Treating Effluent Streams at Coal Power Plants Using Membranes

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U.S. DEPARTMENT OF ENERGY

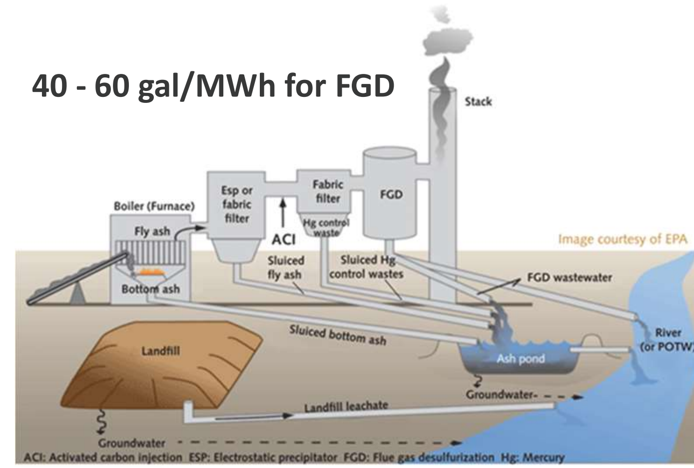
2015 EPA Regulation on Effluent Limitations

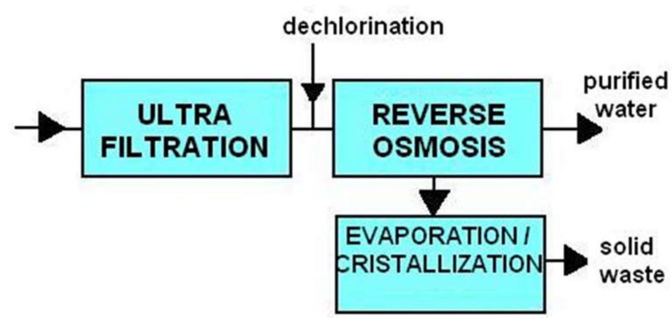
ELGs at Coal Power Plants

- September 30, 2015, finalized a rule revising the regulations for the Steam Electric Power Generating Effluent Guidelines
- Streams effected include:
  - Fly & Bottom Ash Transport Waters
  - Flue Gas Desulfurization (FGD) effluent
  - Ash Pond effluent
  - Flue Gas Mercury Control Water
- 6 regulated heavy metals (Pb, As, Hg, Se, Cr, Cd)
- Compliance Costs are expected by the EPA to be on the order of $500M/yr across the entire U.S. fleet
- September 18, 2017 EPA announced a Postponement of Certain Compliance Dates (does not affect compliance dates for Mercury Control Water and Fly Ash Transport Water)
- Two Options for Compliance

  Zero Liquid Discharge (ZLD)   Chemical & Biological Treatment

40 - 60 gal/MWh for FGD





Standard Option for ZLD

Start of the Art Technologies used in ZLD

Reserve Osmosis (RO)

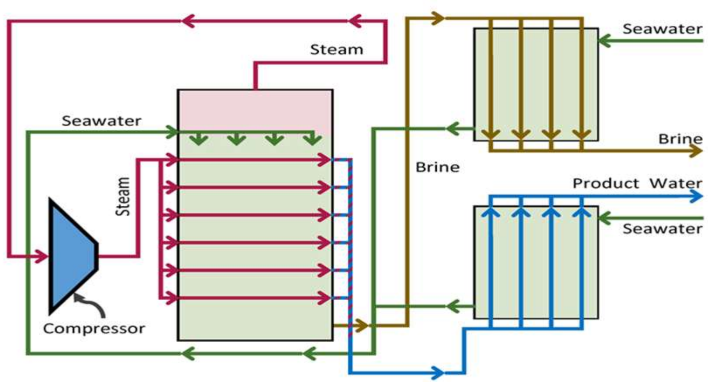
- **Pros**
  - High Efficiency (30%-50%)
  - Low upfront capital investment
- **Cons**
  - Only can concentrate brines up to 6-8 wt% of TDS
  - Highly susceptible to scaling and fouling

W. Lovins et al. "Plant Optimization for an Inland Industrial RO Reuse Facility," in *Proceedings of the 2017 AWWA-AMTA Membrane Technology Conference and Exposition*, February 13-17, 2017.

