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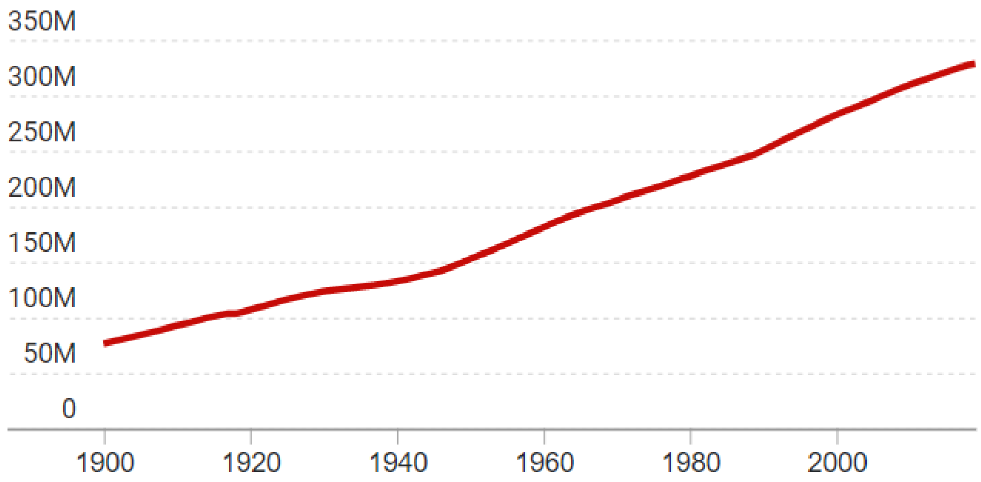
Comparative Techno-Economic and Environmental Assessment of Ozone-Membrane Distillation for Brine Concentrate Management

Varinia Felix[1,2], Mukta Hardikar[1,2], Andrea Achilli[1,2] and Kerri L. Hickenbottom[1,2]

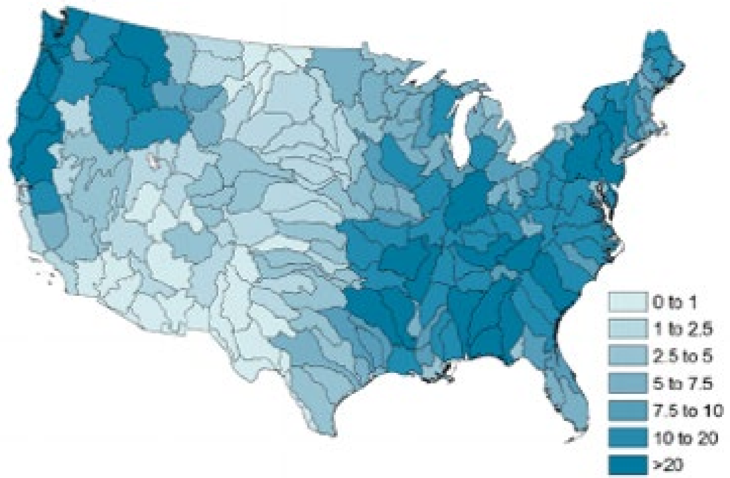
[1]Department of Chemical and Environmental Engineering, University of Arizona
[2]Water and Energy Sustainable Technology (WEST) Center, University of Arizona

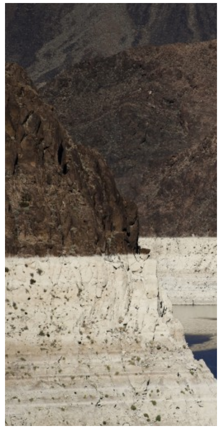
Water Reuse a Means to Secure Potable Water Supply

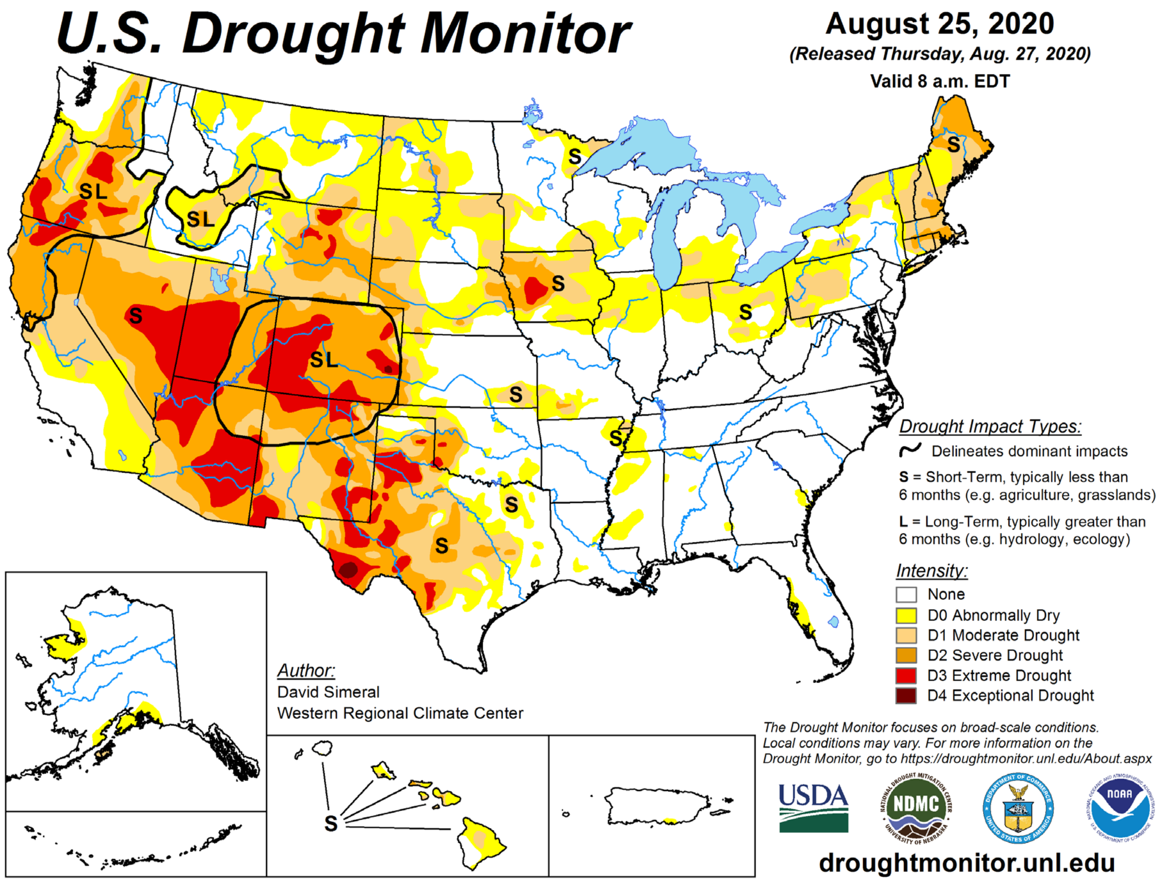
USA Population Census.Gov

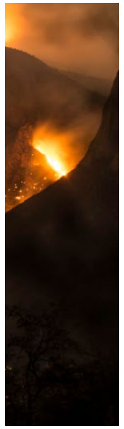


Water Yield 1985–2010 Bm^3





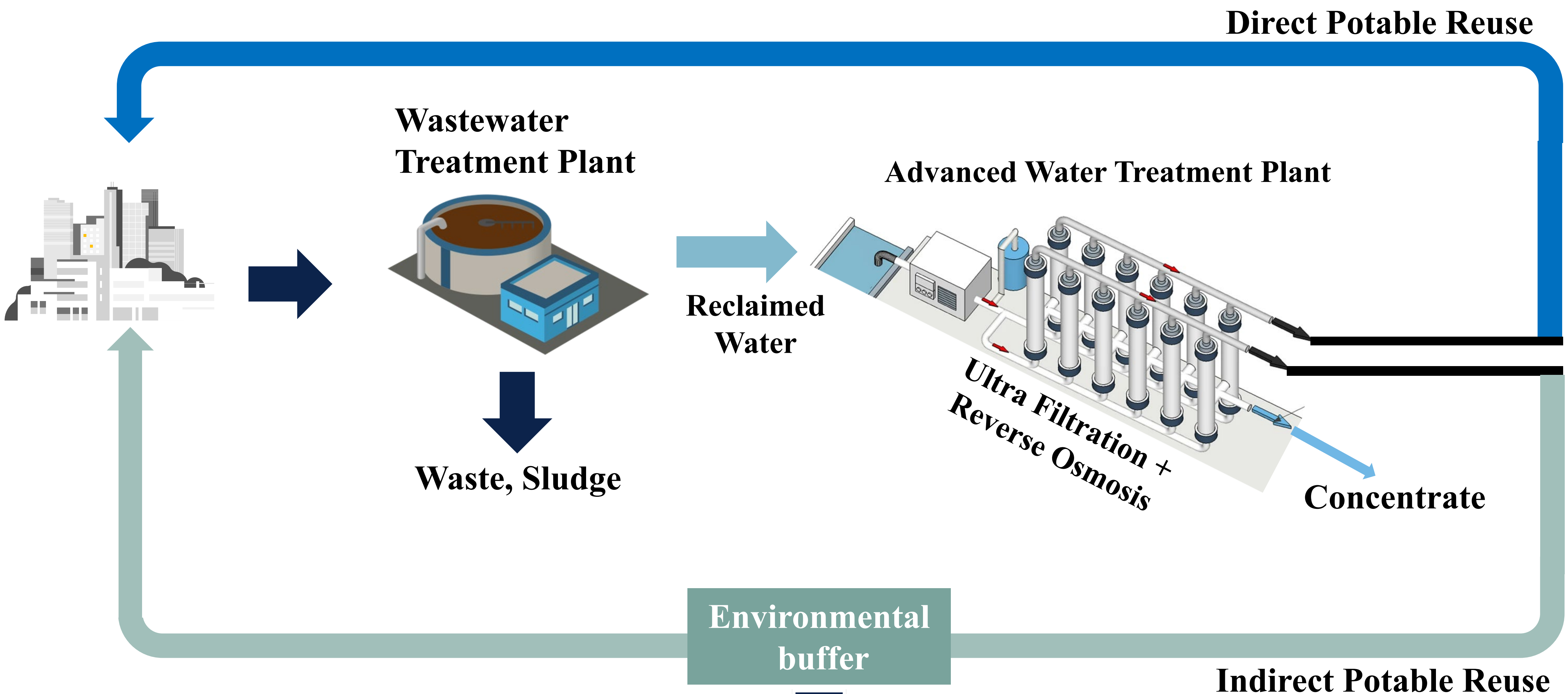




Lake Mead, Colorado, 2015.
(Jae C. Hong / AP Photo)

