Oil and Gas Produced Waters: Reuse in Agricultural Operations

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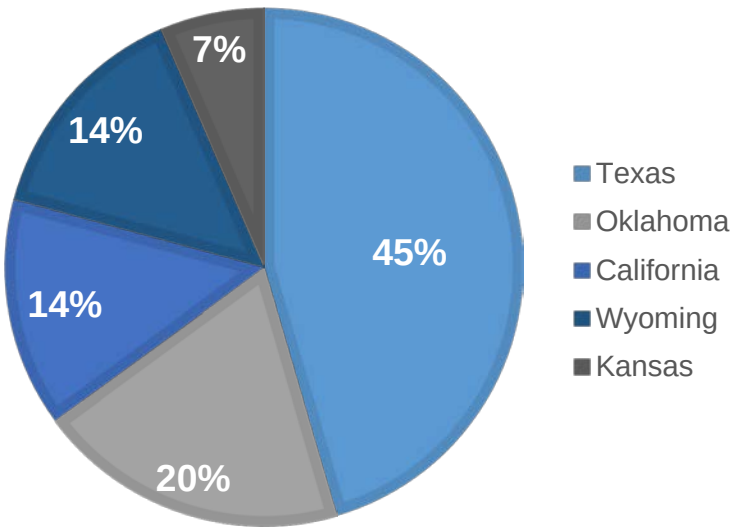
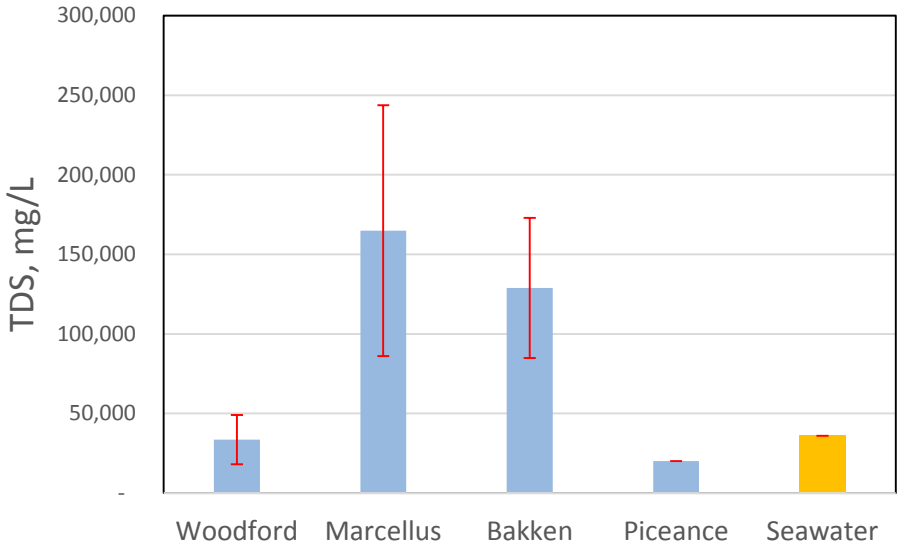
Produced Water

- **Produced water** – all water returned to surface via a well borehole
  - Sum(fracturing fluids, formation water)
  - 21 billion bbl/yr in U.S. (1M wells)
    - 5:1 to 8:1 water:oil
  - 31 Active O&G producing states
- WQ is highly variable
  - Salts, minerals, metals, O&G, radionuclides, and organics





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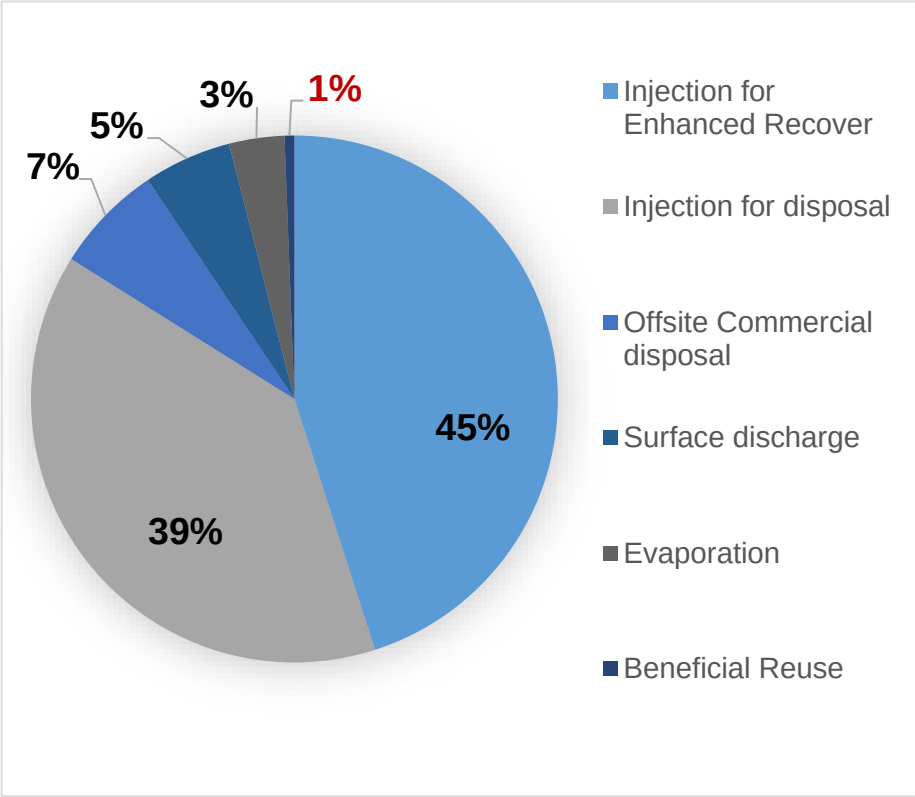
Produced Water Management

- Current management practices:
  - **Injection for EOR**
  - Injection for disposal
  - Offsite treatment & disposal
  - Surface discharge
  - Evaporation and solids disposal
  - Beneficial reuse
- Multitude of factors are motivating energy industry to move from rejection to other reuse options



