Existing and Emerging Technology Innovations: Membrane Technologies and Energy Use for Desalination

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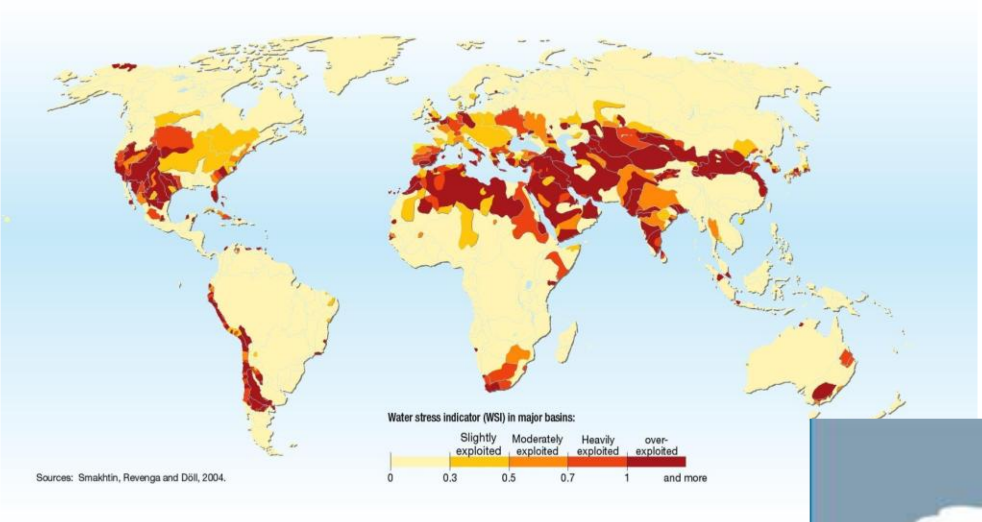
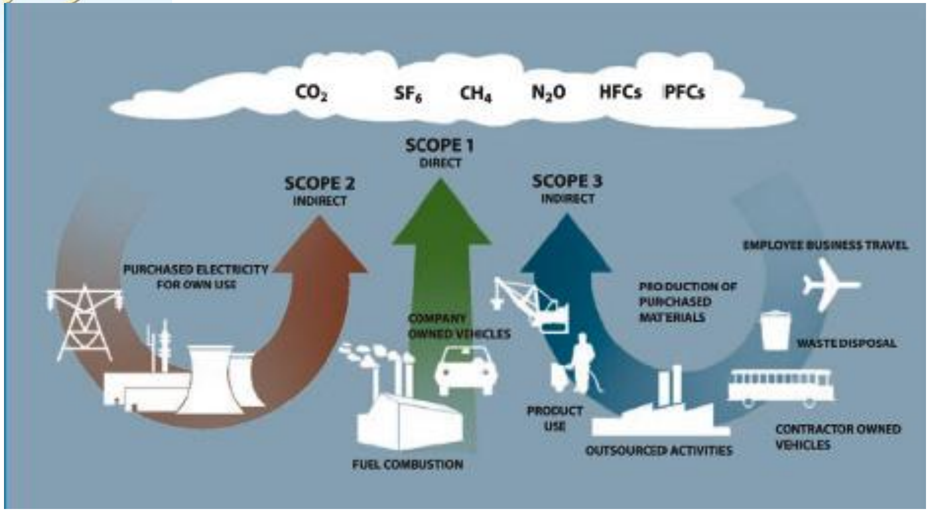
Outline

- Introduction
  - Alternative Water Sources and New Technologies
  - Salinity
  - Desalination by Reverse Osmosis
- Question Posed for Seawater Desalination
  - Energy-Water
  - Energy Price Risk
  - Environmental Impacts
- Desalination Treatment Process Research at USC
  - Membrane Distillation
  - Pressure Retarded Osmosis
- Concluding Remarks