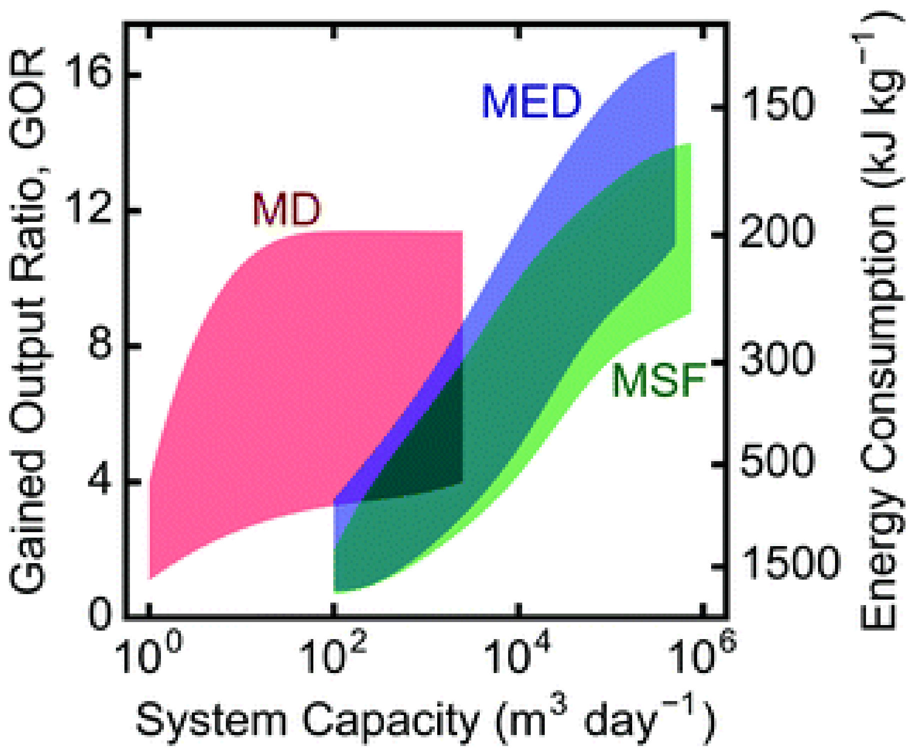
Wildfire in Tucson Arizona 2020
Danielle & Ryan McCrory Photography

Conventional Treatment Train for Potable Reuse (DPR)



Why Membrane Distillation?

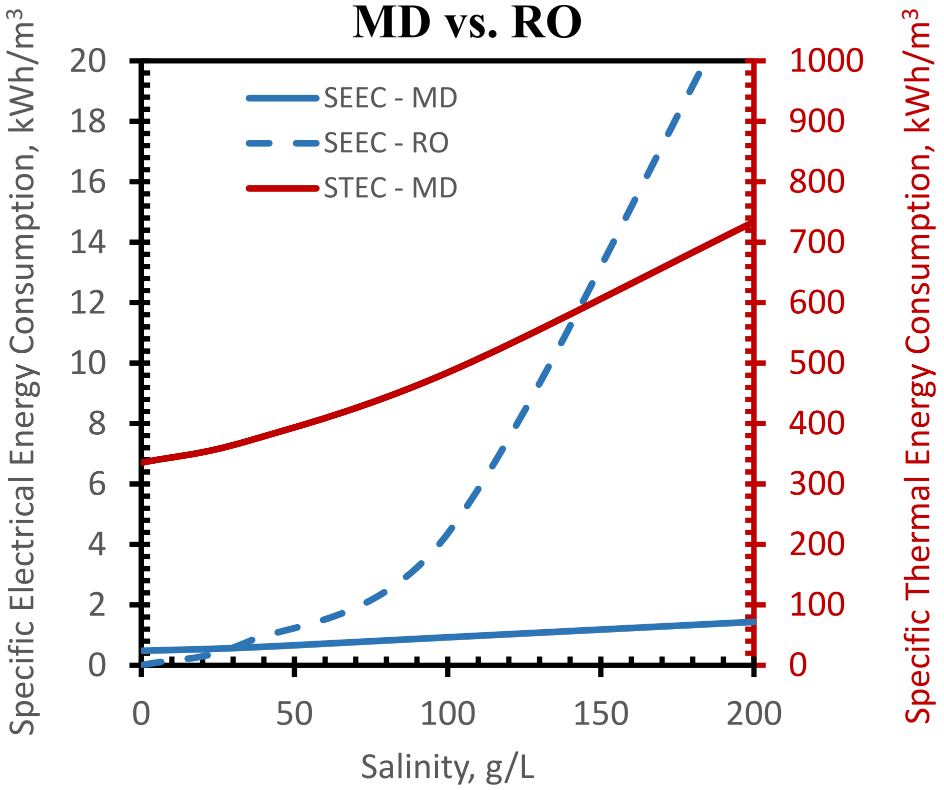
MD vs. Distillation



- Higher energy efficiency (GOR) and lower energy consumption

A. Deshmukh, C. Boo, V. Karanikola,…..,M. Elimelech, Energy & Environ. Sci., 2018, 11, 1177.

MD vs. RO



- Lower Specific Electrical Energy compared to RO at high concentrations
- Viable when low-grade heat or renewable energy is available

M. Elimelech & W.A. Phillip, Science, 2011, 333, 712.
A. Achilli, BOR Report, 2019.

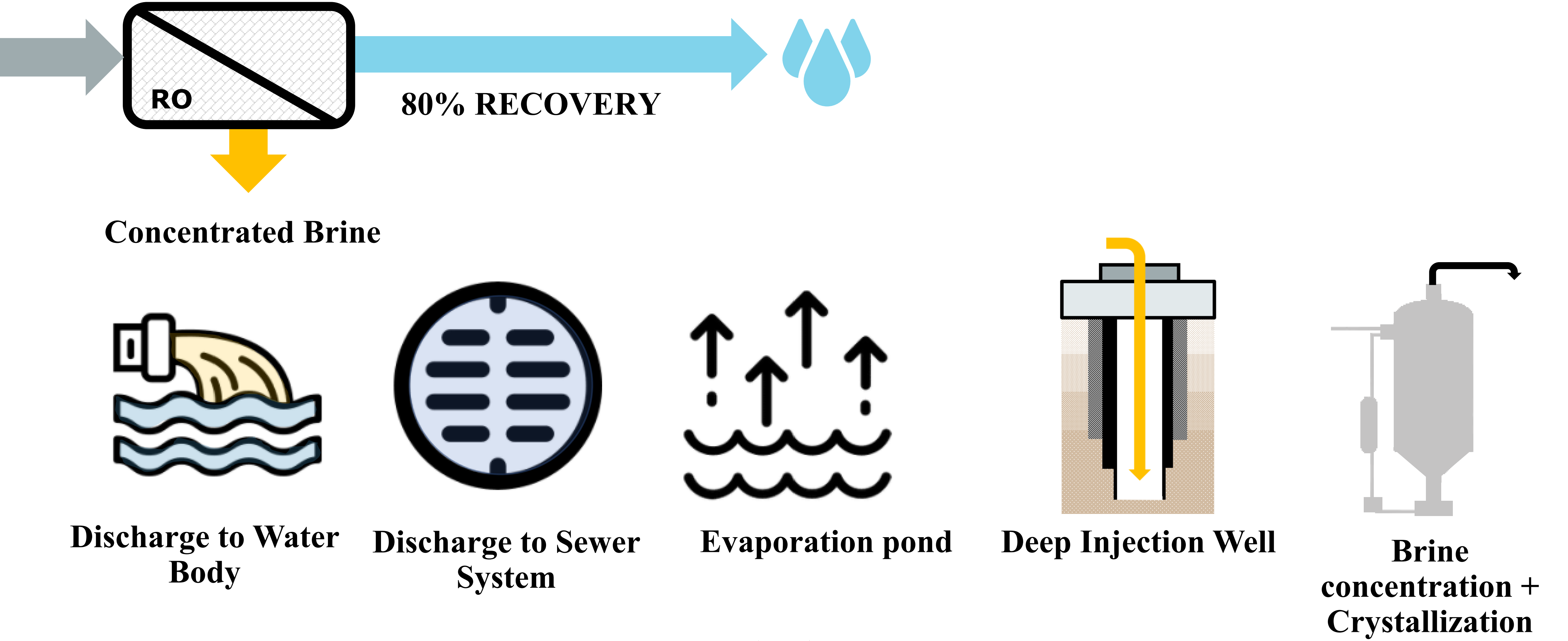
Water Reuse RO Concentrate

Concentrate Management

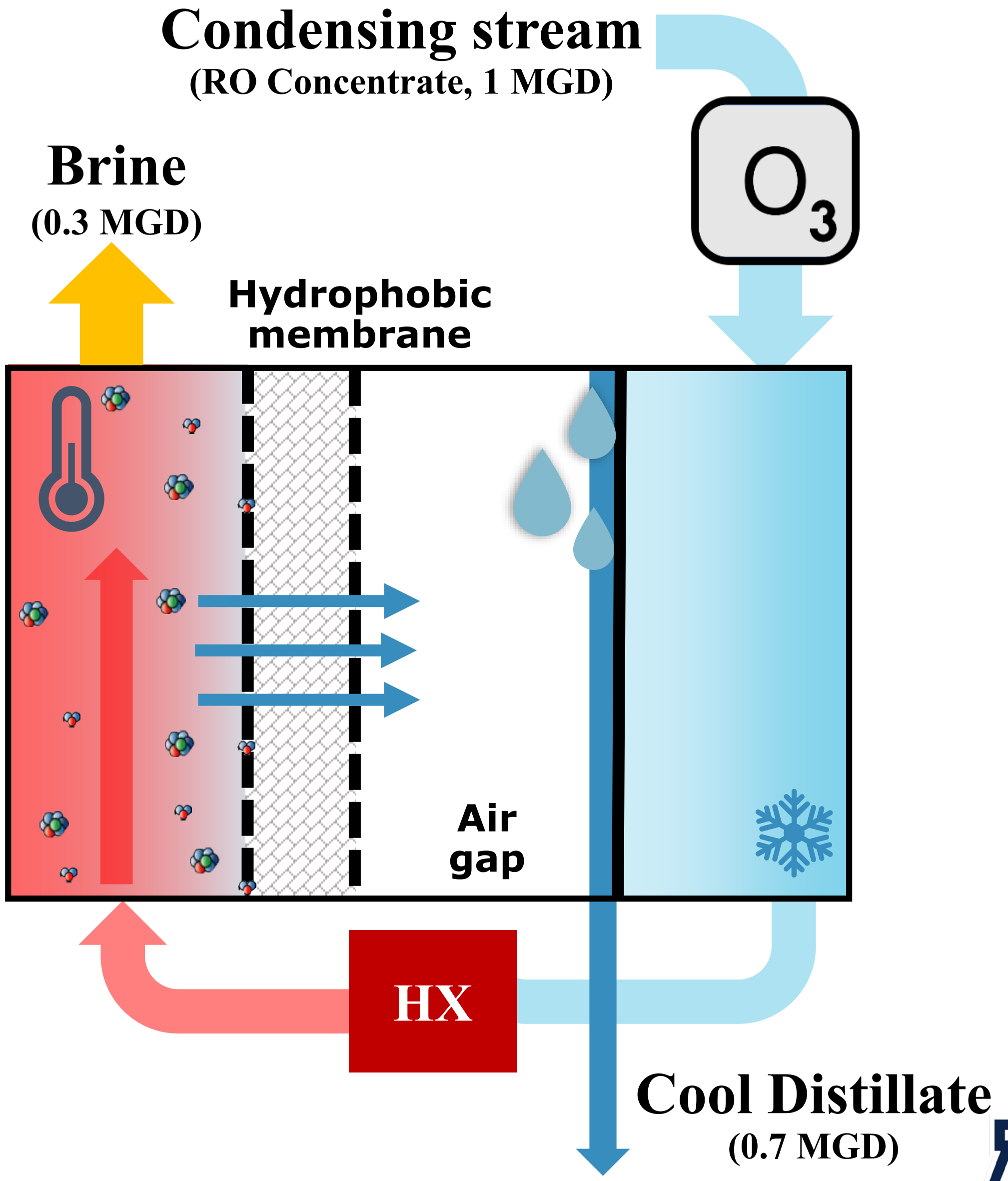
- High TDS: 3-35g/L
- Rich in Organic Matter: >20 mg/L[1]
- High disposal cost: ~33% of desalination[2]
- Environmental effects: salinity, organics, chemicals and temperature

[1]Orange County Water District brine concentrate analyses (Ersever, 2013)
[2] Mickley M., Report 155: Treatment of Concentrate. U.S. Department of the Interior. Bureau of Reclamation, 2008.