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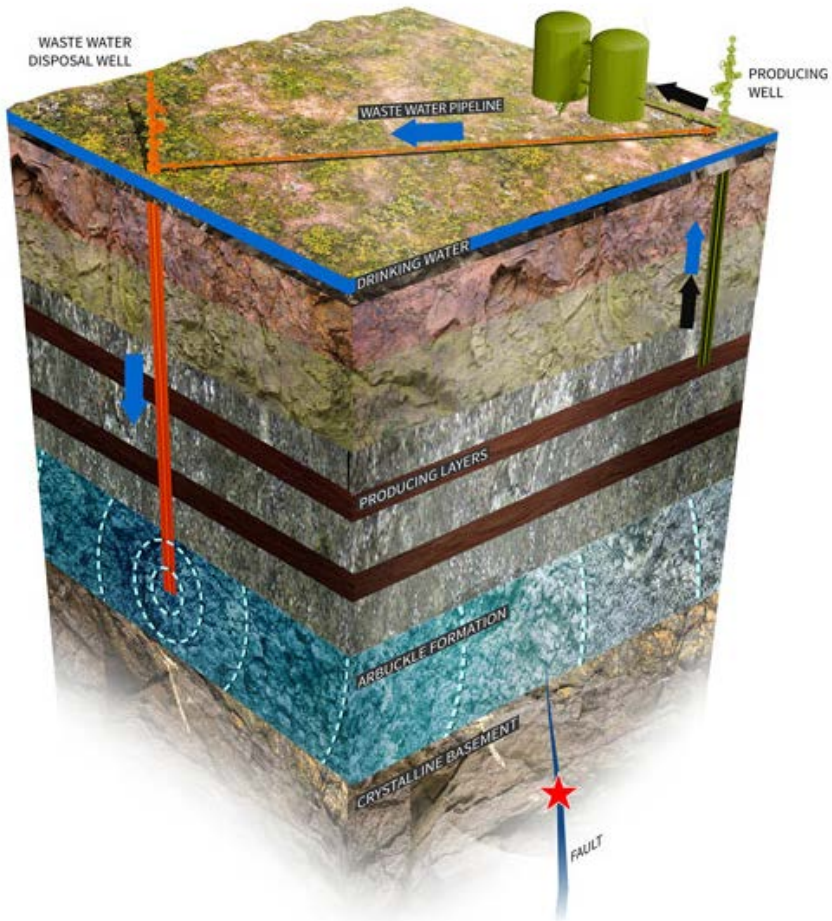
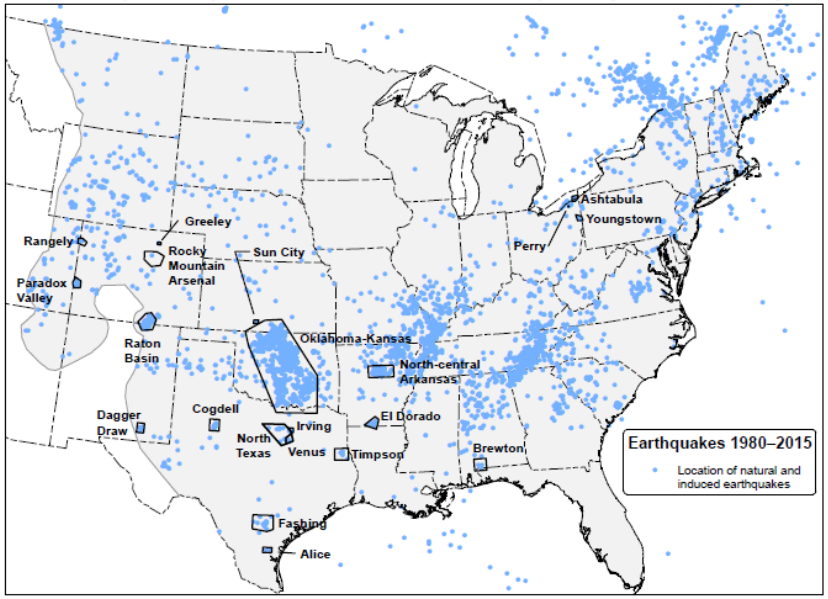
Why not reinjection?



Class II Injection Wells



USGS map displaying 21 areas where scientists have observed rapid changes in seismicity that have been associated with wastewater injection. The map also shows earthquakes—both natural and induced—recorded from 1980 to 2015 in the central and eastern U.S. with a magnitude greater than or equal to 2.5.

"Wastewater disposal is thought to be the primary reason for the recent increase in earthquakes in the CEUS. While **most injection wells are not associated with earthquakes**, some other wells have been implicated in published scientific studies, and **many states are now regulating wastewater injection in order to limit earthquake hazards**."

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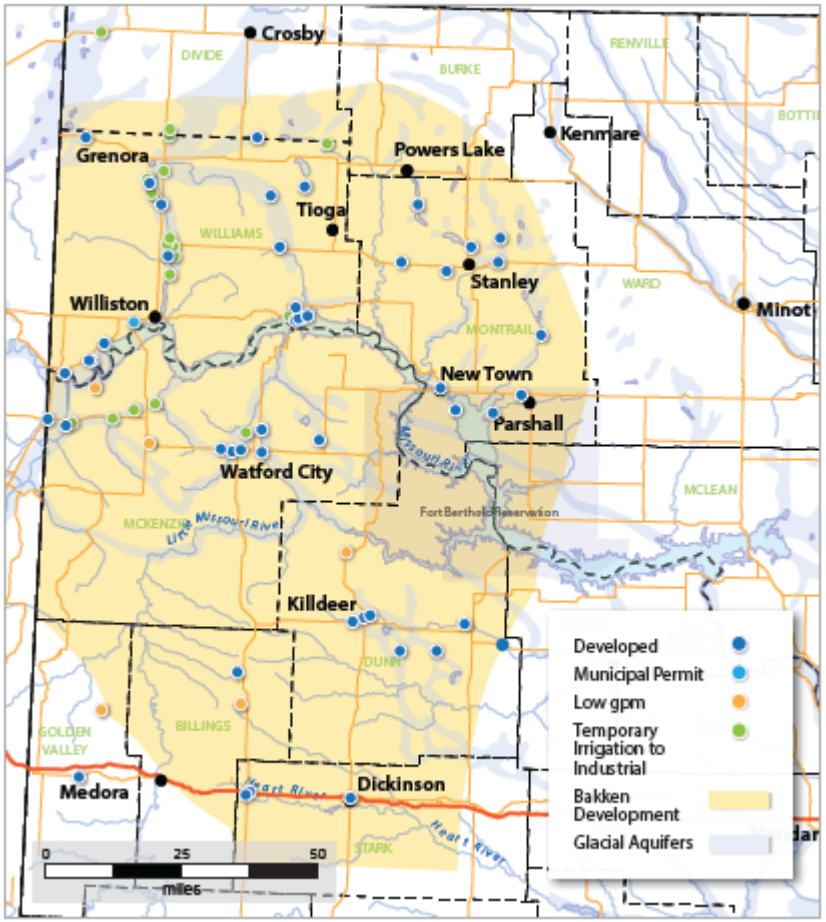
Motivators for Management