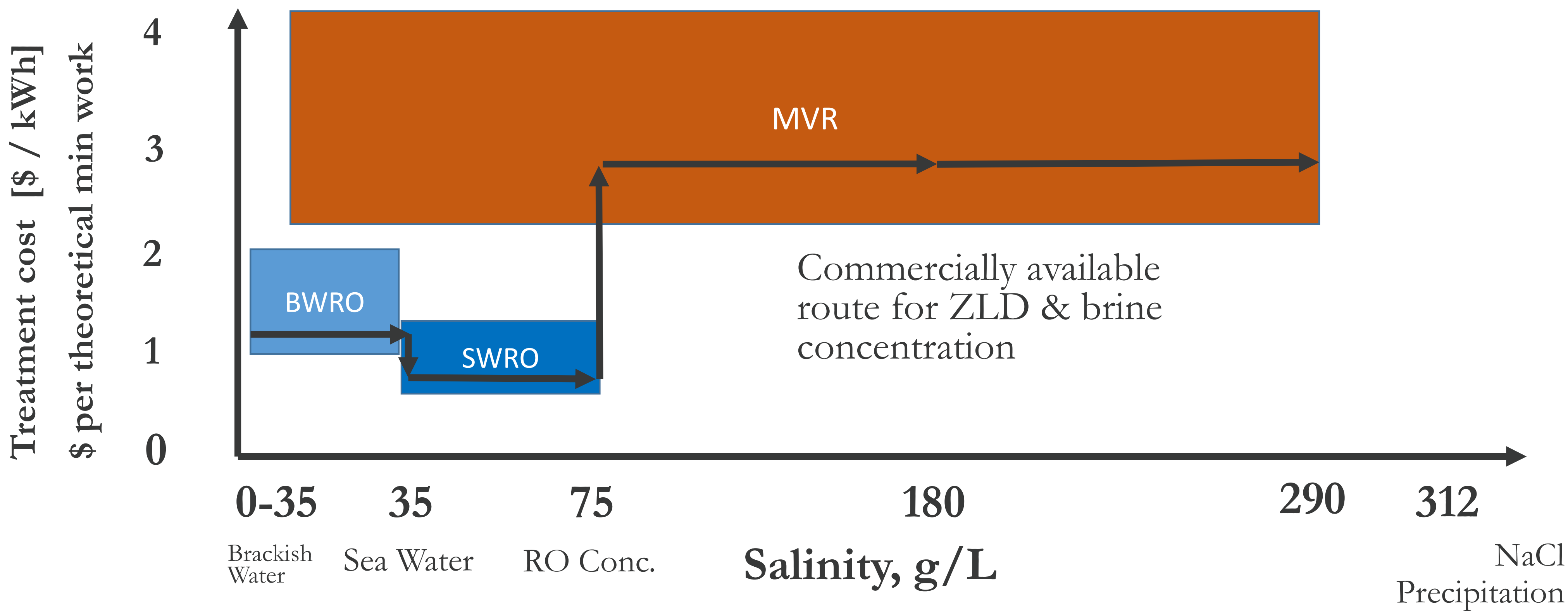
Start of the Art Technologies used in ZLD

Mechanical Vapor Recompression(MVR)

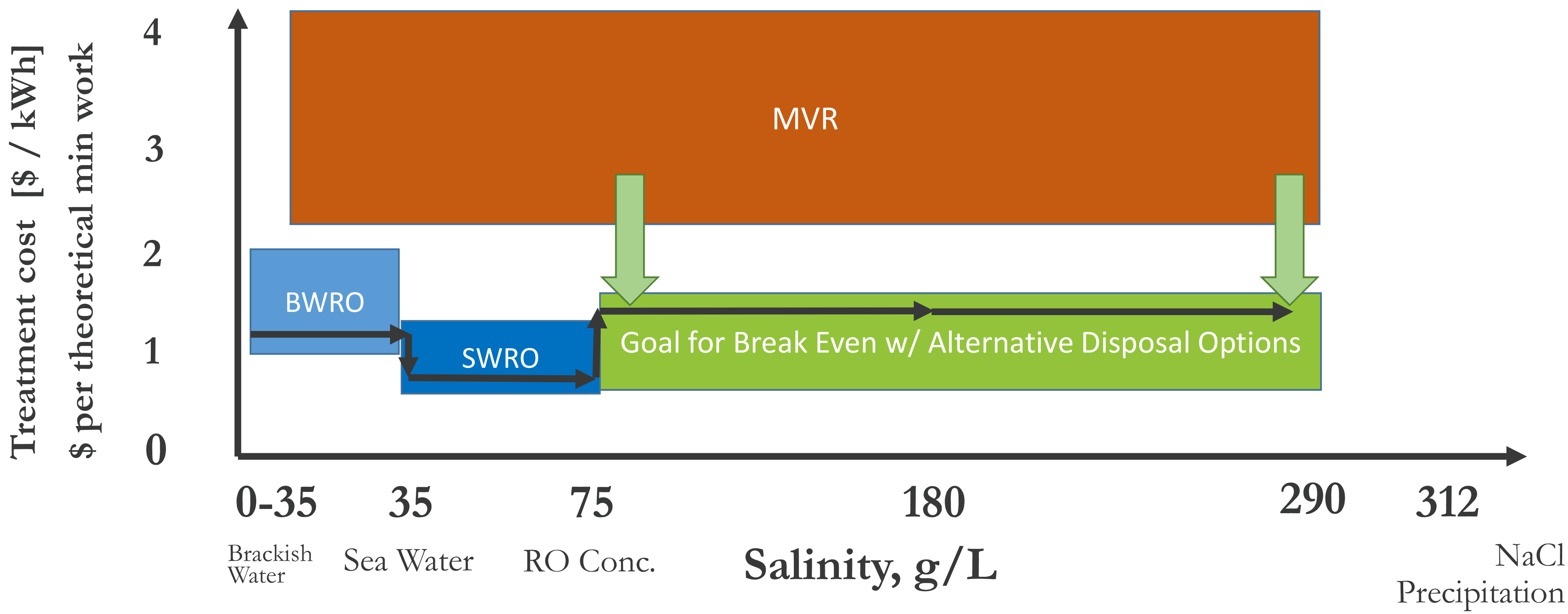
- **Pros**
  - Can concentrate brines up to 20 -25 wt% of TDS
- **Cons**
  - Not particularly scalable or flexible
  - Low efficiency (<10%) and high levelized costs to treat