Conventional Concentrate Management Systems



Ozone-Membrane Distillation (MD)



- Lower Specific Electrical Energy compared to RO at high concentrations
- Viable when low-grade heat or renewable energy is available
- Maximizes water recovery

RO + Ozone MD = 94% water recovery

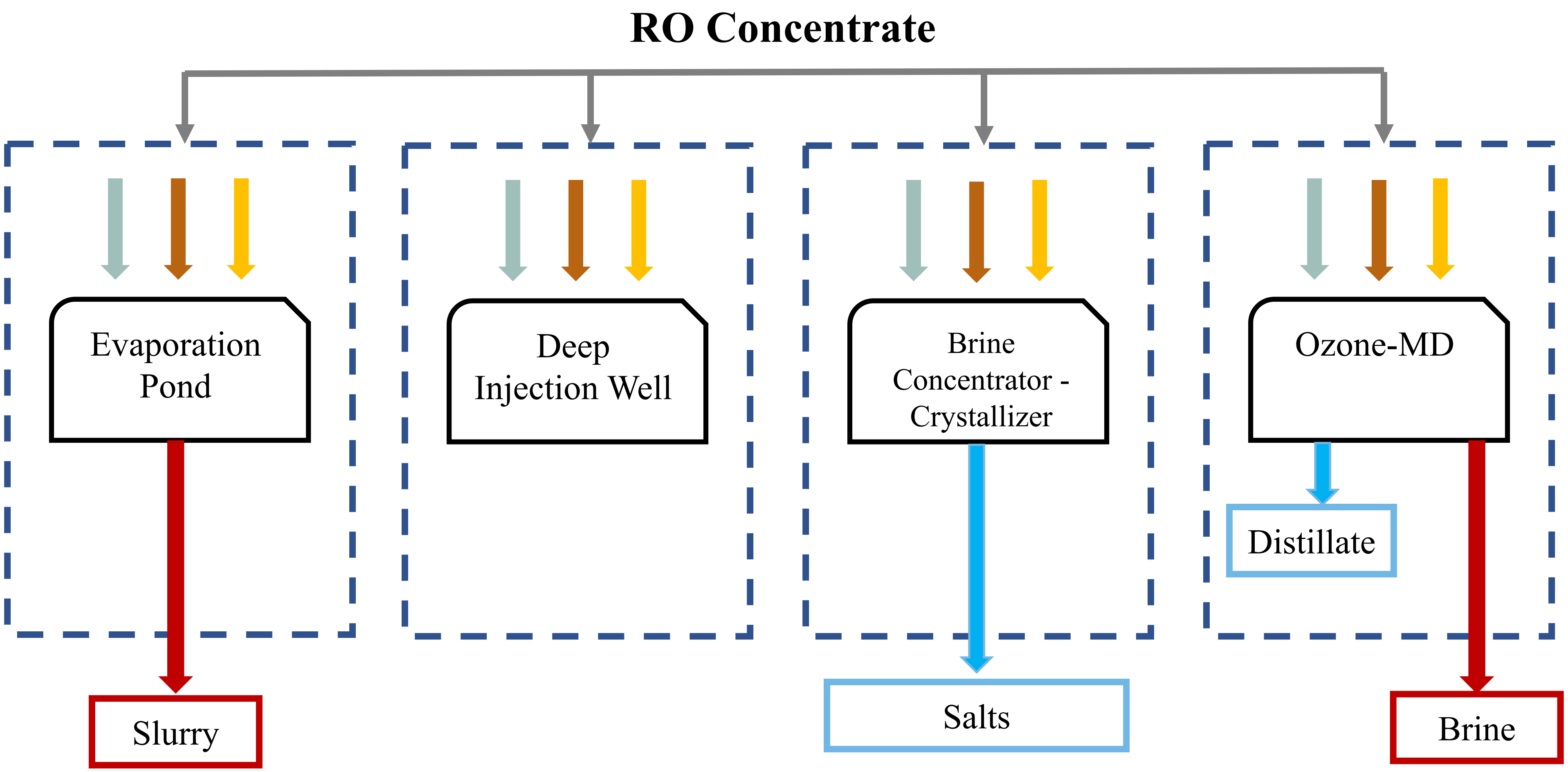
Project Goals

- **Develop** a comparative techno-economic assessment of conventional brine management and the proposed Ozone-MD system.

- Determine key **performance variables** that influence system capital and operation and management cost, energy requirements, and environmental impacts.

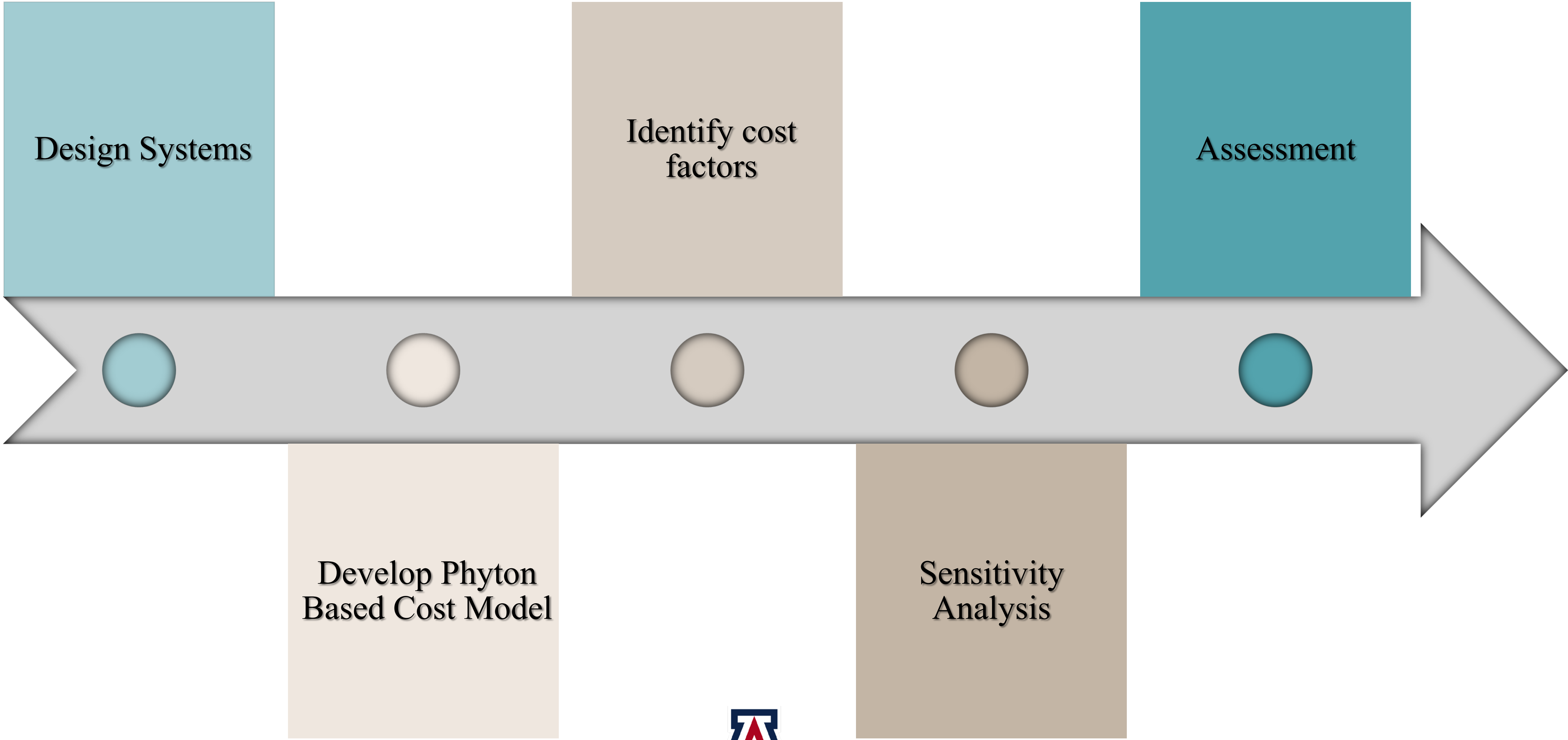
- **Identify** improvement opportunities, evaluate economy of scales, and assess the feasibility for implementing the novel brine management technology.

Boundaries and General Variables



- Infrastructure
- Operation and Management
- Energy requirements

Methods


Design Systems
Develop Phyton Based Cost Model
Identify cost factors
Sensitivity Analysis
Assessment

Concentrate Management Systems Modeled After Experimental Conditions

Pilot-scale UF-RO system at WEST Center, University of Arizona

Using real RO concentrate from a pilot scale RO system with the following properties:

Properties	
Conductivity (mS/cm)	4.2
TDS (mg/L)	2400
Total organic carbon (mg/L)	23
Recovery	80%

Baseline Design Criteria for Concentrate Management Systems

System	Variable	Value	Unit
	Concentrate Volume	3,785 (1)	m^3 (MGD)
	Concentrate Salinity	3 to 35	g/L
	Plant Lifetime	20	Years
	Availability	95	%
	Recovery	70	%
	Concentrate pumping distance*	1.6 to 32 (1-20)	km (miles)
Evaporation Ponds	Liner Thickness	60 to 100 (2.4 to 3.9)	mm (inches)
	Pond depth	1.2 to 3.7 (4 to 12)	m (ft)
Deep Injection Well	Well depth	762-3048 (2,500 to 930)	m (ft)
	Injection velocity	2.4 to 3 (8 to 10)	m/s (ft/s)
Brine Concentrator	Recovery	70 to 99	%
Ozone-MD	Temperature gradient hot side (MD)	50 to 80 (122 to 176)	°C (°F)
	Temperature gradient cold side (MD)	30 to 40 (86 to 104)	°C (°F)
	Concentrate feed flow rate to MD	0.5 to 1.5 (2.2 to 6.6)	m^3/hr (gpm)
	Membrane cost	60**-280	USD/7.2 m^2