Operating Water Depots (as of September 11, 2012)



Water in Oil & Gas Development

1. Acquisition
   - 1 to 5 MG/well for fracturing
   - Competition for limited supplies
   - $6 to $25/1,000 gal
2. Disposal
   - $12 to $42/1,000 gal for deep well injection
   - $0.40 to $3.98/bbl for evaporation pits
3. Transportation (new and used)
   - Limited # supply locations = long transportation distances
   - $15 to $120 for acquisition
   - $15 to $214 for disposal
   - Piping infrastructure present in limited scenarios

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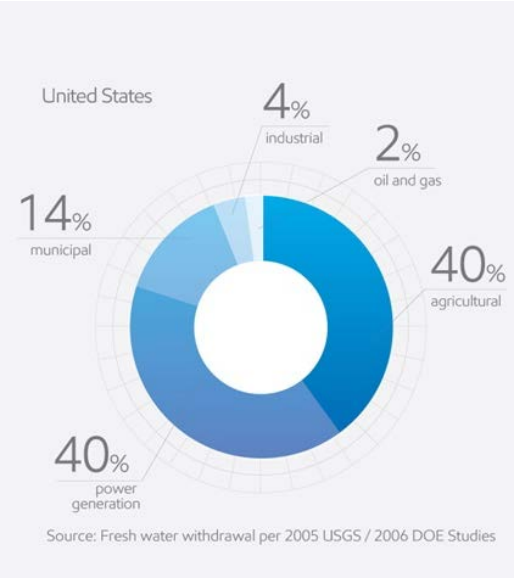
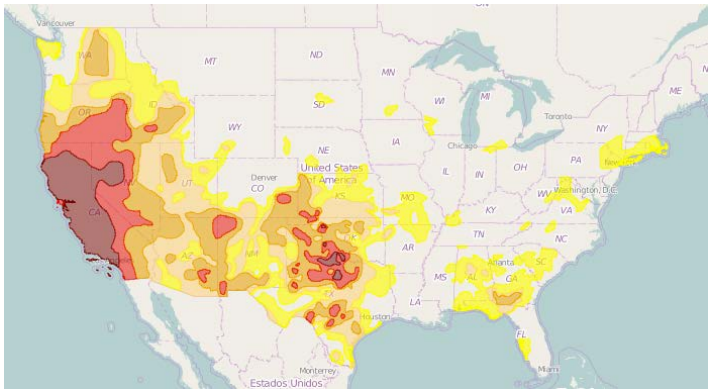
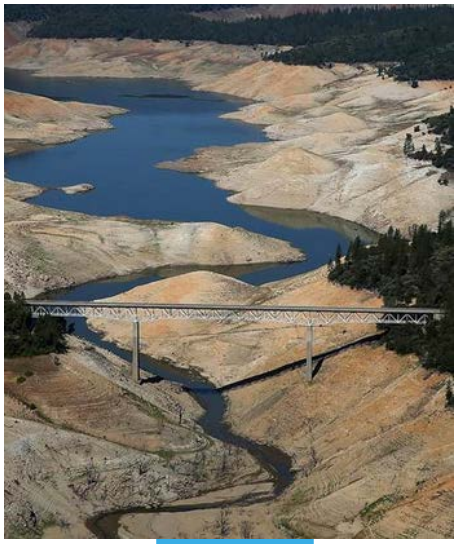
Why reuse produced water?







Reduction in surface water = increased demands on groundwater

Over pumping of groundwater = deeper & more $$$$ wells

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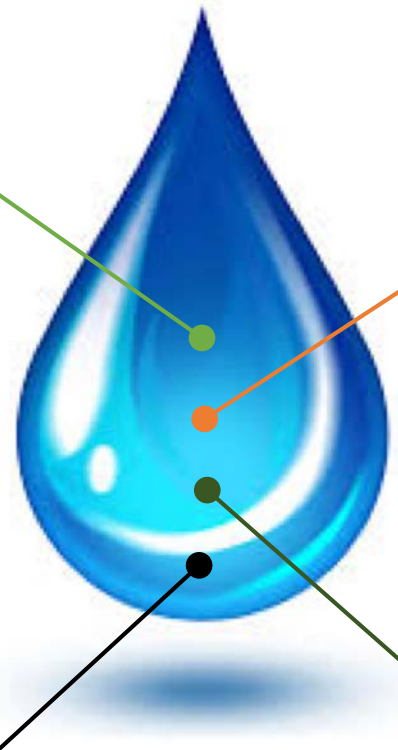
Produced Water as a Resource

Precious Metals –

- Lithium, iodine and uranium
- Rare earth elements (REEs)



Water – 2.4 BG/day

- Irrigation and livestock watering
- Stream augmentation
- Industrial process make-up

90k acres irrigated w/ 50k acre-feet of PW in CA

Tx A&M used 4:1 blend of PW to irrigate cotton (GW conservation)

Other –

- Oil and gas recovery, $$
- Methanol + other additives for reuse
- Energy production (heat & chemical potential)

