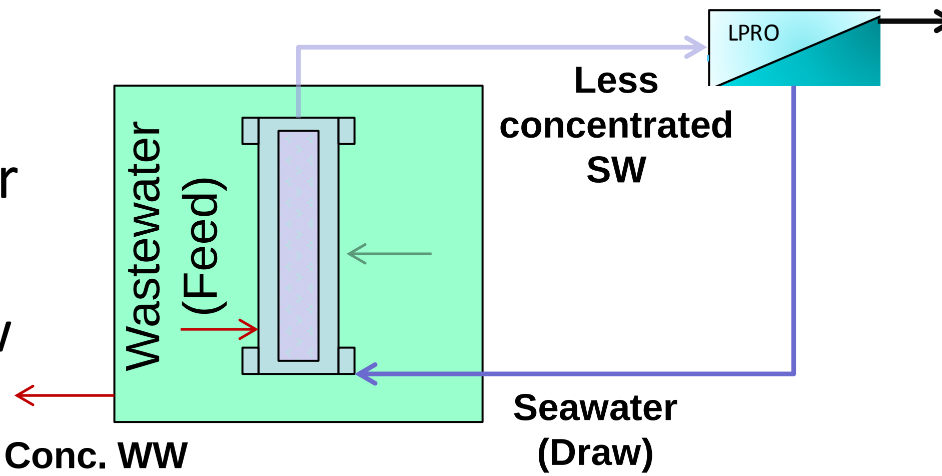
Application of FO

Prof. Amy

Applications

- Coastal cities can recover water from wastewater seawater as draw solution
- Osmosis will dilute the SW with FO by taking water from WW source
- FO could be demonstrated as low energy alternative for water reclamation
- It could be coupled with low pressure membrane to MBR-MF/UF-RO

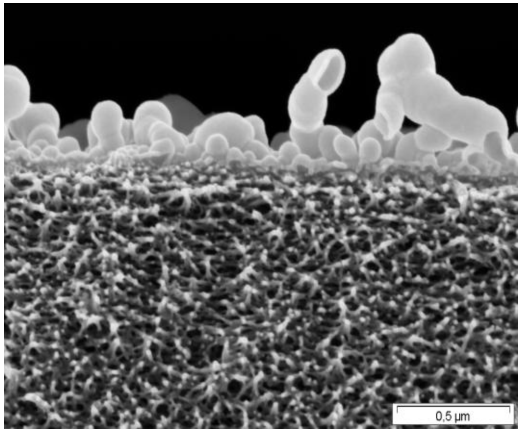




Forward Osmosis (FO) - Status

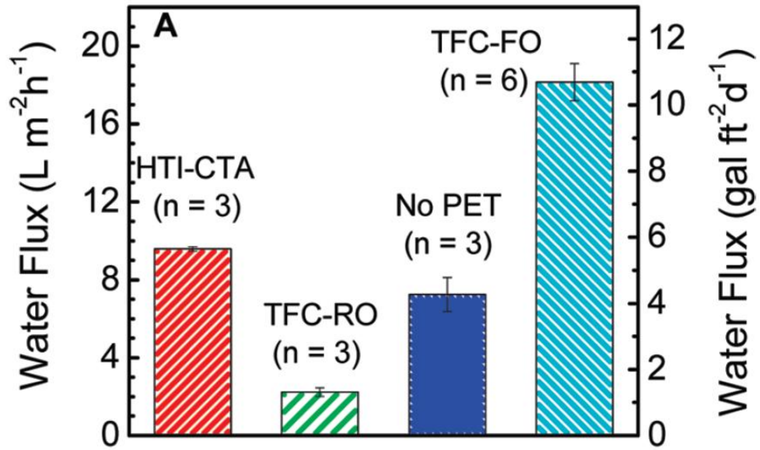
Profs. Nunes and Amy

- **Membrane Type:** Adequate membrane for FO process are under development
- **Needed:** Semipermeable membranes that are selective but with higher flux than RO
- **Under development:** Thin-film composite membranes by interfacial polymerization



Thin-film composite membrane interfacial polymerisation

- **New Membrane**
  - Development of high performance thin-film composite (TFC) membrane for FO application
  - Polyamide active layer on top of polysulfone support layer
  - Finger like morphologies