Grand Challenge for Concentrating Effluent Streams



Grand Challenge for Concentrating Effluent Streams



Dewatering Processes

Reverse Osmosis

Forward Osmosis w/ NH_3:CO_2 Draw

- Ability to dewater high salinity brines
- Electricity driven process
- Minimal chemical handling

Osmotically Assisted Reverse Osmosis

Mechanical Vapor Compression

Membrane Distillation

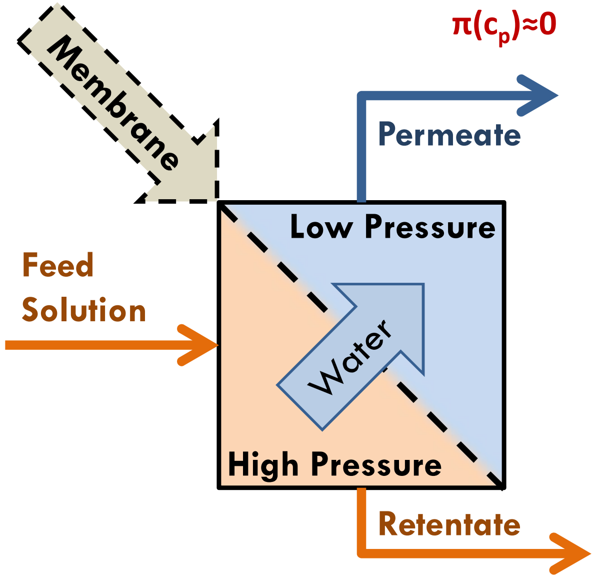
Osmotically Assisted Reverse Osmosis

Osmotically Assisted Reverse Osmosis (OARO) differs from conventional membrane processes