Minerals –

- NaOH production from $NaHCO_3$ w/ membrane electrolysis
- Na, K, Mg, and Ca

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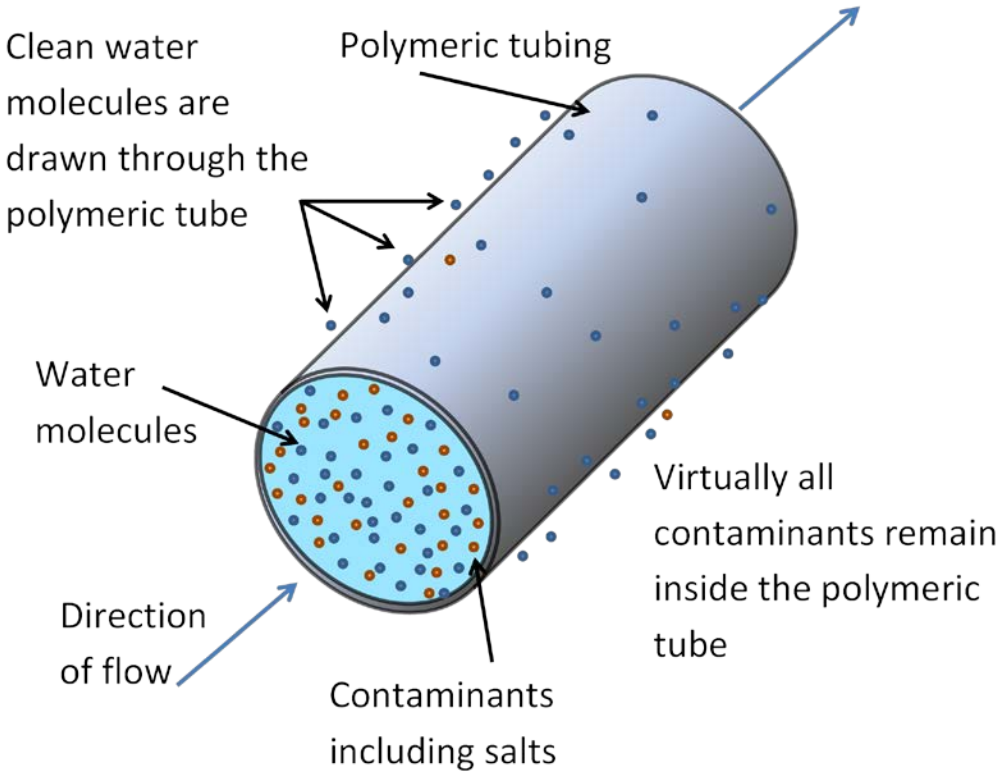
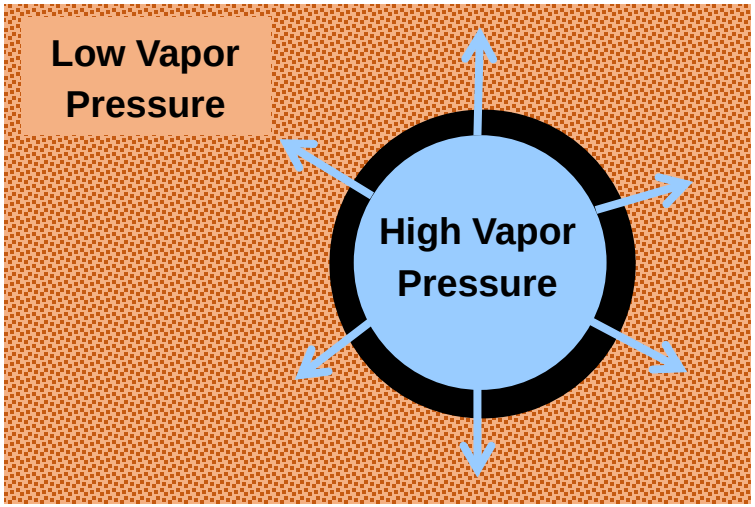
Reuse Options

- Reuse options for produced water
  - Stream flow augmentation
  - Dust suppression
  - Industrial processes
  - Agricultural/livestock production
- Numerous constraints make reuse unappealing for industry
  - Diffuse nature of water production
  - Cost and complexity of treatment
  - Proximity of water production to reuse site
  - Environmental regulations
  - Water is ***NOT*** their business – managed by service companies
- The case for use in agricultural production is strong
  - Agriculture accounts for ~80% of freshwater withdraws in the U.S.
  - Rapid population growth in Western U.S. and other rural areas has increased competition for water resources
  - Nexus of food-energy-water becoming more prominent in national psyche
  - Sustainability and security of agricultural production is a domestic concern in light of climate change and other factors
  - Energy resource development in close proximity to agricultural areas
- We have done it before….CBM boom in WY led to explosion in agricultural production due to water availability
  - Key challenge is desalinating water simply and cheaply!

Subsurface Desalination Irrigation





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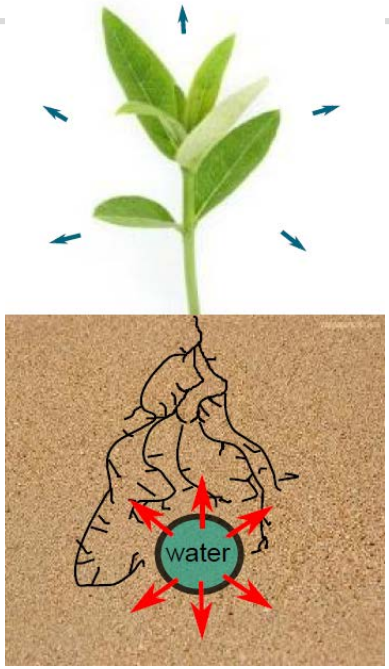
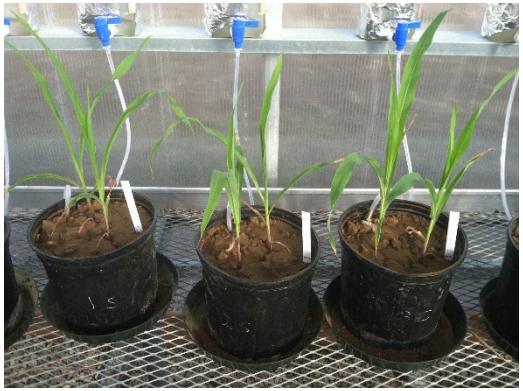
Subsurface Desalination Irrigation

- Non-pressure driven membrane process
  - Transport driven by water potential in the soil (soil suction)
- Process allows for minimal pretreatment and capability to treat variable water qualities
  - High salinity, high organics
  - VOC removal ~90%
  - Tested CBM, conventional produced, and frac flowback waters