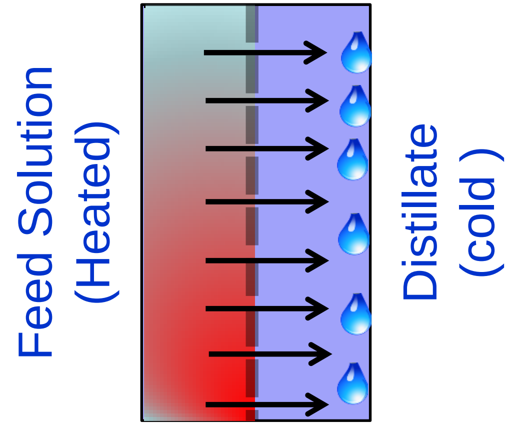


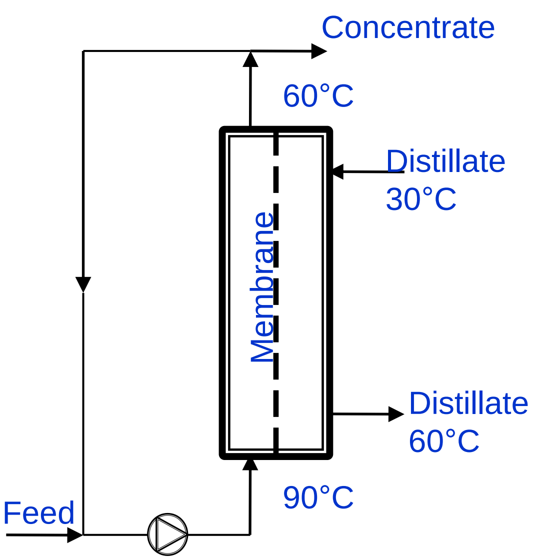
[Source: Peinemann, Nunes, 2008; Elimelch and Yip, 2010 (bottom)]

Concept of Membrane Distillation (MD)

Membrane Distillation (MD)

- In MD process water is heated/evaporated and allowing only the water vapor to pass through a hydrophobic membrane and to condense into liquid on other side of the membrane
- It is not necessary to heat the water above boiling temperature, feed temperature ranges from 60-90°C
- The temperature/vapor difference across the membrane provides driving force, that causes diffusion of vapor through the membrane pores, producing distillate



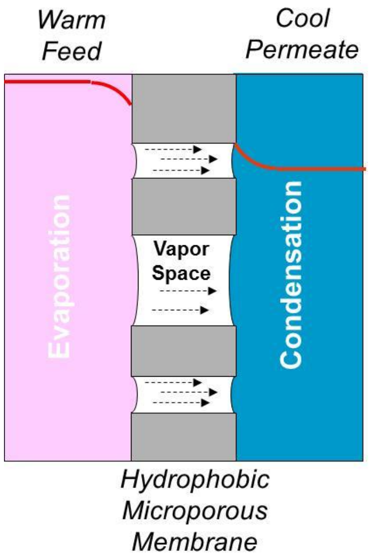


Application of MD and Status

Dr. Ghaffour, Prof. Nunes

Membrane Distillation (MD)

- Seawater desalination, by heating seawater on one side of the membrane to create water vapor; vapor crosses the membrane and is condensed to pure water
- Hydrophobic membrane + evap. process
- Can be coupled with solar or waste-heat
- MD for extreme salinity (e.g.. Gulf): No or Little Effect on Flux



Research Needs

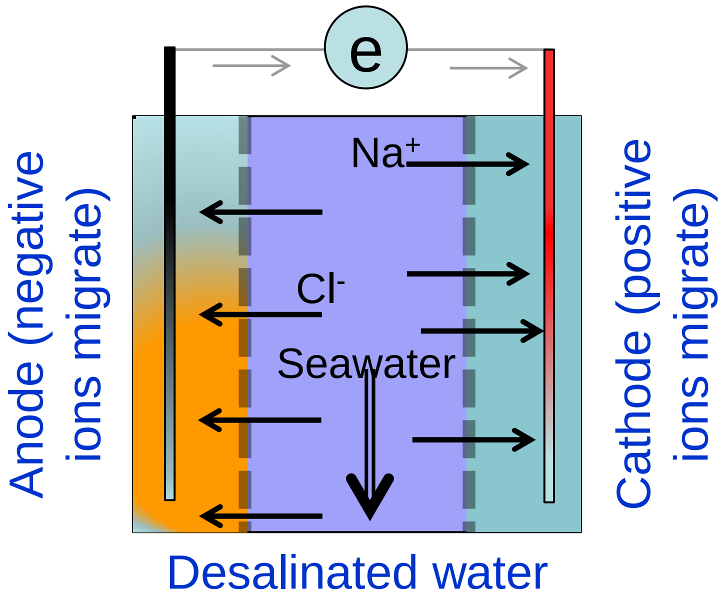
- Improved MD membranes, increased flux
- MD membrane under development
- Porous membrane type with very highly hydrophobicity (e.g., fluorinated polymers)