Reverse Osmosis

$$J_w = A \cdot \{[P_f - P_p] - [\pi(c_{f,m}) - \pi(c_p)]\}$$

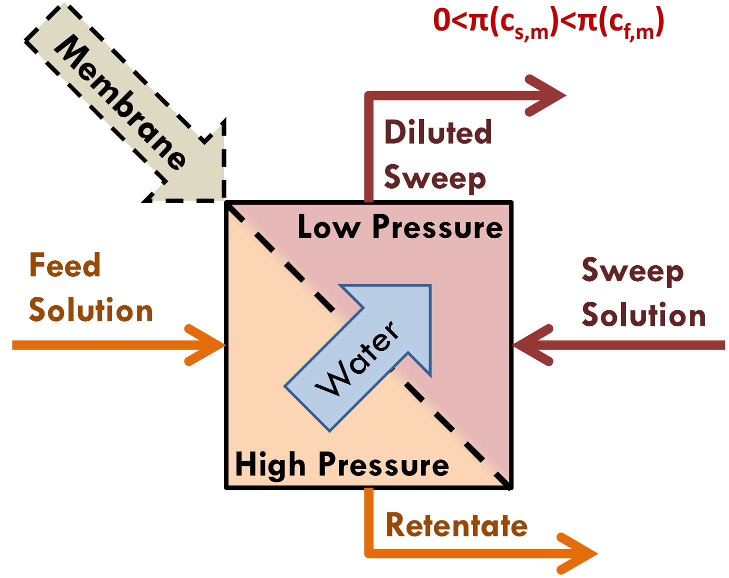
$\pi(c_p) \approx 0$



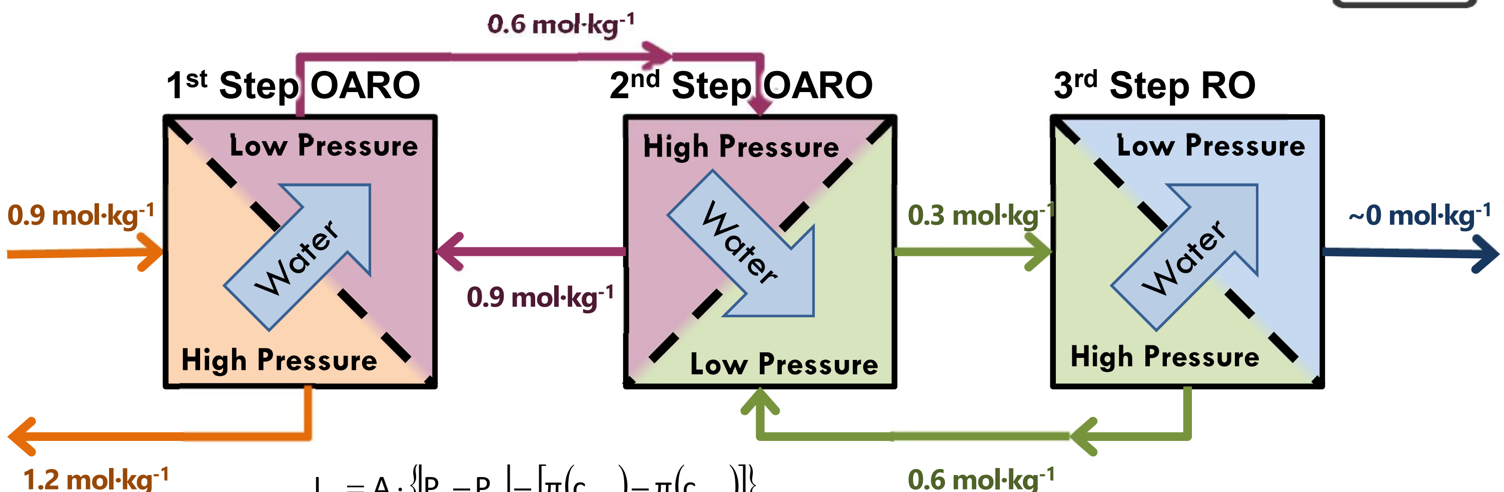
Osmotically Assisted Reverse Osmosis

$$J_w = A \cdot \{[P_f - P_p] - [\pi(c_{f,m}) - \pi(c_{s,m})]\}$$