*Deep Well Injection and Evaporation Ponds

**Mass production

Financial Assumptions for Cost Model

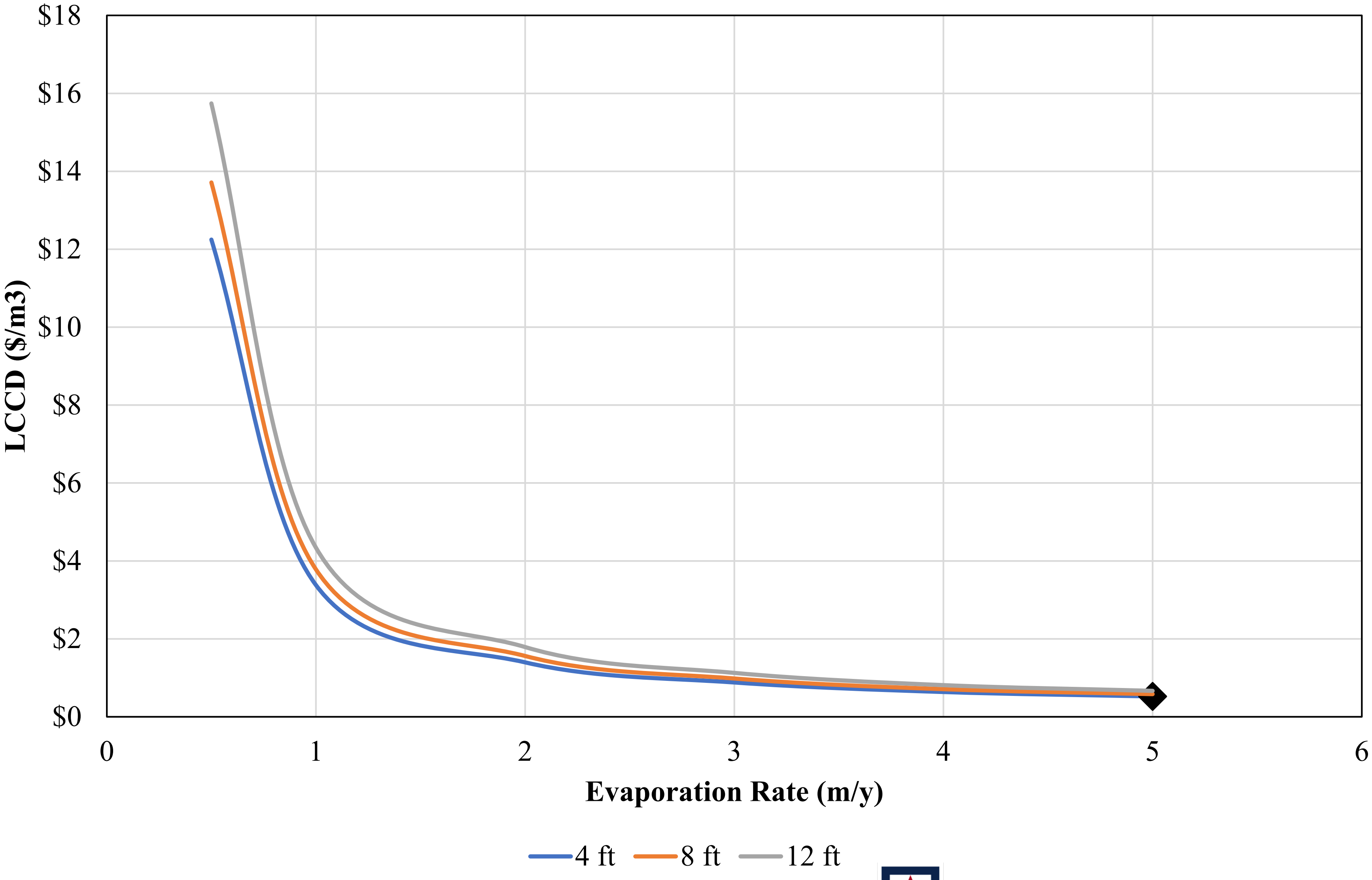
Financial Assumptions	
Interest Rate %	10
Inflation Rate %	3
Amortization Factor %	12
Land Cost $\$/m^2$ [3]	1.4
Electricity $/kWh[4]	0.07
Natural gas $\$/m^3$ [5]	0.14
Liner Cost $\$/m^2$	3-15
Regenerated water $\$/m^3$[6]	0.67
Indirect Cost %	10
Land clearing $/Acre	1000-4000

- **Levelized cost of disposal (LCCD) will be compared between systems.**
- **LCCD: net present cost of 1m^3 of concentrate disposed of by the system over its lifetime**

[2] Goodrich A, James T, Woodhouse M. Residential, commercial, and utility-scale photovoltaic system prices in the U.S: current drivers and cost-reduction opportunities.; 2012.
[3] USA Energy Information Administration. Average Price of Electricity to Ultimate Customers by End-Use Sector. 2021.
[4] USA Energy Information Administration. Natural Gas Prices. 2021.
[5] Graham J, Adam Z, Winnie S, Parameshwaran R, Michael N. Evaluation and Selection of Available Processes for a Zero-Liquid Discharge System for the Perris, California, Ground Water Basin. Report 149. Bureau of reclamation. 2008.

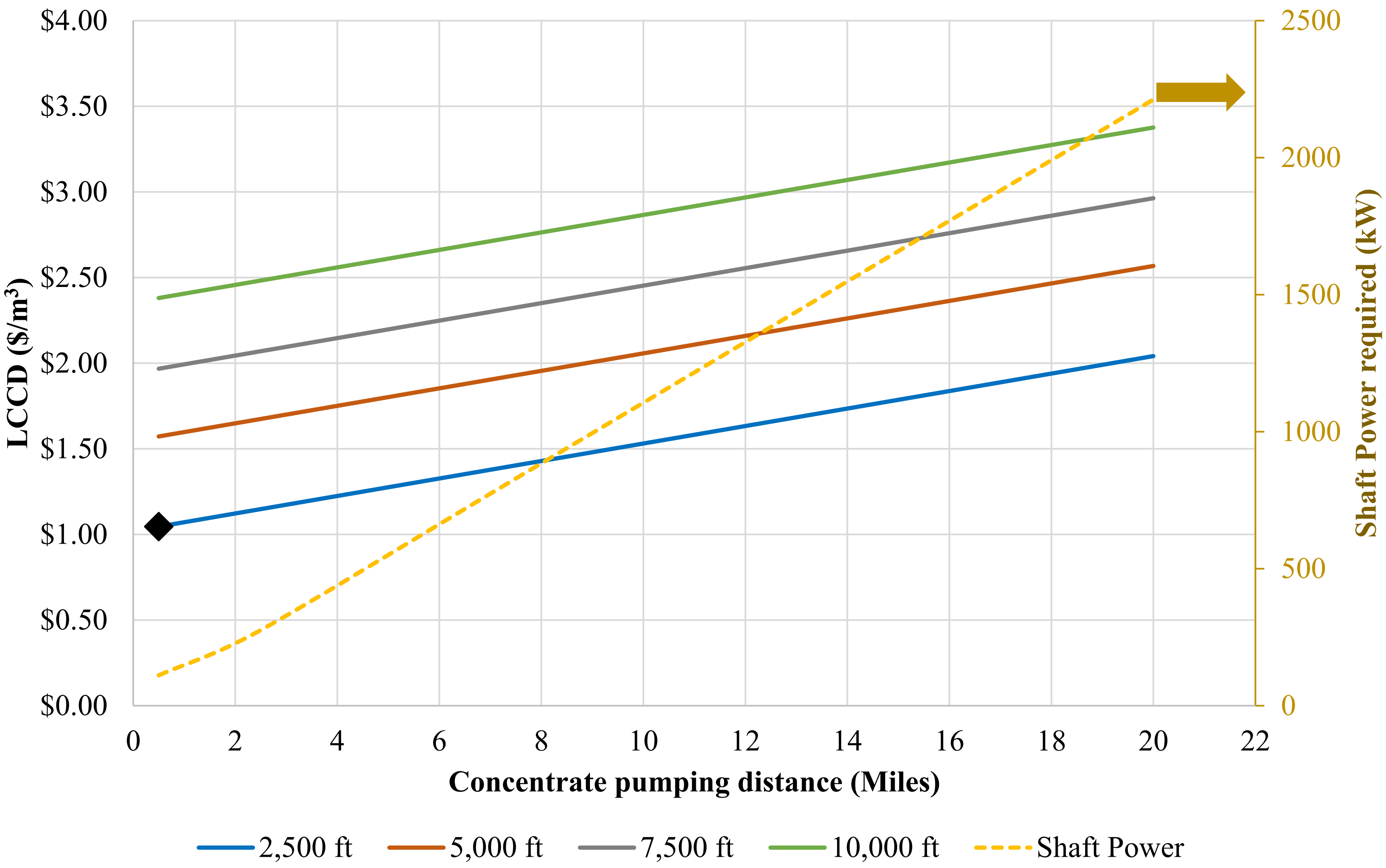
Results

Evaporation Rate Effect on Disposal Costs



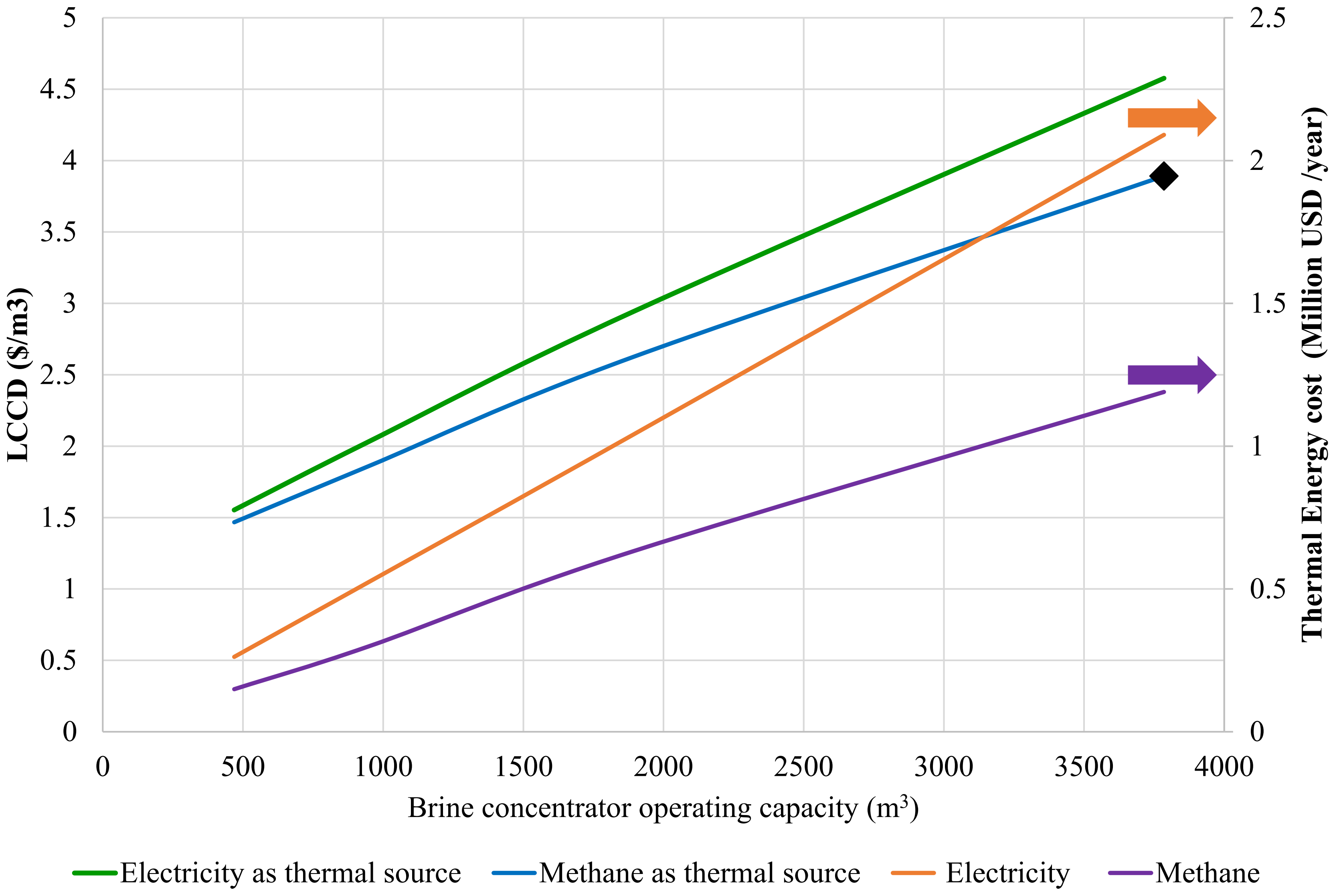
- **Higher evaporation rate and lower rainfall provide better conditions for evaporation ponds, lowering disposal cost.**
- **Lower evaporation rates require larger evaporative areas**