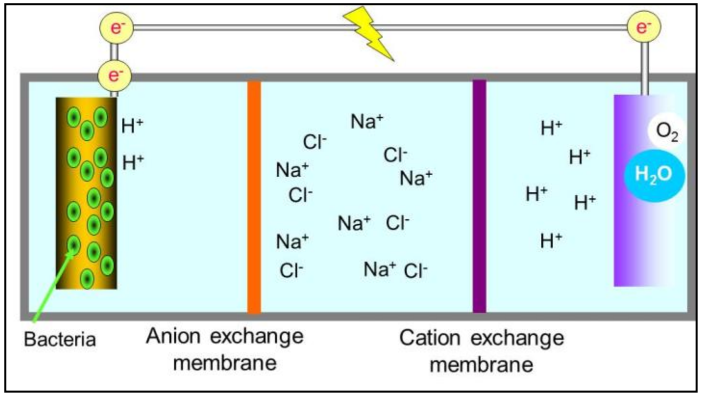
(Source: Noreddine 2011, Tzahi Y. Cath 2008)

Concept of Microbial Distillation Cell (MDC)

Microbial Distillation Cell (MDC)

- Two Chambers, one with anode (oxygen starved /anaerobic) and cathode (oxygen rich/aerobic) and third chamber with seawater
- Wastewater introduced to anaerobic chamber, oxidized and releases electrons
- Third chamber in between separated by ion-specific membrane, allows either positive and negative charges to pass though the membranes
- Electron migrates toward cathode in aerobic chamber and produces energy and desalination simultaneously



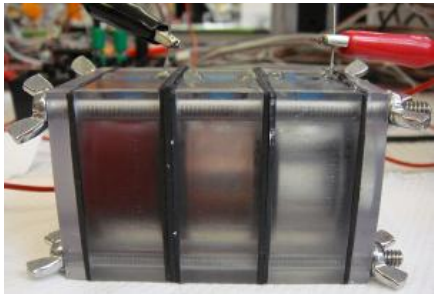


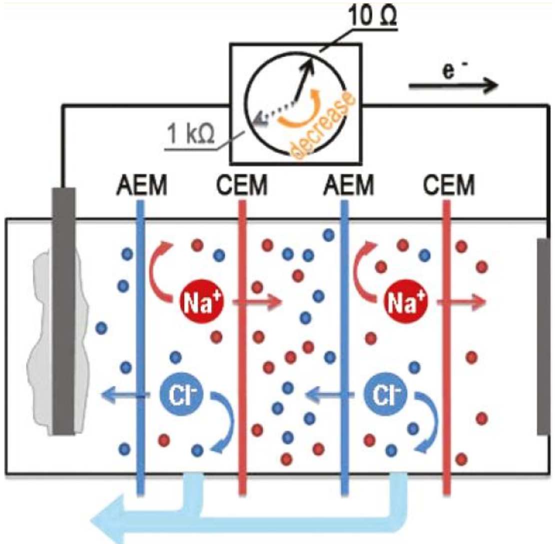
MDC- Status

Profs. Saikaly and Amy

Knowledge Gap

- Opportunity for low-energy desalination
- Batch-mode vs. continuous mode
- Possible fouling of membranes
- Presently limited 90% TDS reduction with a set of ion exchange membranes
- New, multiple stacks (Stacked MDC, SMDC) with ion exchange membranes, up to 98% reduction
- Use of wastewater vs. simple substrate
- MDC-RO Hybrids





Stacked MDC (SMDC)

(Source Logan, 2011)