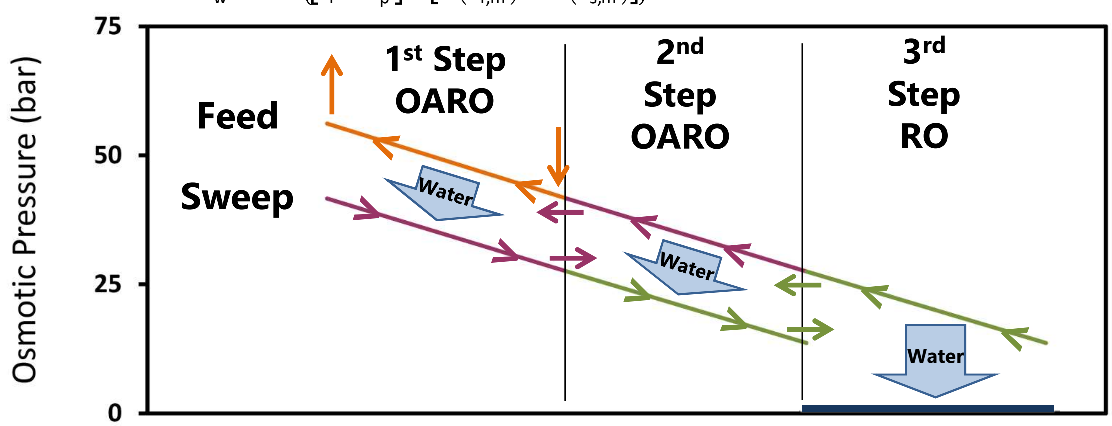
$0 < \pi(c_{s,m}) < \pi(c_{f,m})$



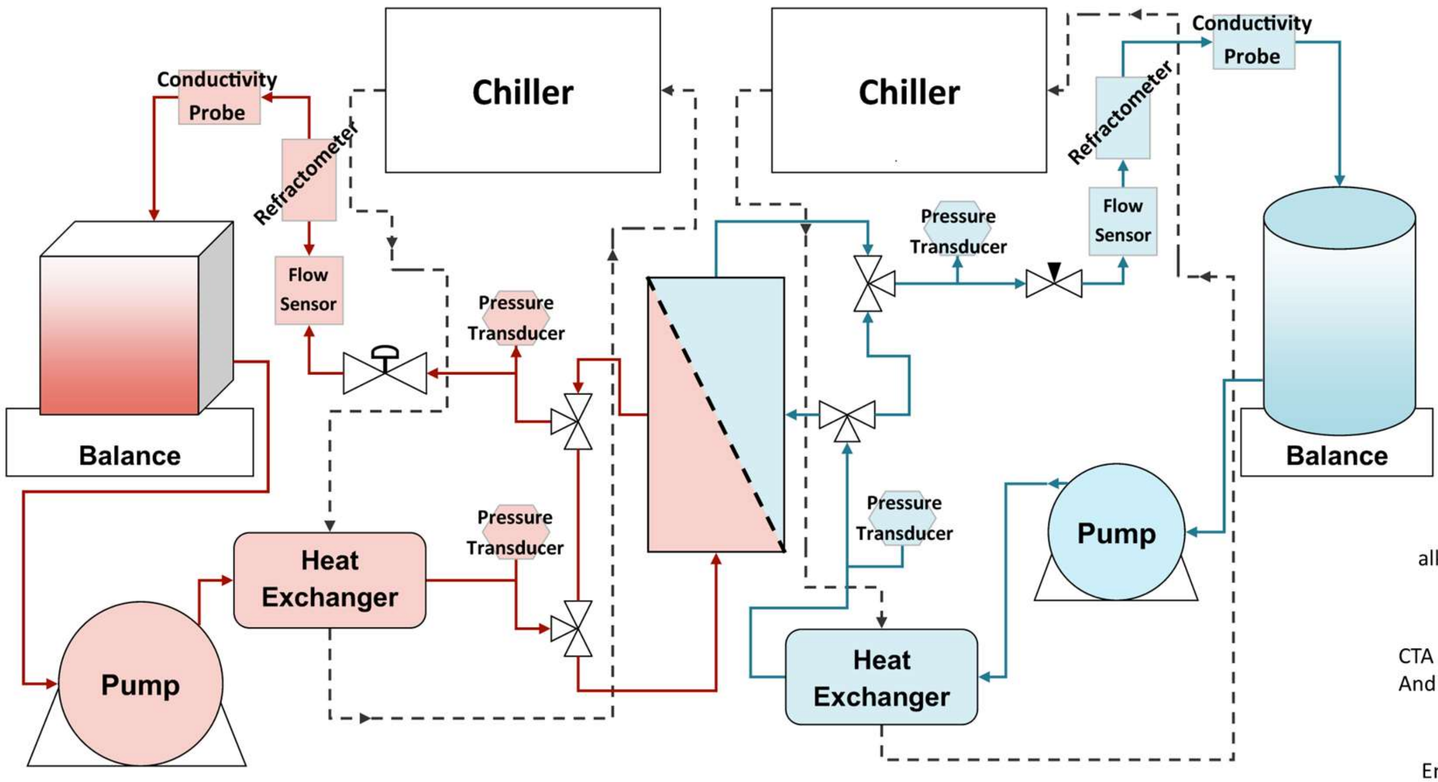
Process Configuration

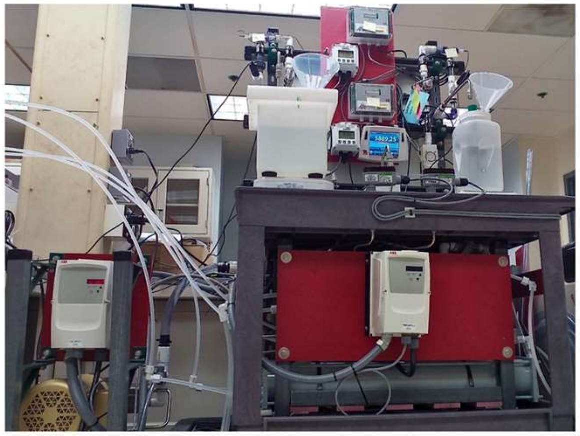


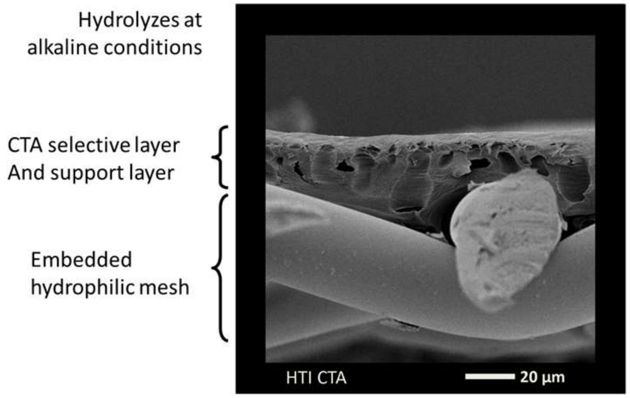
$$J_w = A \cdot \{[P_f - P_p] - [\pi(c_{f,m}) - \pi(c_{s,m})]\}$$