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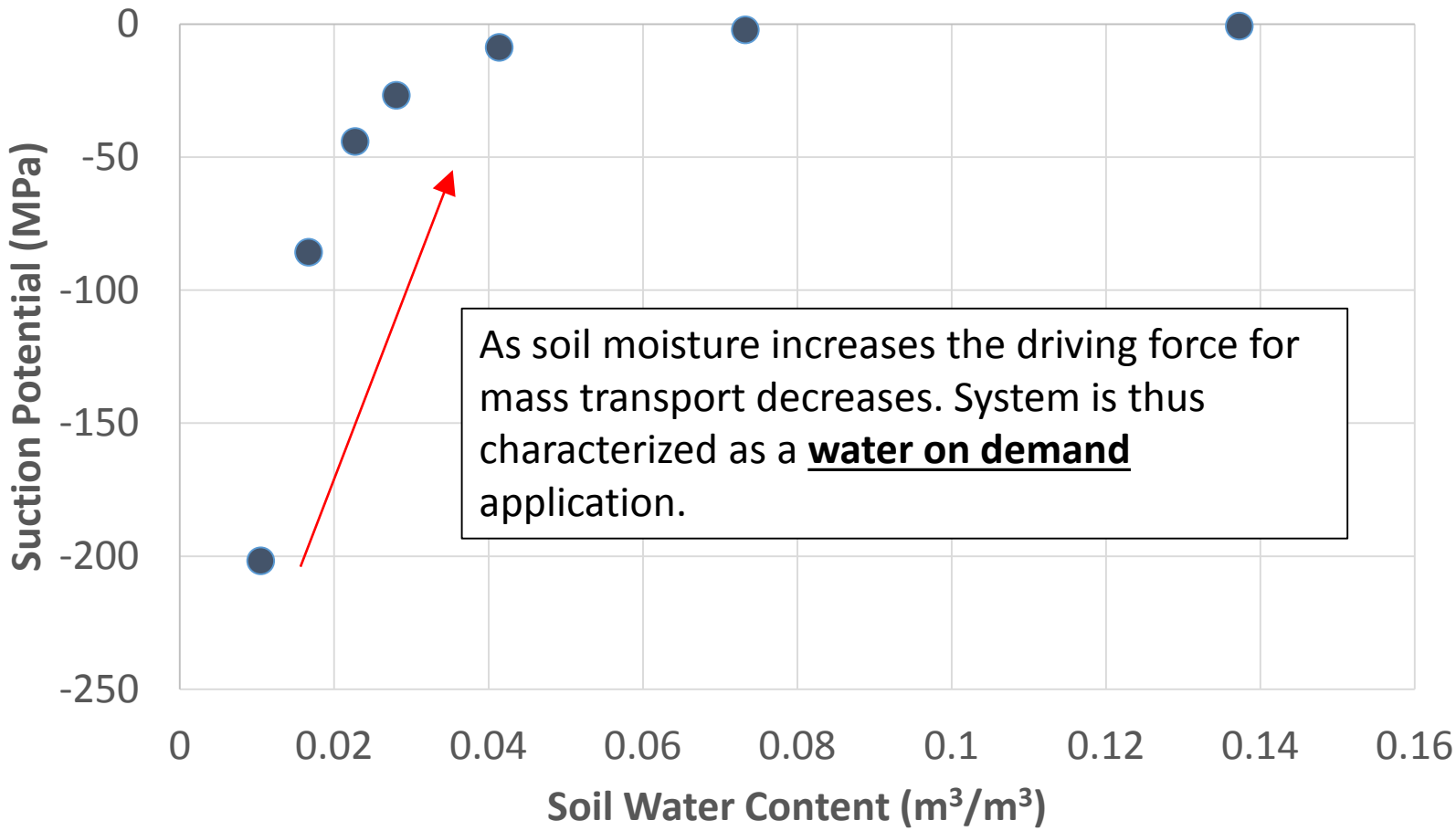
Water Potential for a Sandy Loam



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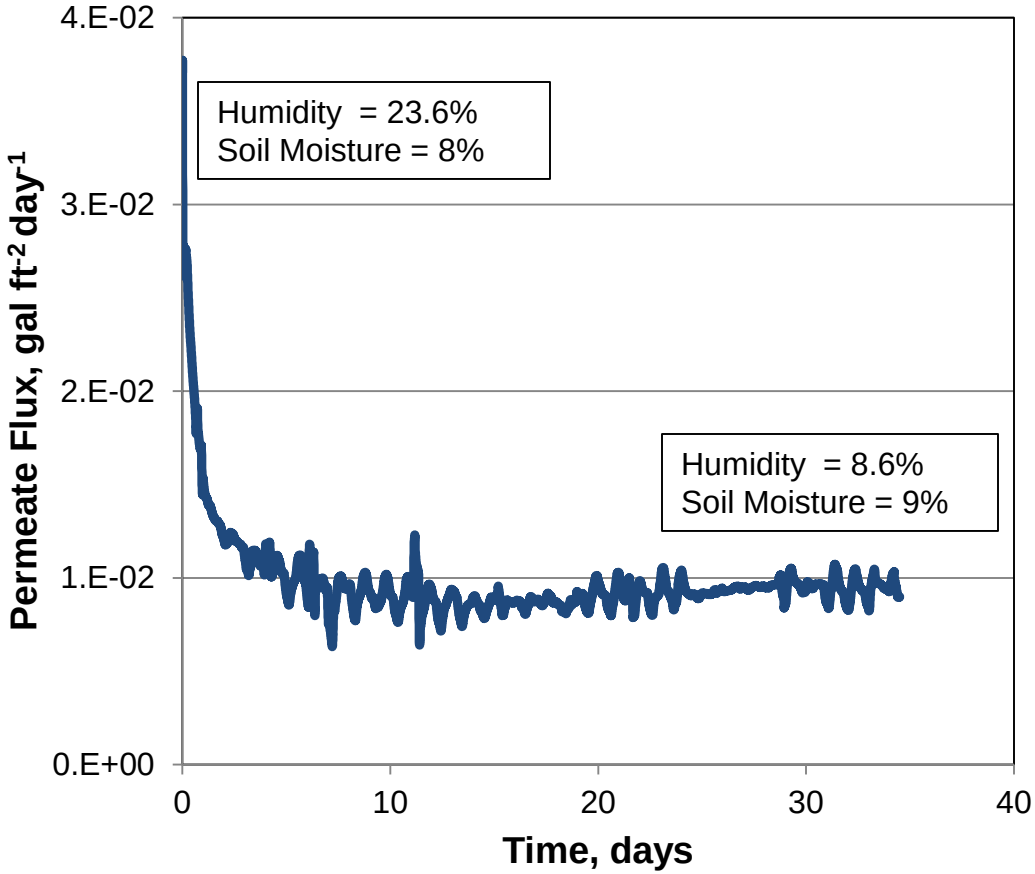
Soil Water Potential and Flux



Optimization of membrane design required to increase water fluxes to match demand as plant matures