Modified Membrane with Nanoparticles

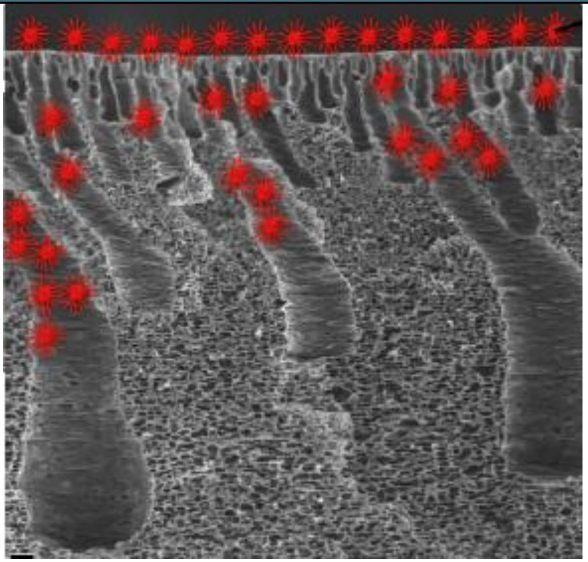
Profs. Nunes and Wang

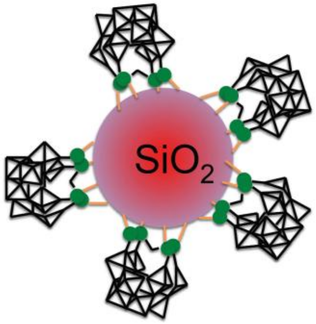
Modified membrane with Nanoparticles

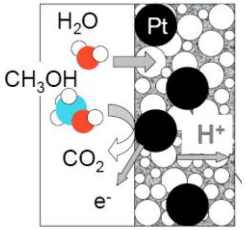
- Adsorbents
- Biocides (biofouling control)
- Catalysts

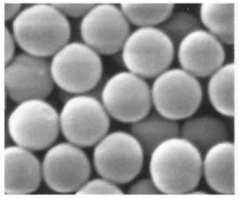
Research Needs

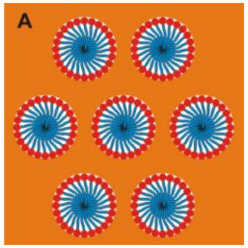
- Stable polymeric membranes with controlled porosity and optimized distribution/linking to accommodate nanoparticles
- Evaluate performances in eliminating targeted contaminants











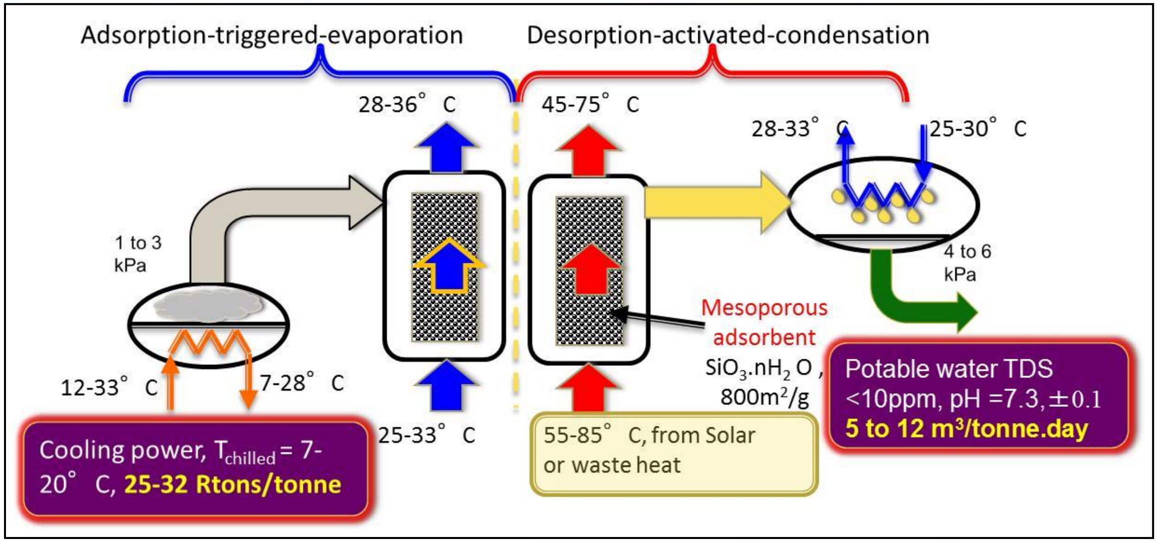
(Source: Nunes 2010)

Solar Adsorption Desalination (AD)

Prof. Ng

AD

- Mesaporous adsorbent, such as silica, is used to adsorb water vapor,
- Heat (solar energy) is used to desorb water
- Produces two useful effects (cooling and water desalination) with low temperature heat input (~65°C)
- Low energy usage and no moving parts
- Economical



Process	kWh/m3*	US$/m3
Thermal	6 -16	0.60-1.00
Membrane	3 - 6	0.45- 0.80
AD	1.4-1.9	0.29-0.30