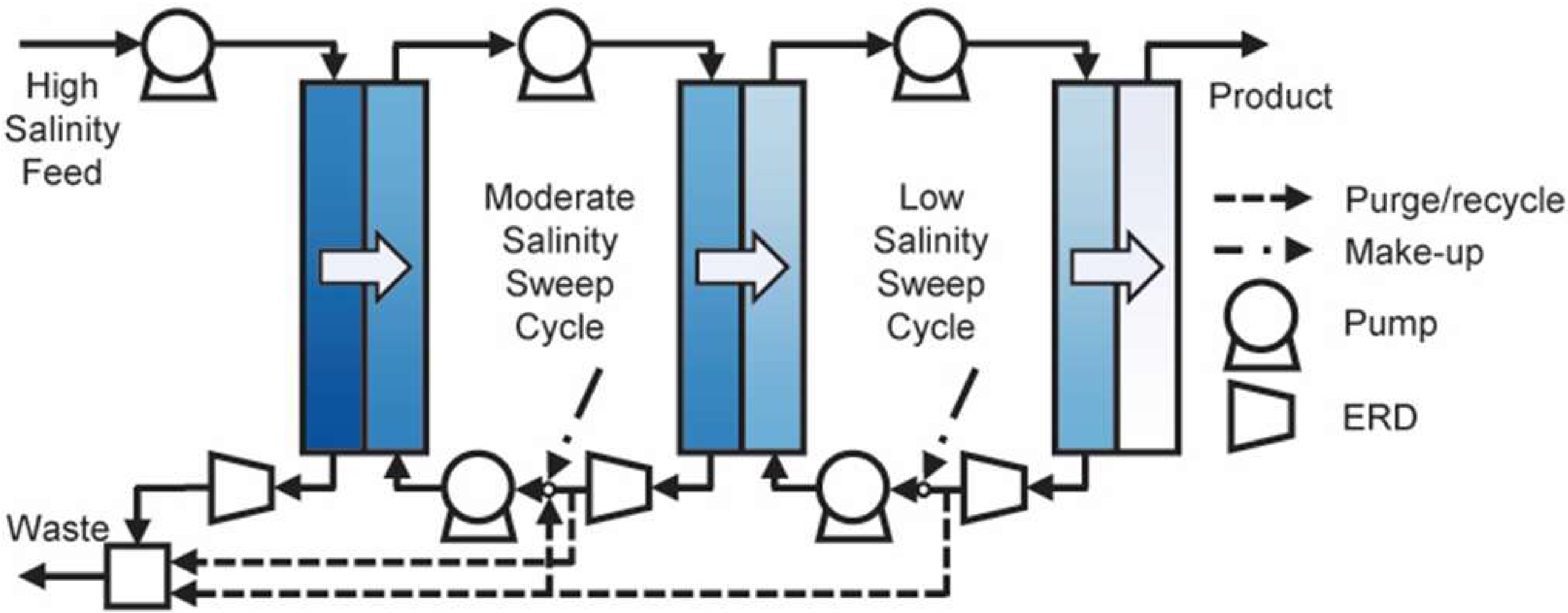
Test System at NETL







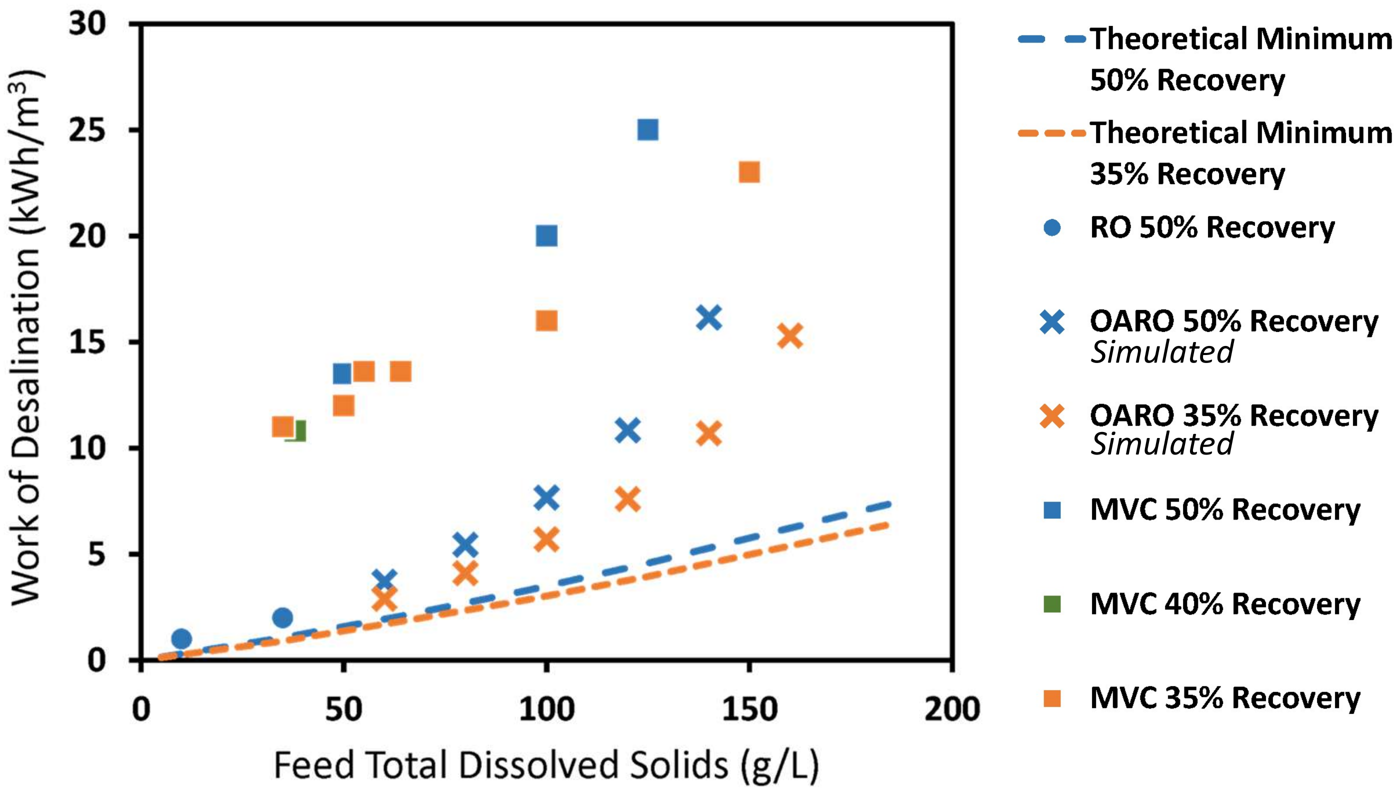
OARO Process Simulation



ERD = Energy Recovery Device Pressure Recovery assuming between 90% - 96% efficiency