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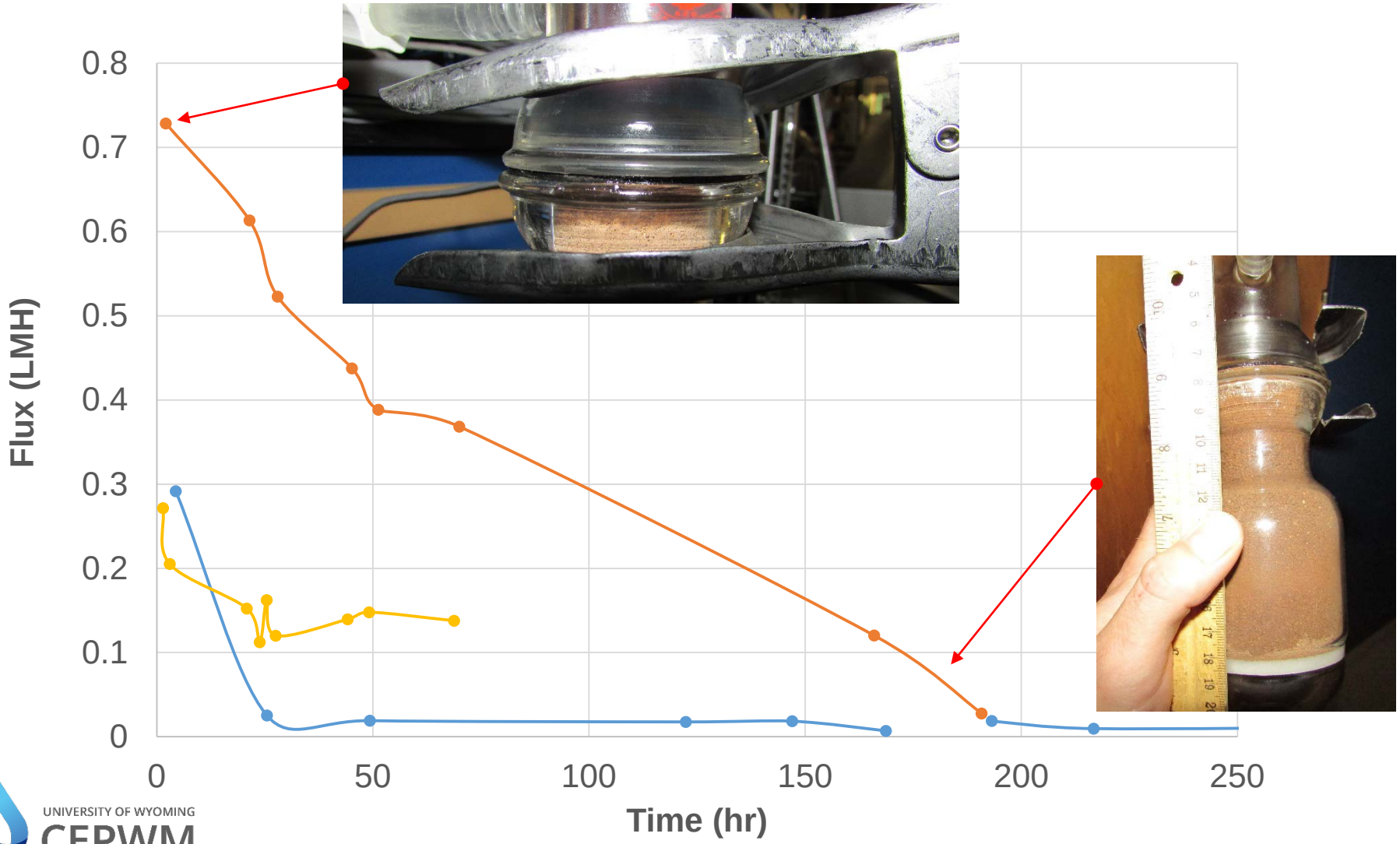
Soil Water Potential and Flux



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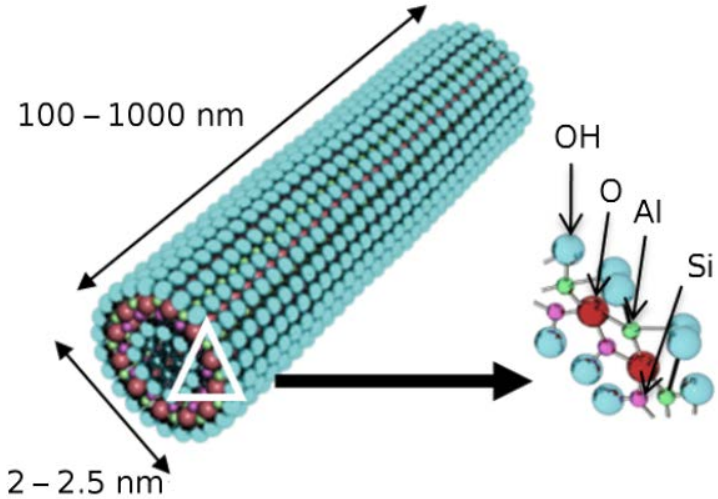
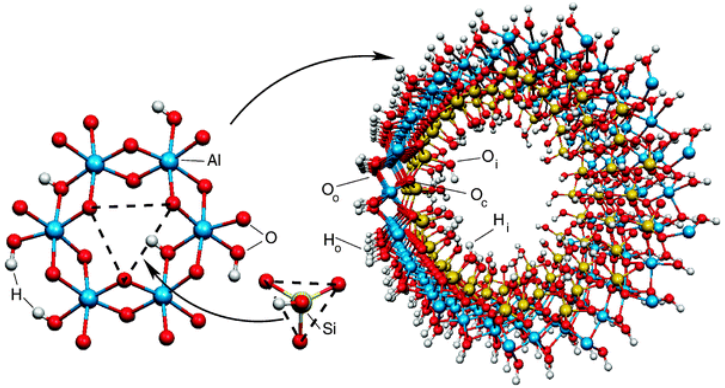
Nanocomposite Membranes

- Nanocomposite membranes – nanomaterials used to enhance thin-film properties
- Nanomaterials selected to tailor mechanical and chemical properties of thin-film
  - Zeolite and silica
  - Metal oxides
  - Nanotubes
- Mechanical properties
  - Enhanced robustness
- Low-fouling surfaces
  - Increased hydrophilicity
  - Catalytic reactions / ROS production
- Flux improvements
  - Increased hydrophilicity
  - High-speed water pathways

Imogolite Nanotubes

- Imogolite - mineral (aluminum silicate) that forms nanotubes
  - Rigid / straight structures as opposed to “spaghetti” structures formed by CNTs
  - “Simple” synthesis techniques relative to CNTs
- Modifiable physical and surface properties
  - Interior and exterior surface chemistry modified by grafting
  - Precursor (Si, Ge) determines opening diameter
  - Length controlled by pressure and temperature conditions





Credit: Creton et al. (2008).