Water and Energy Sustainability

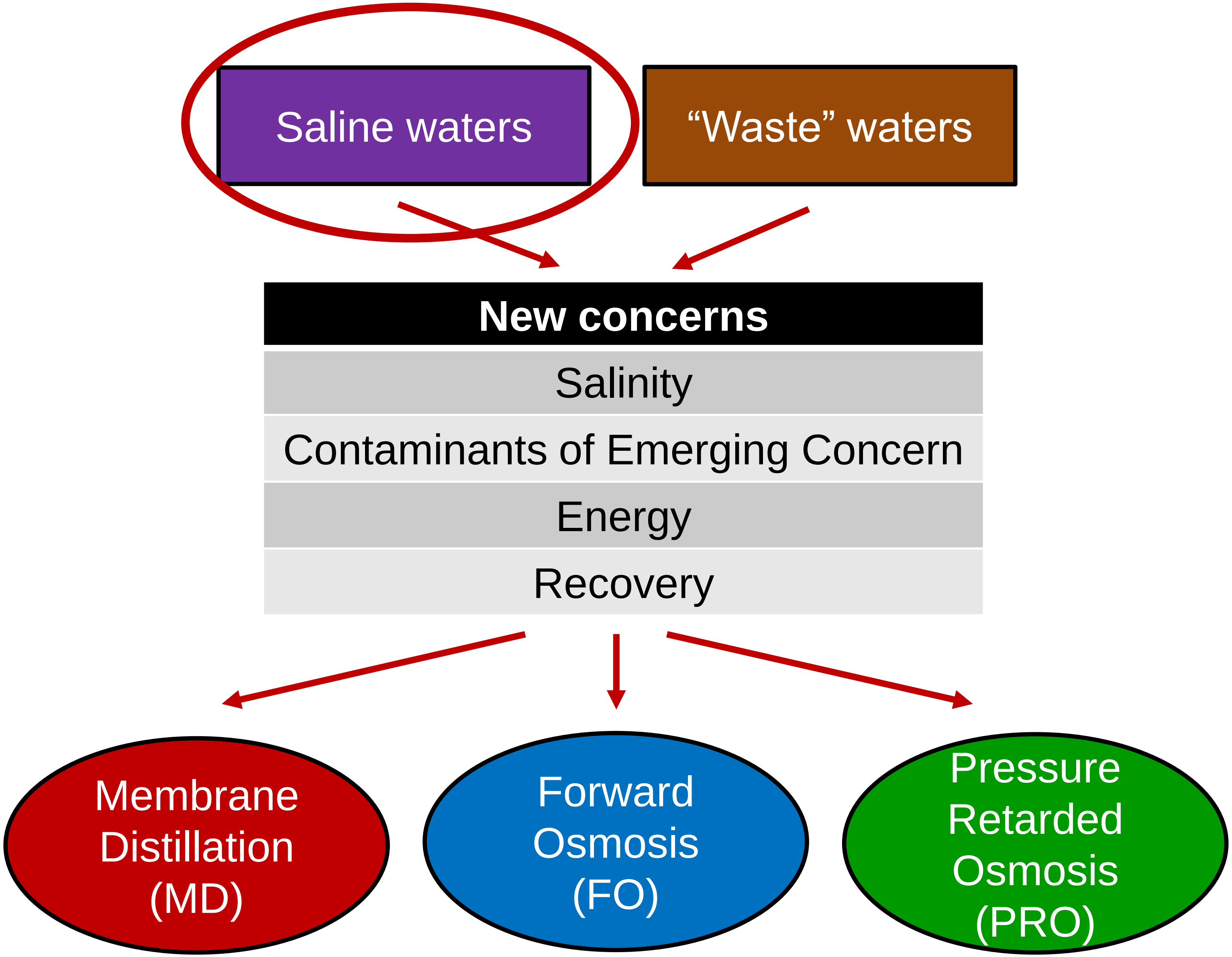


Global water stress:
Water providers relying on alternative sources



Greenhouse gas emissions:
Water providers considering new technologies

Alternative Sources and New Technologies



Salinity

- What is it?
  - Natural or anthropogenic presence of soluble salts in soils and waters
  - Sodium, calcium, magnesium, chloride, carbonate, bicarbonate, sulfate, silica
- What are typical concentrations?
  - Drinking Water: <500 mg/L total dissolved solids
  - Fresh water: <1,000 mg/L
  - Brackish water: 1,500-20,000 mg/L
  - Seawater: 33,000-41,000 mg/L
- Why is salinity an issue?
  - Salts do not degrade naturally over time; accumulate until removed
  - Increasing salinity is exacerbated by human activities
  - Rising salinity levels have agricultural, environmental, and economic costs

Mono Lake 78,000 mg/L
280 M tons dissolved salts

Desalination: Not just for Seawater

- Coastal regions (seawater desalination)
- In-land desalination (brackish water desalination)

Phoenix Example:

CAP aqueduct system	1.3 M tons of salts
+	
Salt River	0.4 M tons of salts

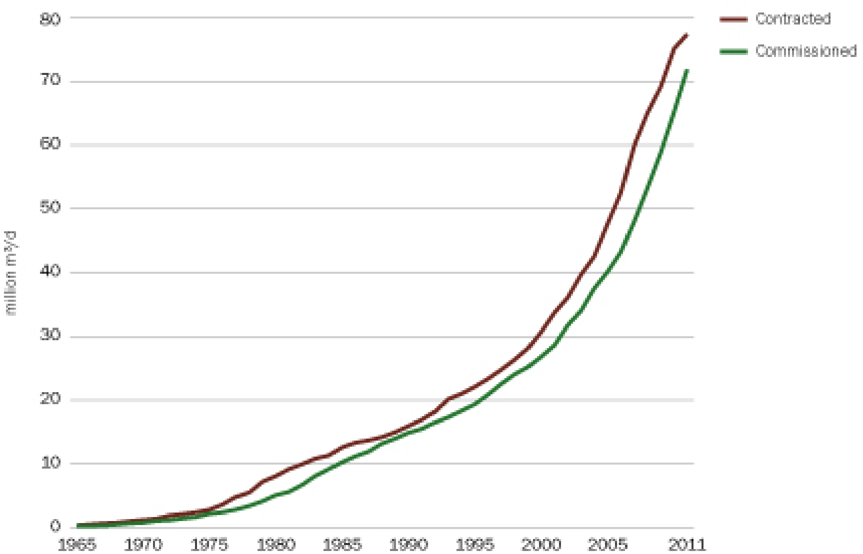
Annual accumulation	~1 M tons of salts

- “Extreme” salinity scenarios
  - Upwards of 300,000 mg/L
  - Often with challenging solution chemistries