Effect of Pumping Distance on Deep Injection Well Disposal Costs



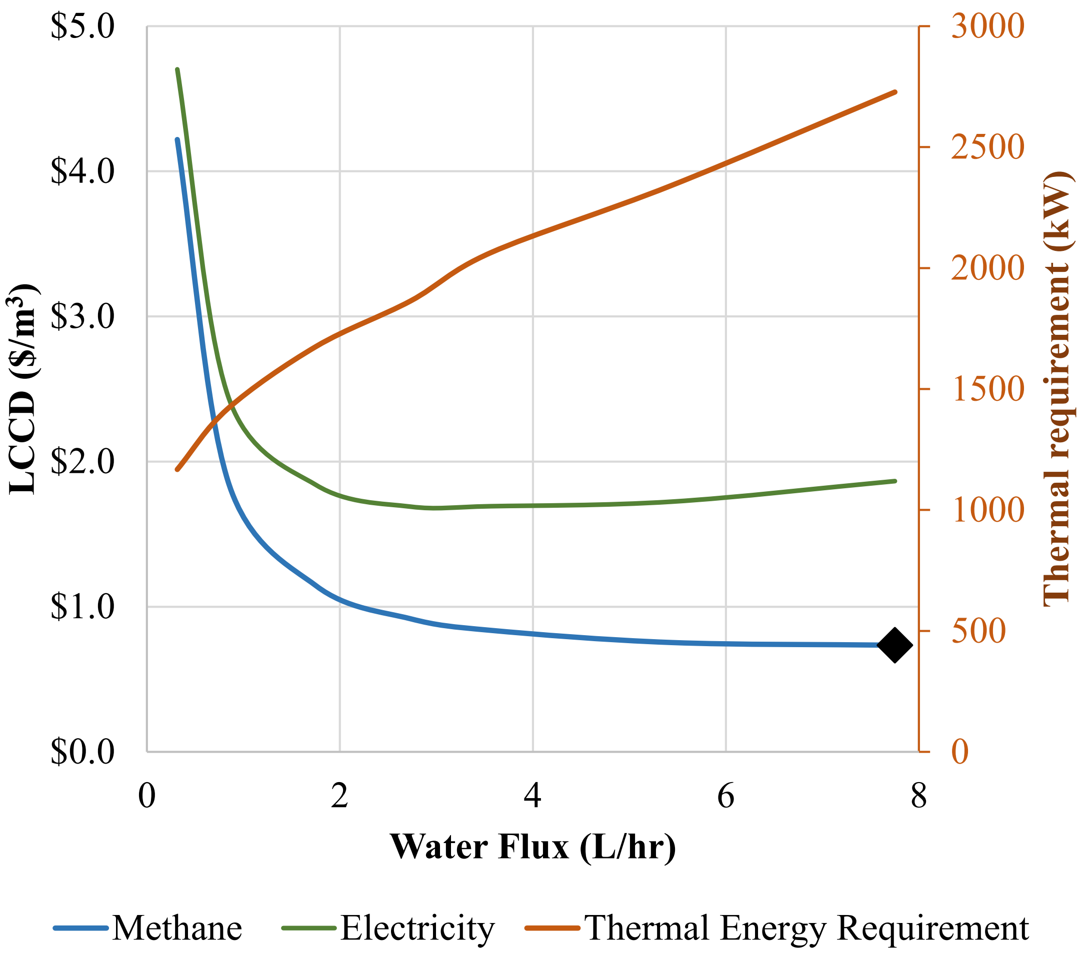
- **Increase in pumping distances results in higher energy requirements**

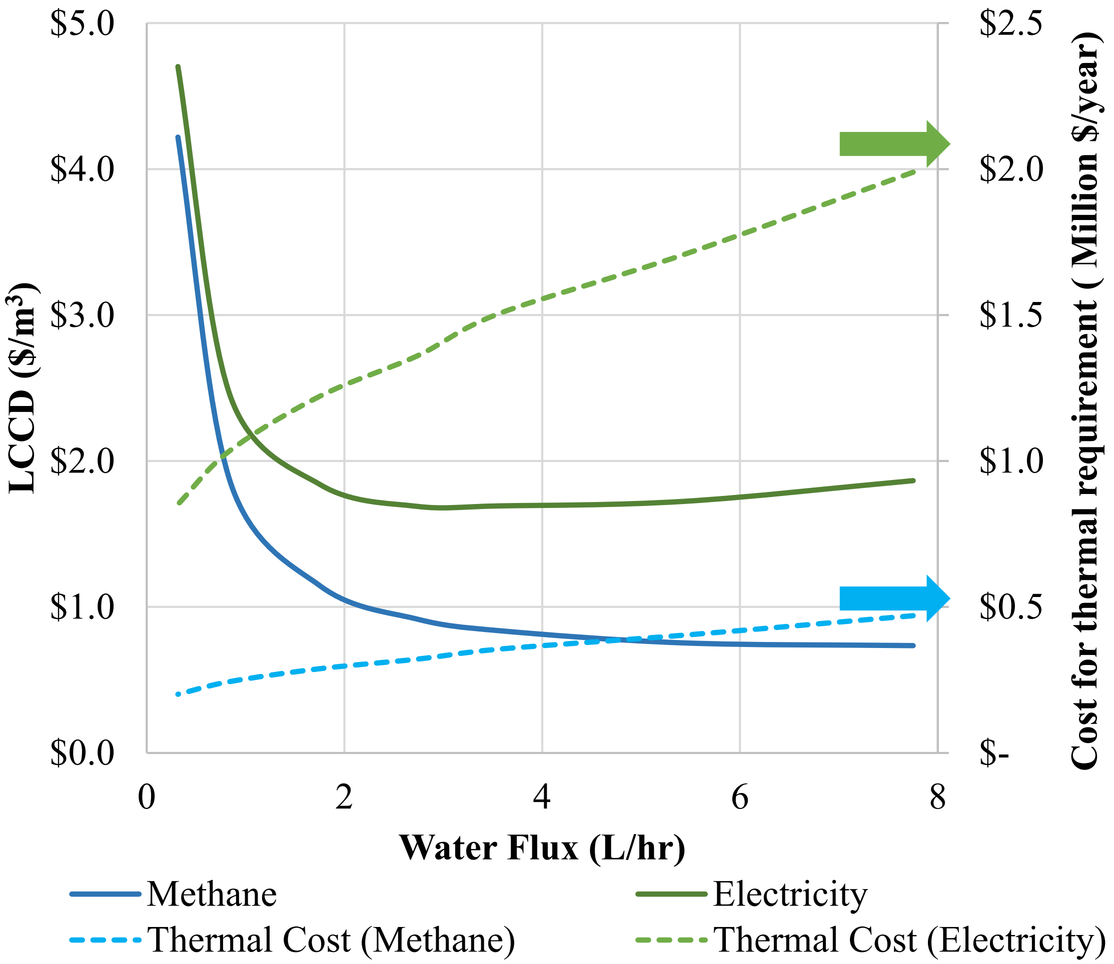
Brine Concentrator + Crystallizer Thermal Source Effect on LCCD



- Using methane as the thermal source for the brine concentrator reduces costs significantly and allows to use smaller systems at full capacity

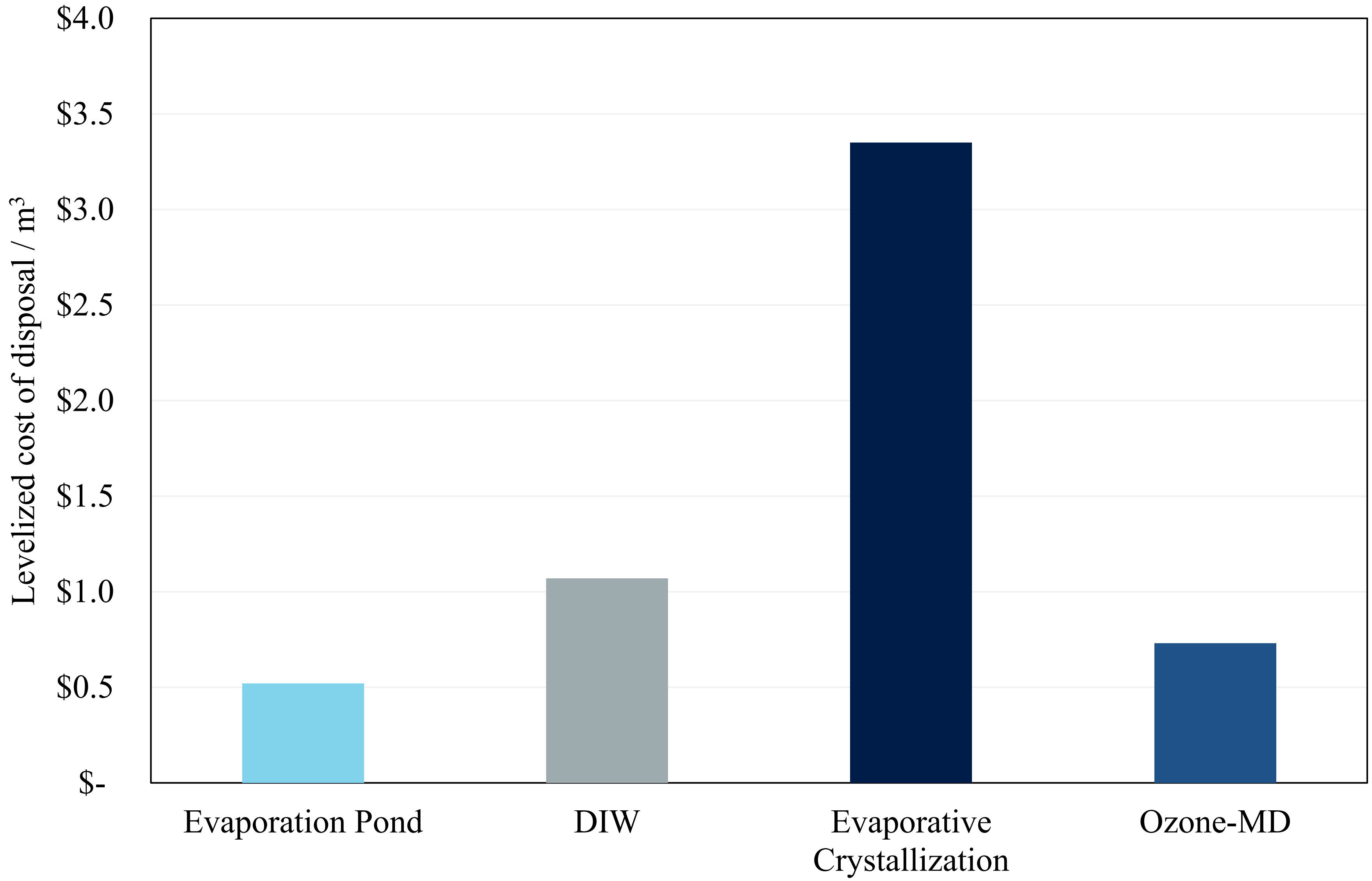
Ozone-MD Thermal Source Effect on LCCD





Increase in flux increases energy requirements, making thermal source the key cost component for O&M

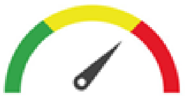
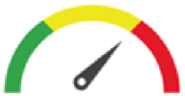
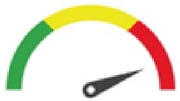
Levelized Cost



LCCD is lowest for evaporation ponds due to low O&M requirements.