Comparison of Energy Demand

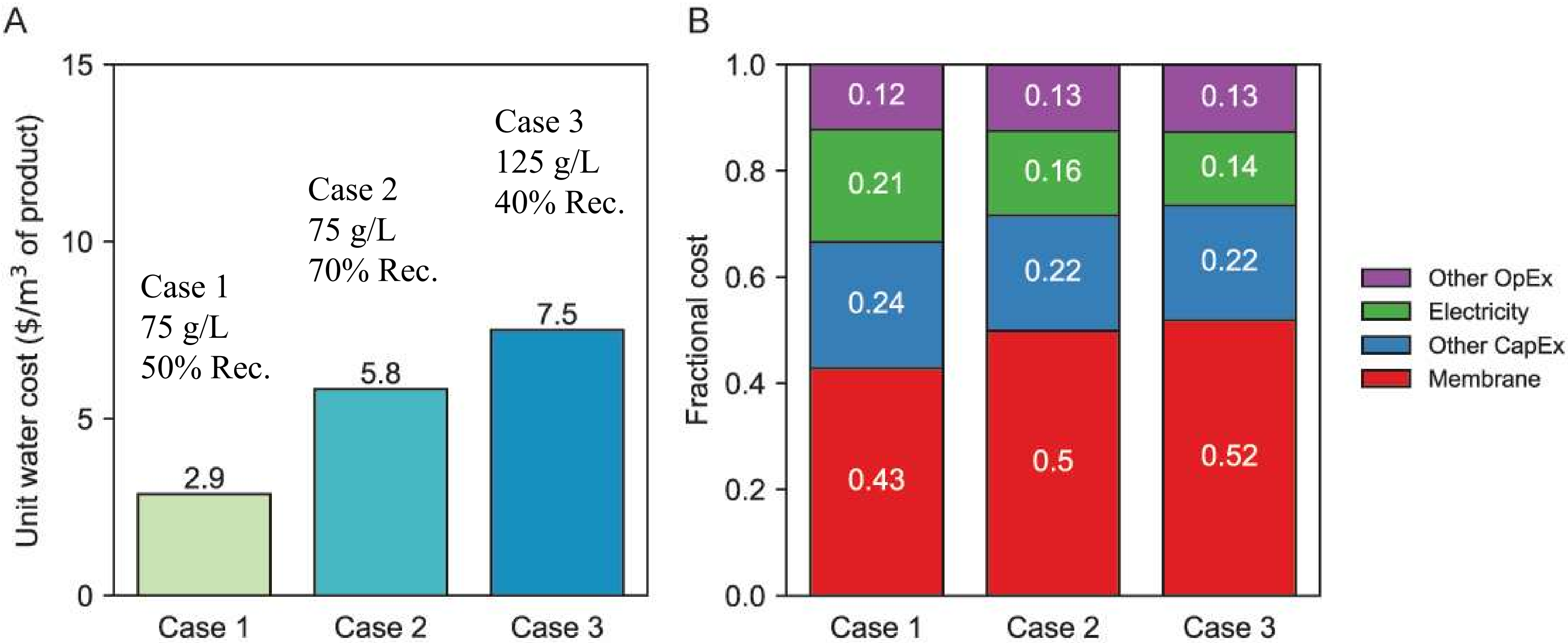
OARO has the Potential for 50% Savings in Electrical Energy



Energy consumption of RO, MVC/MVR, OARO water treatment and theoretical minimum work with respect to feed TDS concentration and recovery

T.V. Bartholomew *et al.* *Desalination* (2017). doi:10.1016/j.desal.2017.04.012
G.P. Thiel et al. *Desalination* 366 (2015), 94-112.
J. Veza, *Desalination* 101 (1995) 1-10.
A. Koren, et al. *Desalination* 98 (1994), 41-48.

Techno-Economic Analysis: Base Case



Cost optimal unit water costs (A) and normalized component costs (B) for the three high salinity brine desalination cases: Case 1: 75 g/L TDS with 50% recovery, Case 2: 75 g/L TDS with 70% recovery, and Case 3: 125 g/L with 40% recovery

Bartholomew, Siefert, and Mauter, *Env. Sci. Tech.* (in preparation)
Case 2 Outlet Salinity = 235 g /L