** Total energy (includes thermal and electrical)*

(Source: Ng 2011)

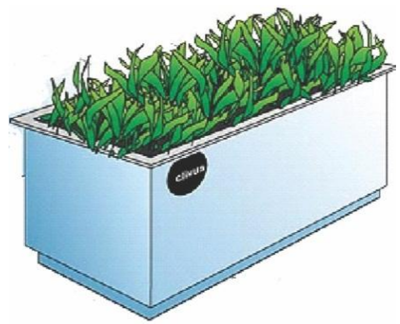
Pilot Facilities at WDRC

Pilot Facilities

Dr. Sinha

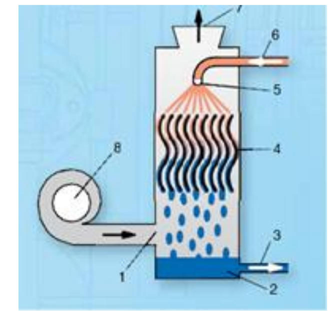
Desalination

Reuse



Natural Systems

Solar Adsorption



Industrial Water

Desalination: Membrane based desalination facility to test Red Sea water

Water Reuse: Membrane based Bioreactor (MBRs) for water reuse

Natural Systems: Constructed wetlands to further treat treated wastewater and Infiltration basin simulating aquifer recharge and recovery (ARR)

Solar Adsorption: Solar based adsorption desalination facility

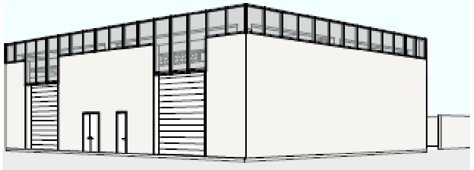
Industrial Water: Cooling tower to reduce biofouling, scaling and corrosion

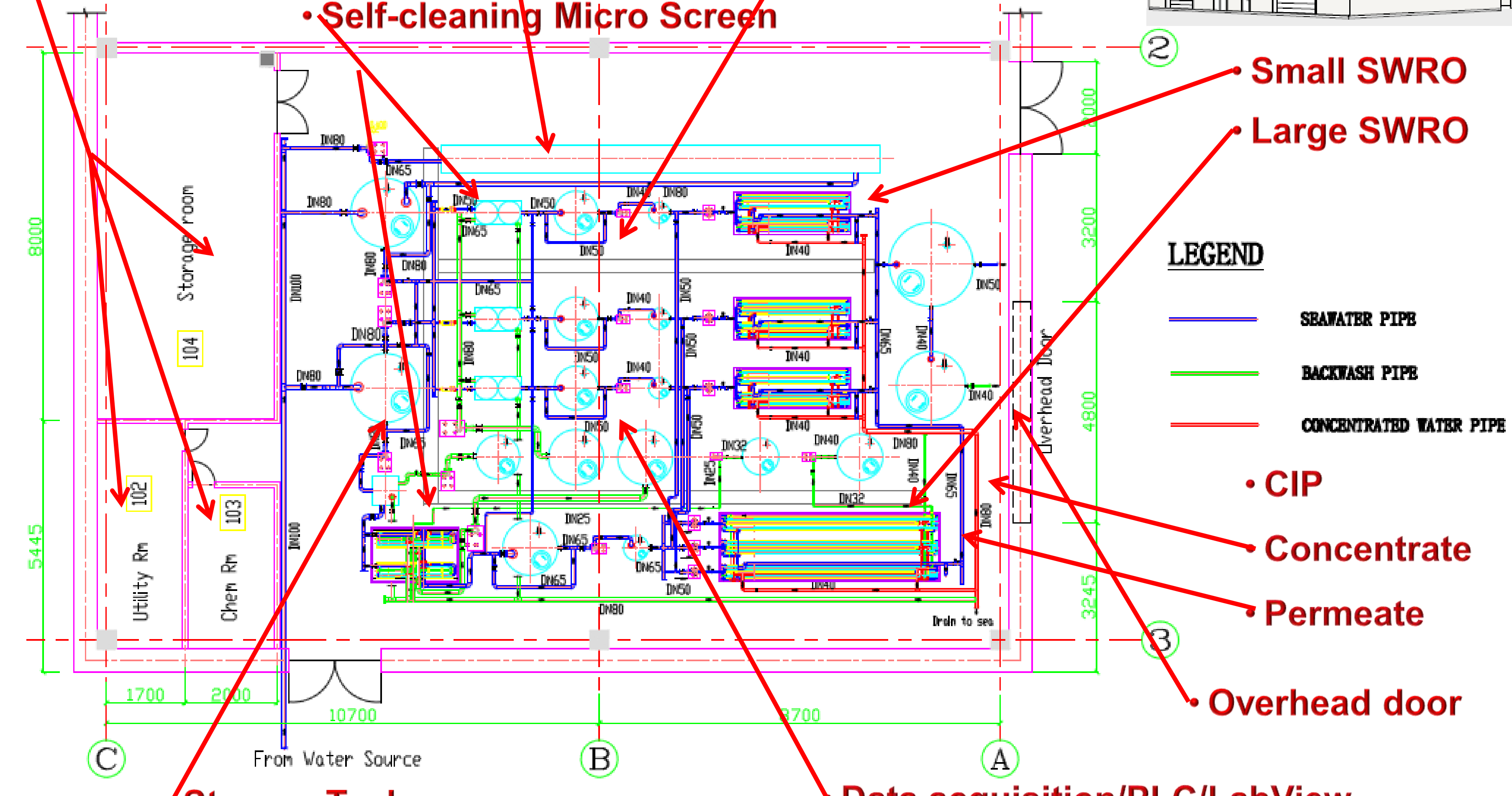
Beach Well: Transect beach-wells for SWRO pretreatment