Conversely high energy requirements and equipment cost for evaporative crystallization make this option the highest LCCD.

General Observations

System	Cost of disposal $(\$/m^3)$	Resource recovery	Energy consumption	Modularity
Ozone-MD	\$ \$	✓		✓
Evaporation Pond	\$	✗		✗
Deep Injection Well	\$ \$ \$	✗		✗
Brine concentrator + Crystallizer	\$ \$ \$ \$	✓		✓

Conclusion

Ozone-MD is placed second when considering methane as a thermal source. The levelized costs of disposal are competitive to those of conventional concentrate management systems

Ozone-MD is a viable option when value is placed on resource recovery. Which is of vital importance for water-stressed regions.

There is no one size fits all solution when selecting concentrate management systems. Best scenario conditions are site dependent.

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Zachary Binger

Southern Nevada Water Authority
Universities Council on Water Resources

WEST

HER Lab

ART Lab

THE UNIVERSITY OF ARIZONA

Questions?

Additional Slides

General Observations

- Evaporation pond LCCD is the lowest at $0.52/m^3, however this system is highly limited by region-specific conditions

- LCCD for DIW, rapidly increases with pumping distance. If the pumping distance is more than 30 km, the best-case scenario costs double.

- The best-case scenario for Ozone-MD using methane as a heat source places the system LCCD second to the evaporation ponds. When considering the market price of recovered water, ozone-MD costs are competitive to those of evaporation ponds.

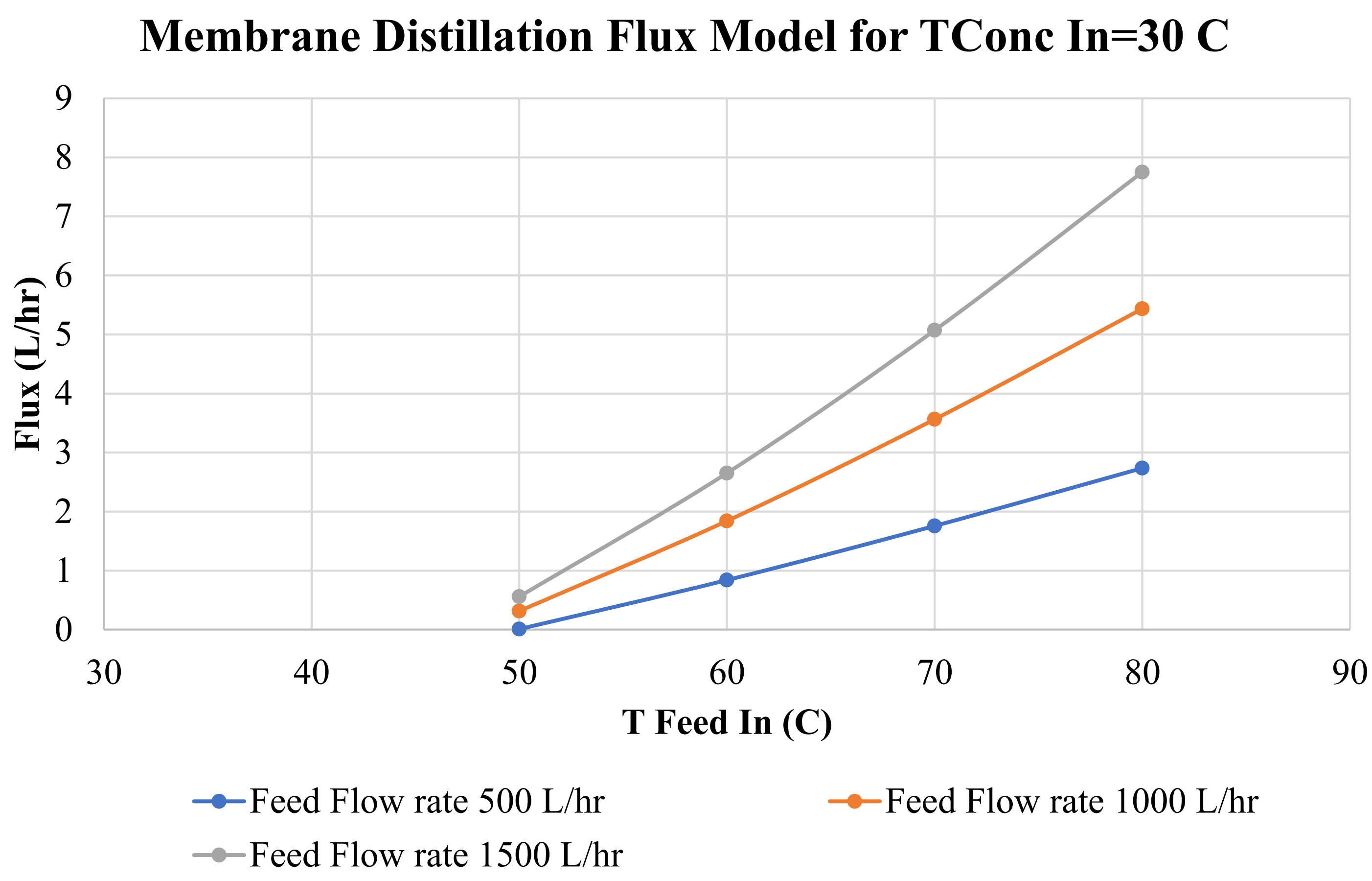
Ozone-MD system Model

Input variables

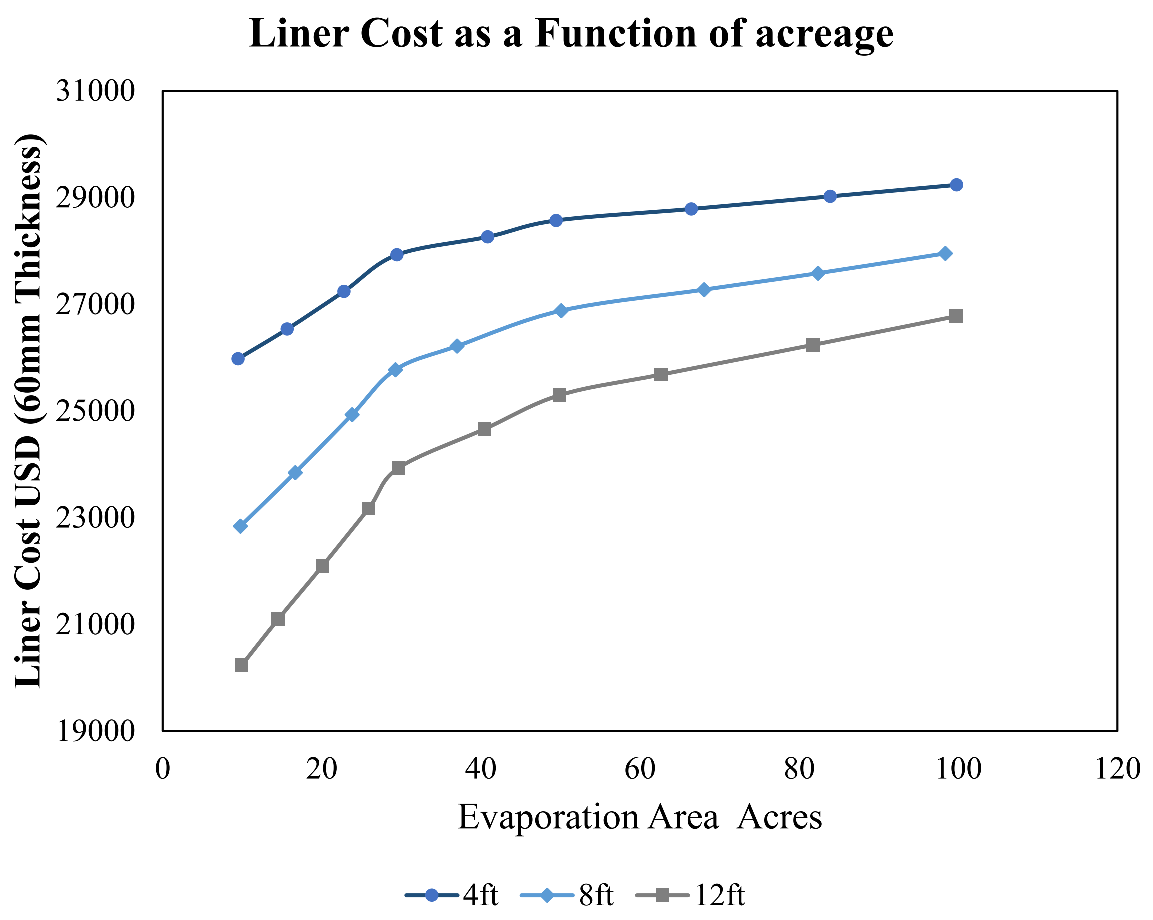
Feed Flow Rate	500-1500	L/hr
Salinity	3-35	g/L
Tf,m	50-80	°C
Td,m	30-40	°C