Optimization within the Base Cases

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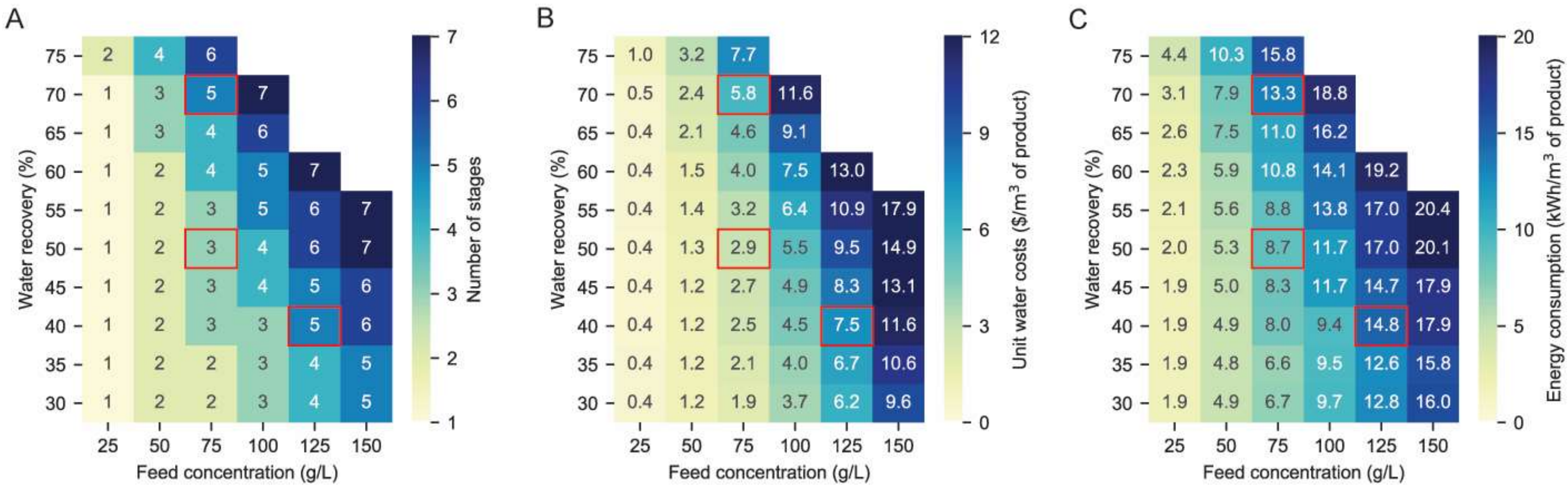
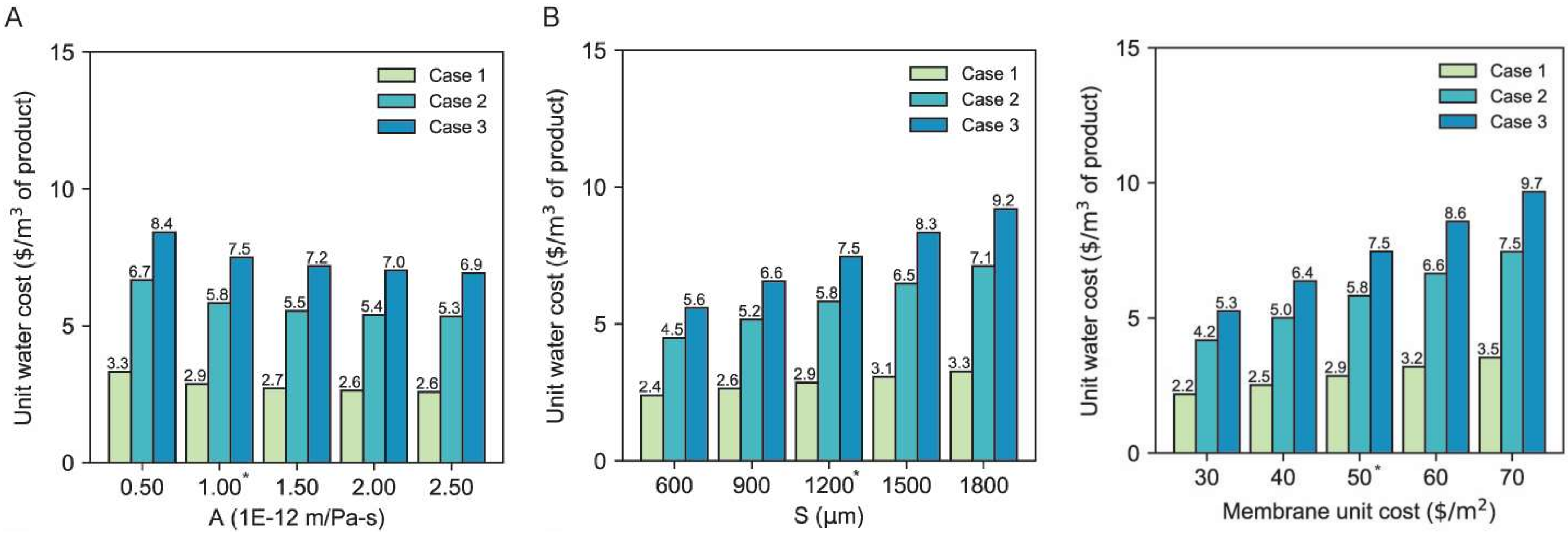


Cost optimal design configurations and associated performance metrics for OARO/RO membrane-based desalination processes: A) number of stages, B) unit water costs, C) energy use. The three high-salinity brine desalination cases are denoted with a red box.

OARO cost sensitivity



OARO cost sensitivity for A) water permeability coefficient, A; B) structural parameter, S; C) membrane unit cost.

The baseline value used in modeling each of the cases is marked with an asterisk.

Conclusions & Future Work

- OARO is a membrane process capable of concentrating effluent streams to high salinity
- Electrical energy cost of OARO is <50% of the electrical energy consumption of Mechanical Vapor Recompression (MVR)
- Preliminary Techno-Economic Analysis show modest cost savings compared with MVR using the Base Case assumptions
- Sensitivity Analysis shows the requirements for the structural parameter and the membrane cost that would allow for a 50% cost savings compared with MVR

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Questions?