SWRO Pilot Options

Dr. Sinha

- Chem./Utility/ Storage
- MMF
- UF/MF
- Self-cleaning Micro Screen
- Beach-well
- By-pass lines
- VFD





PIPE LAYOUT

Technology Roadmap for Low-Cost (-Energy) Desalination

Current
> 2.0 kWh/m^3

- SWRO

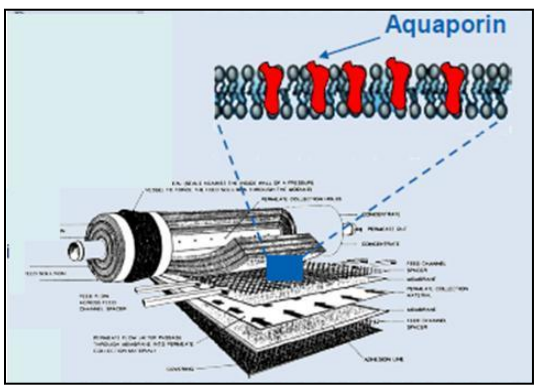
Near Horizon
(5 years)
< 2.0 kWh/m^3

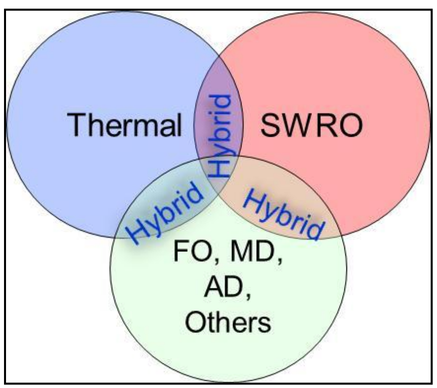
- FO
- MD
- AD

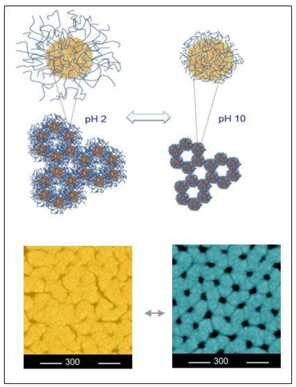
Far Horizon
(10 Years)
< 1.0 kWh/m^3 *

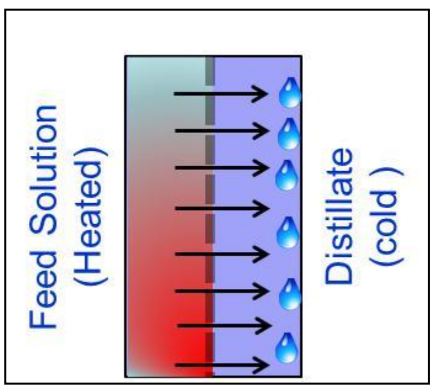
- MDC, MD, FO
- Biomimetic
- Membranes Hybridization
- Other innovative processes

** Thermodynamically minimum energy requirement for desalination 0.75 kWh/m3; <1.0 kWh/m3 attained by improving efficiency*









(patterned after PUB, 2010)

Thank you!