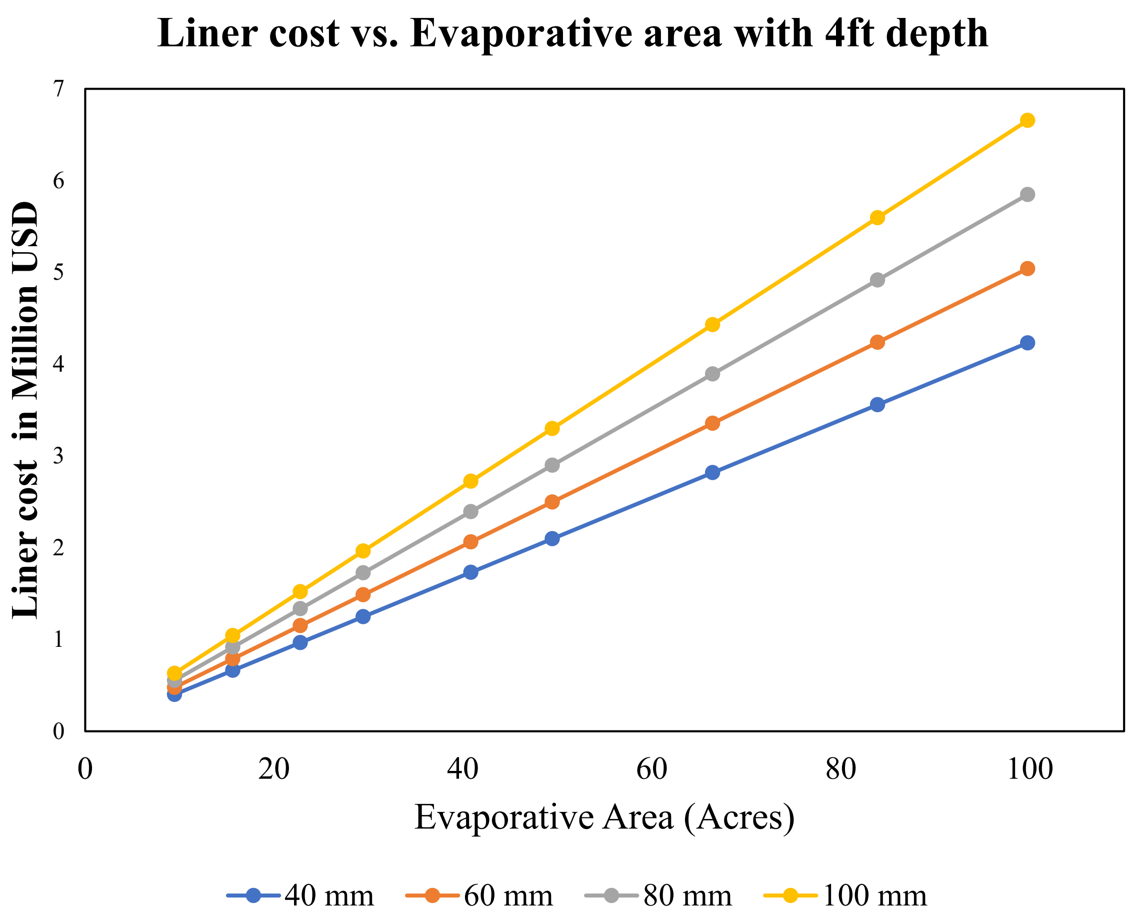
$$J_w = \frac{1}{R}\left(P_{f,m}\left(T_{f,m}, S_{f,m}\right) - P_{d,m}\left(T_{d,m}, S_{d,m}\right)\right)$$

Jw = flux
(Pf,m)= Water vapor pressure on feed side
(Pd,m)= Water vapor pressure on DI side
R= mass transfer resistance
(Tf,m and Td,m)= Temperature at membrane surface
(Sf,m and Sd,m)= Salinity at the membrane surface

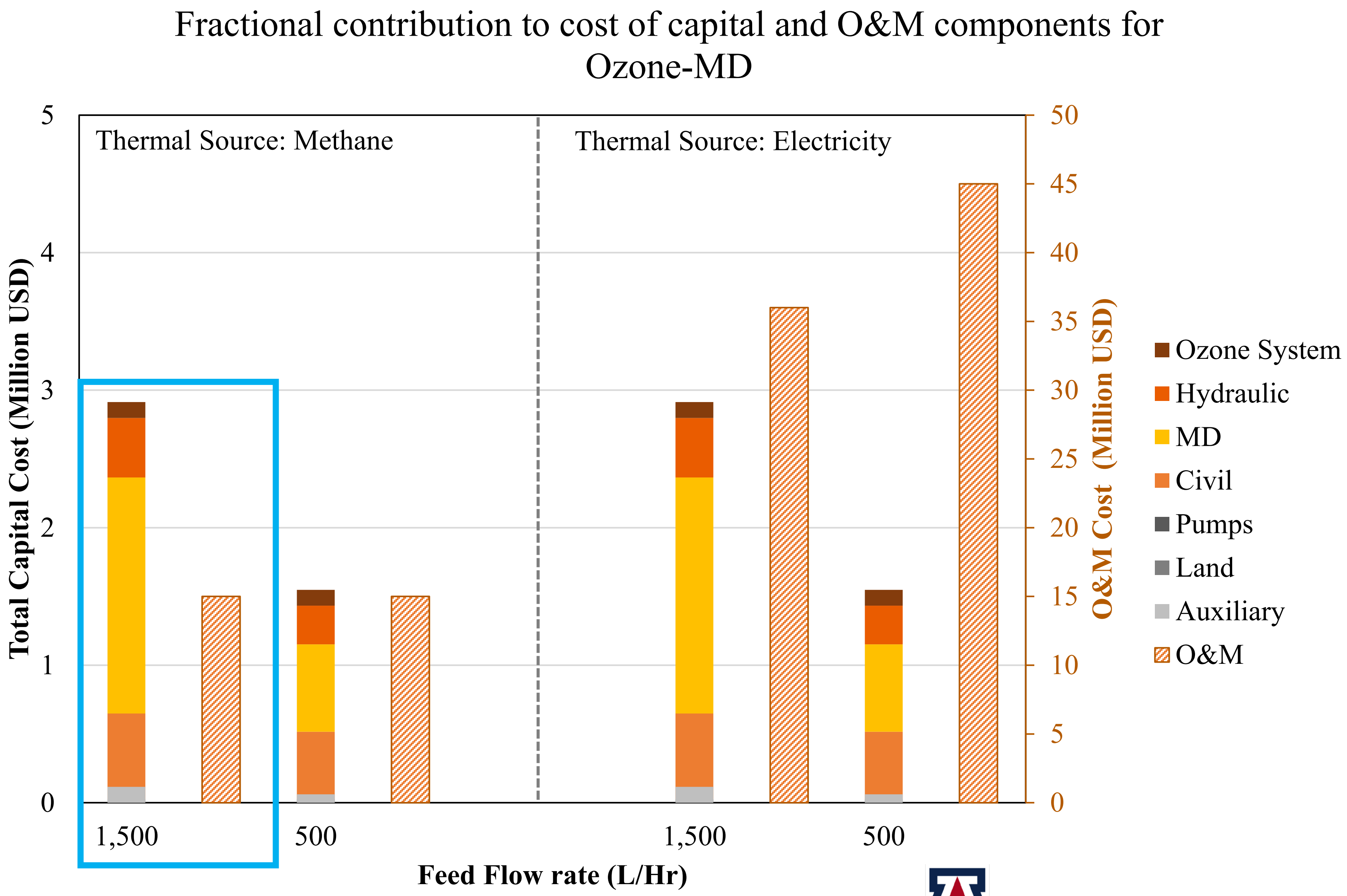


Ozone-MD liner thickness sensitivity effect on cost





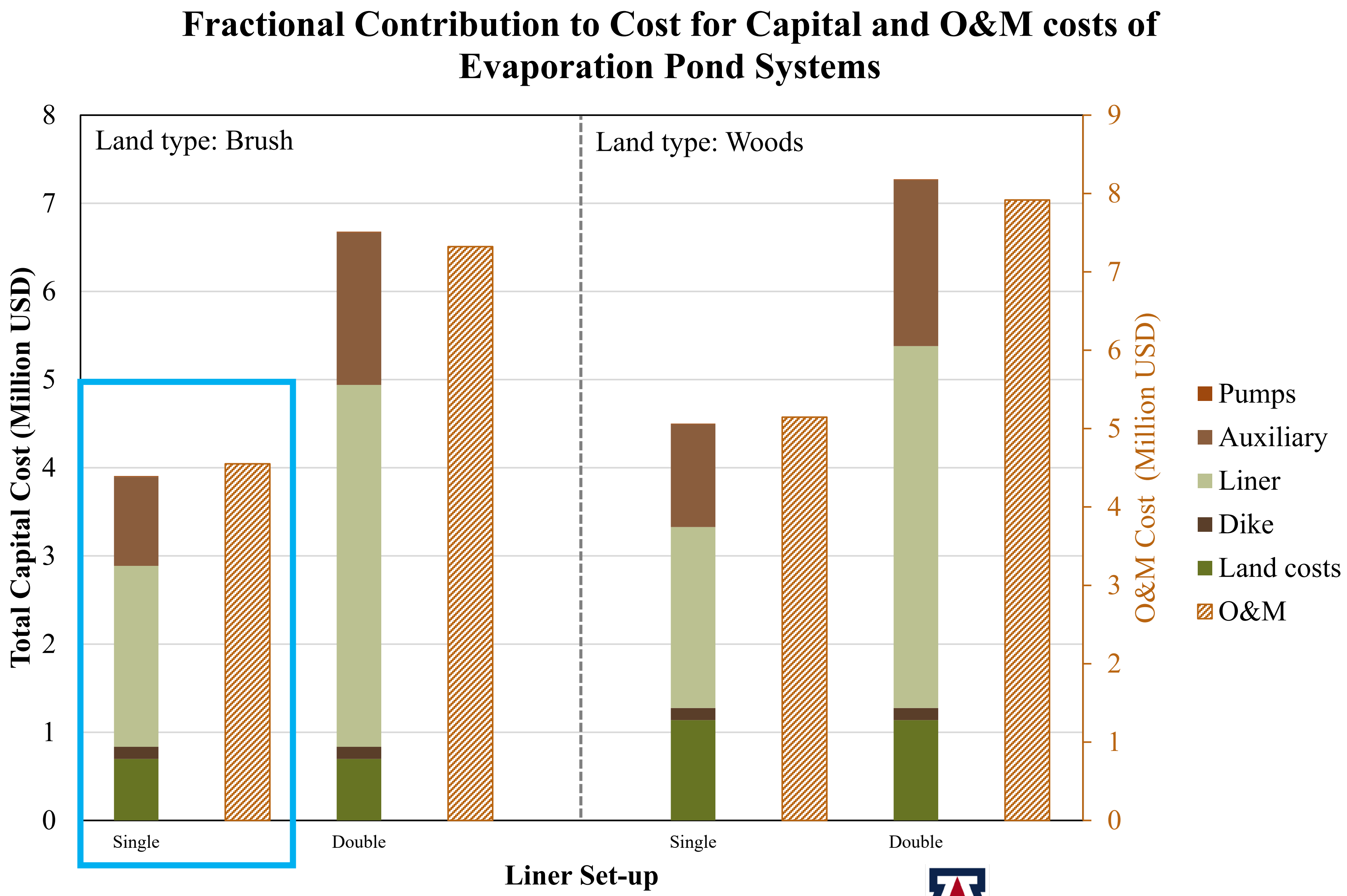
Ozone-MD



LCCD is $0.73/m3

Membrane modules make up 21-35% of the capital cost.