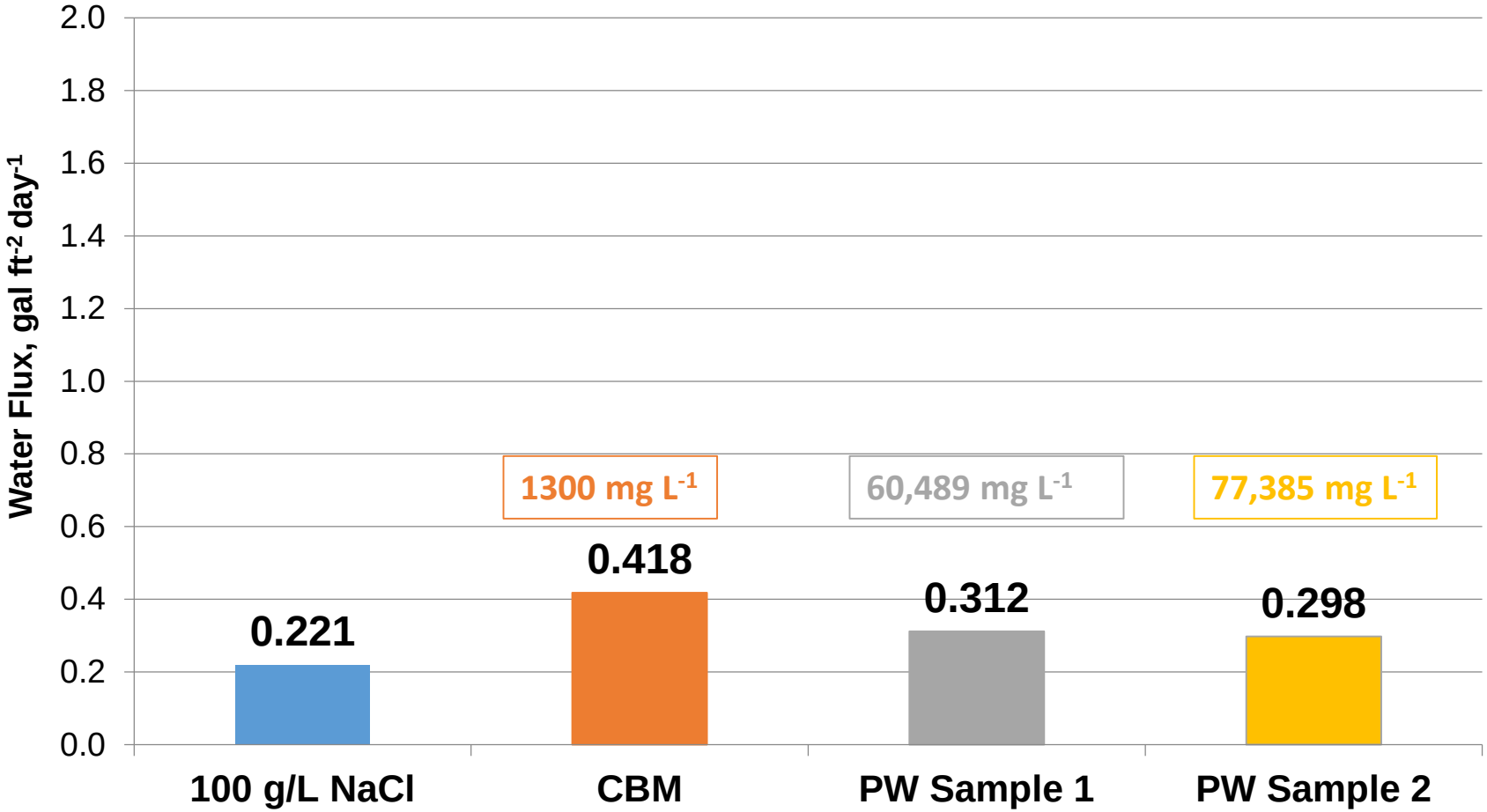
Membrane Design Optimization

Membrane Type	Feed Water g/L NaCl	Permeate Flux gal ft^{-2} day^{-1}	Rejection %
Formulation 1 250 µm Thickness	10	0.0238	99.29
	50	0.0157	99.46
	100	0.0158	99.46
Formulation 1 20 µm Thickness	10	0.289	99.62
	50	0.256	99.96
	100	0.319	99.96
Formulation 2 75 µm Thickness	10	1.93	99.87
	50	1.59	99.98
	100	1.37	99.95

1× Magnitude Increase

2× Magnitude Increase

Water Flux – PV Formulation 1 (20 µm)