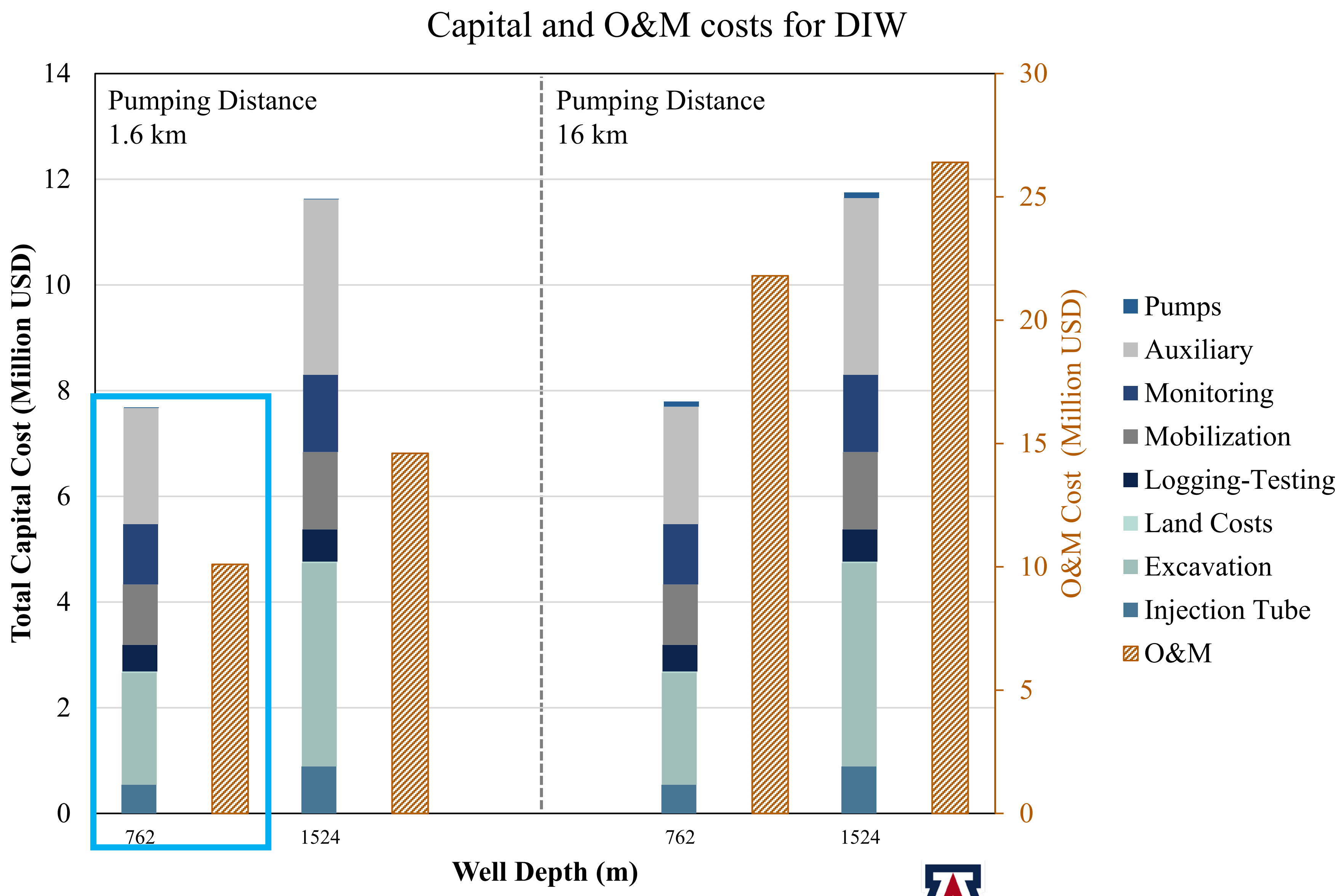
Evaporation Pond



Levelized cost of concentrate disposed (LCCD) is **$0.52/m3**

Biggest contribution is liner at 39 to 50% of capital costs

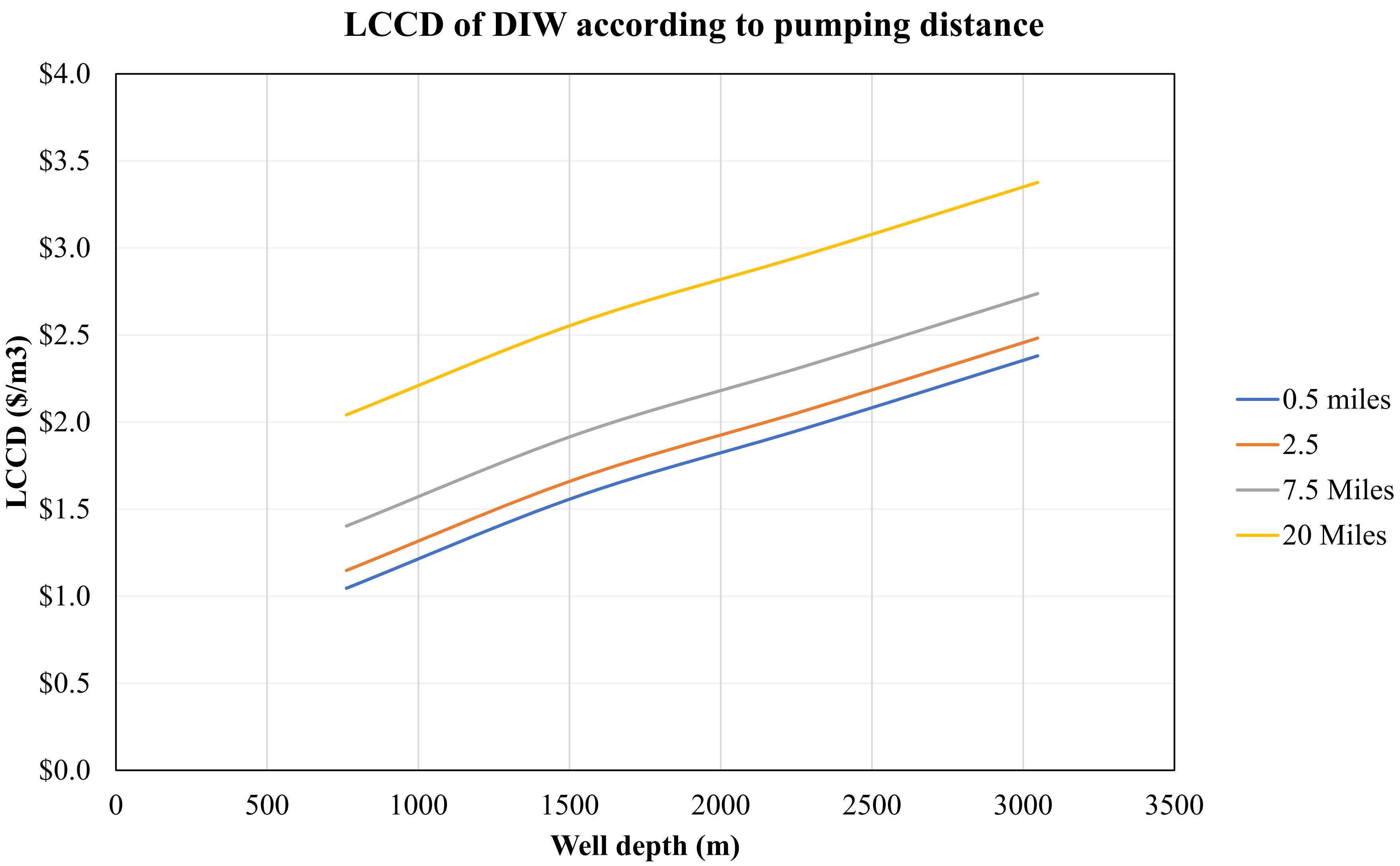
Deep Injection Well DIW



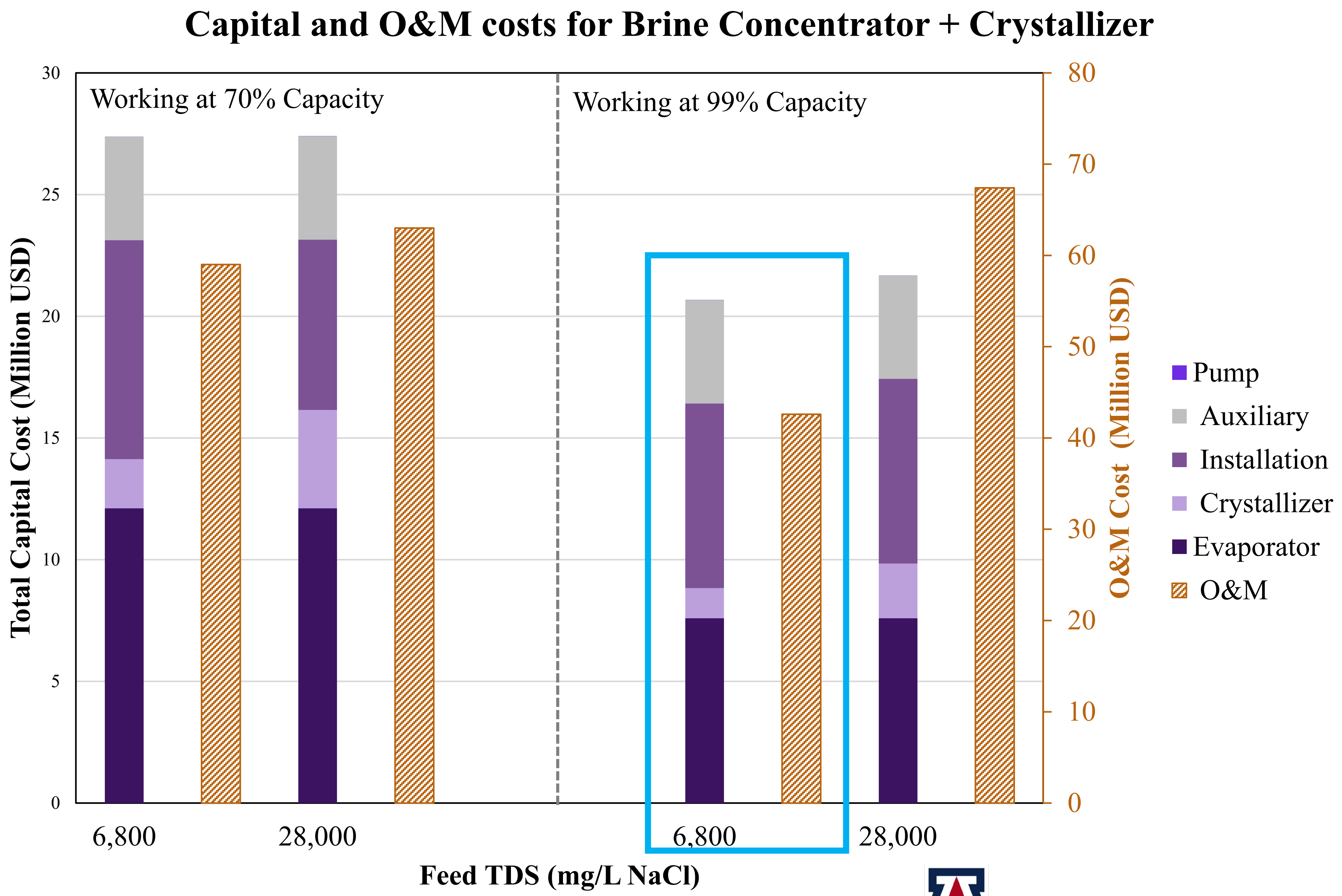
LCCD is 1.07$/m^3

Biggest effect on cost is for installed casing which contributes up to 22% of capital cost.

Effect of pumping distance on DIW LCCD



Brine Concentrator + Crystallizer



LCCD is $3.35/m3

Evaporator and installation costs are 56-74% of capital cost