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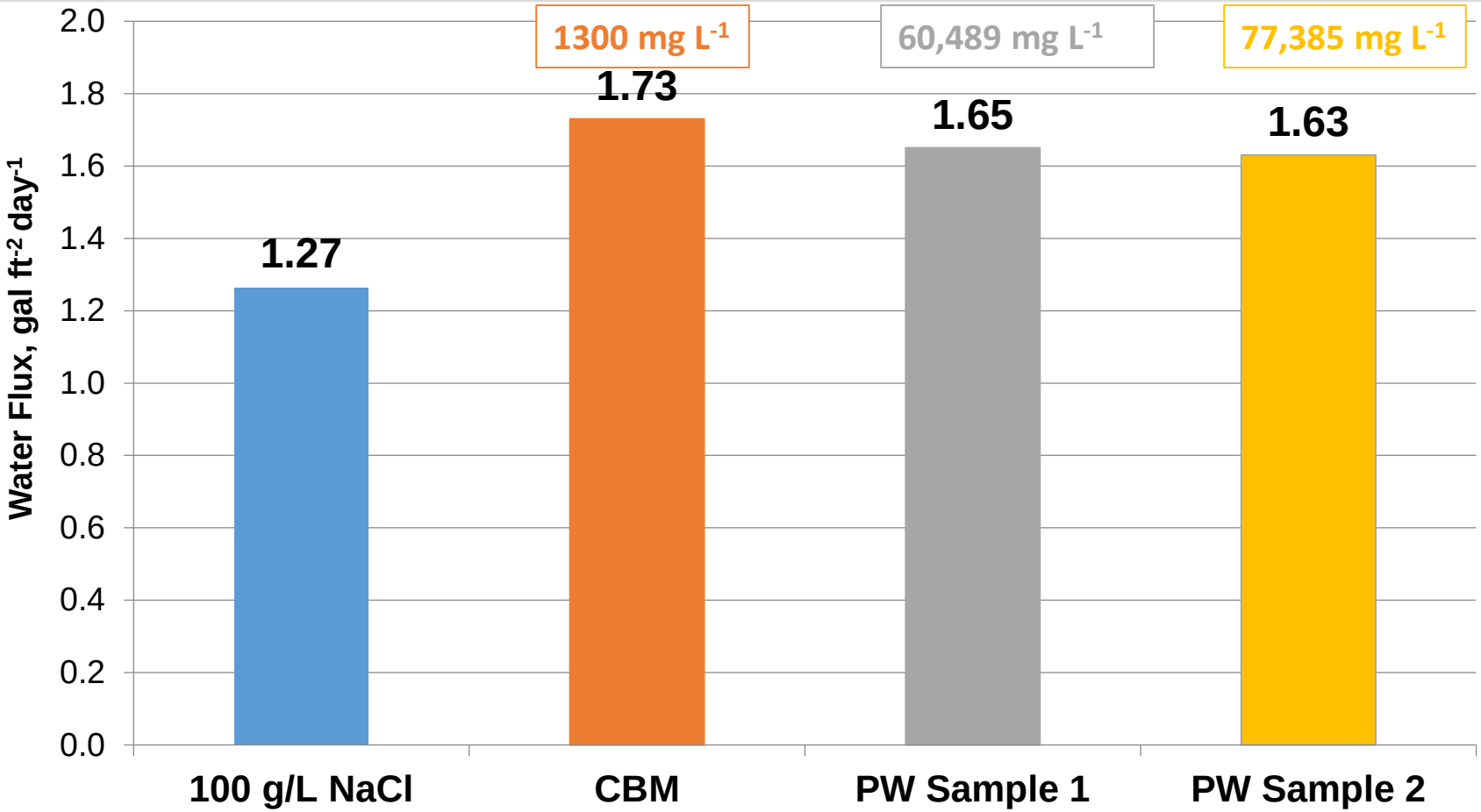
Water Flux – PV Formulation 2 (75 µm)



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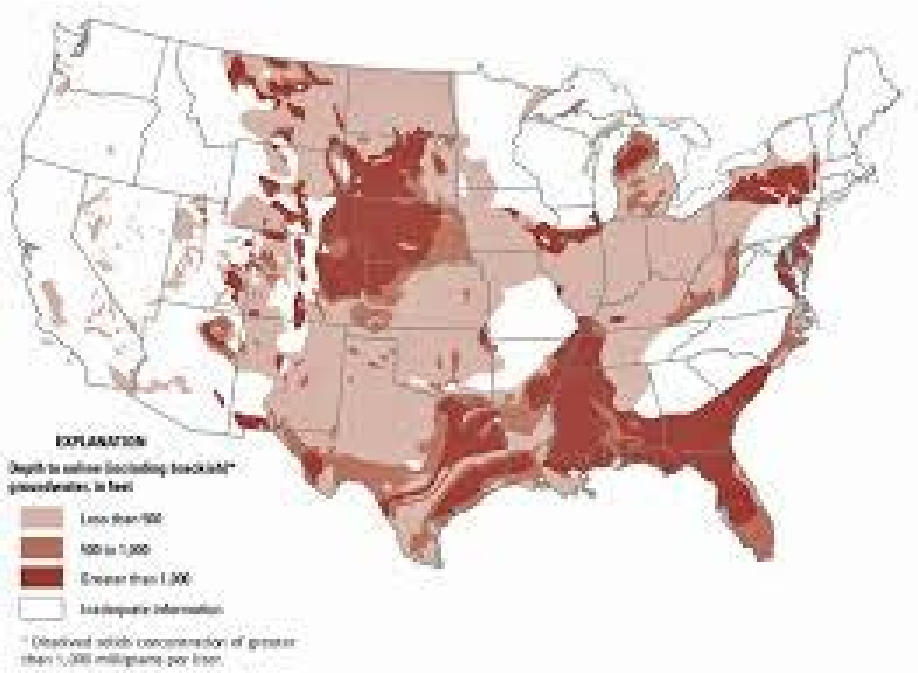
Where do we go from here?

- Produced water is ***but one*** source of brackish water to be used
  - Brackish groundwater
  - Agriculture return flows
- Synergies b/n FO and PV can reduce energy required for producing water suitable for irrigation
  - Future tests focused on quantifying energy consumption and bench marking against RO systems



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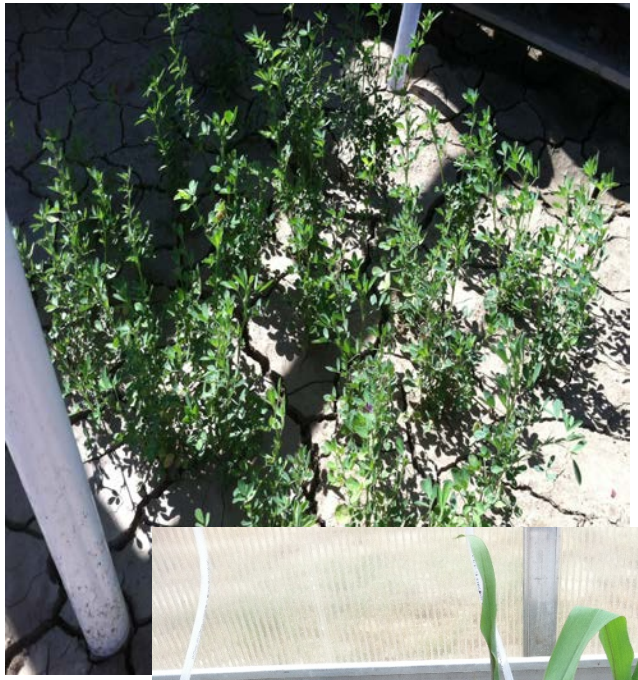
Summary

- Produced water management is a growing concern presenting challenges and opportunities
- Reuse for agricultural production is an important opportunity for arid and semi-arid regions
- SDI process addresses complexity and operational needs for agricultural systems
  - FO-SDI removes contamination risks & improves mobility
  - Membrane development ongoing for flux improvements



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Questions?

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