Data from: http://phoenix.gov/WATER/ph2planrpt.pdf

Rising Desalination Capacity

World



http://www.desalination.com/market/desal-markets

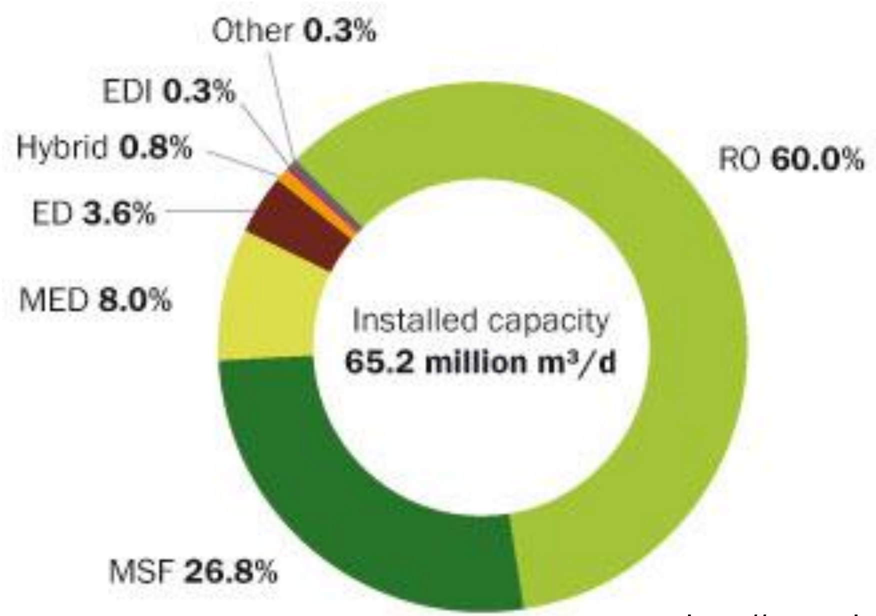
Top 20 desal markets, 2010-13

1 (2)	Saudi Arabia	$5,159m
2 (7)	USA	$4,419m
3 (3)	Australia	$3,237m
4 (16)	Israel	$2,503m
5 (13)	Kuwait	$2,480m
6 (15)	Libya	$2,443m
7 (1)	UAE	$2,198m
8 (5)	China	$1,517m
9 (9)	India	$1,293m
10 (21)	Chile	$1,200m
11 (17)	Caribbean	$1,069m
12 (29)	Morocco	$926m
13 (4)	Spain	$861m
14 (11)	Oman	$785m
15 (20)	Iran	$709m
16 (14)	Egypt	$660m
17 (12)	Bahrain	$646m
18 (10)	Turkey	$545m
19 (6)	Algeria	$529m
20 (31)	Jordan	$496m

The numbers in brackets represent the country's market rank during 2008-2009

http://www.globalwaterintel.com/archive/11/7/market-insight/desalination-market-returns.html

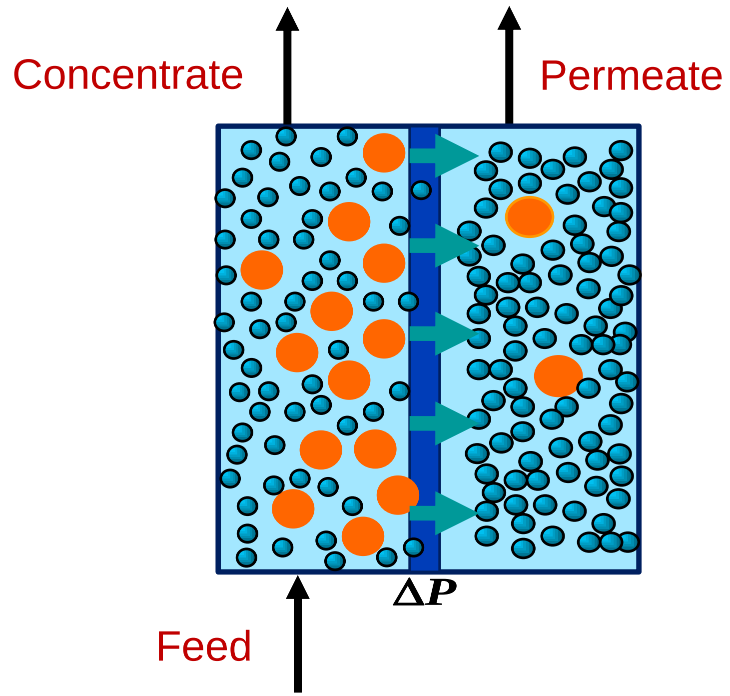
Desalination Capacity by Processes



http://www.desalination.com/market/destinations

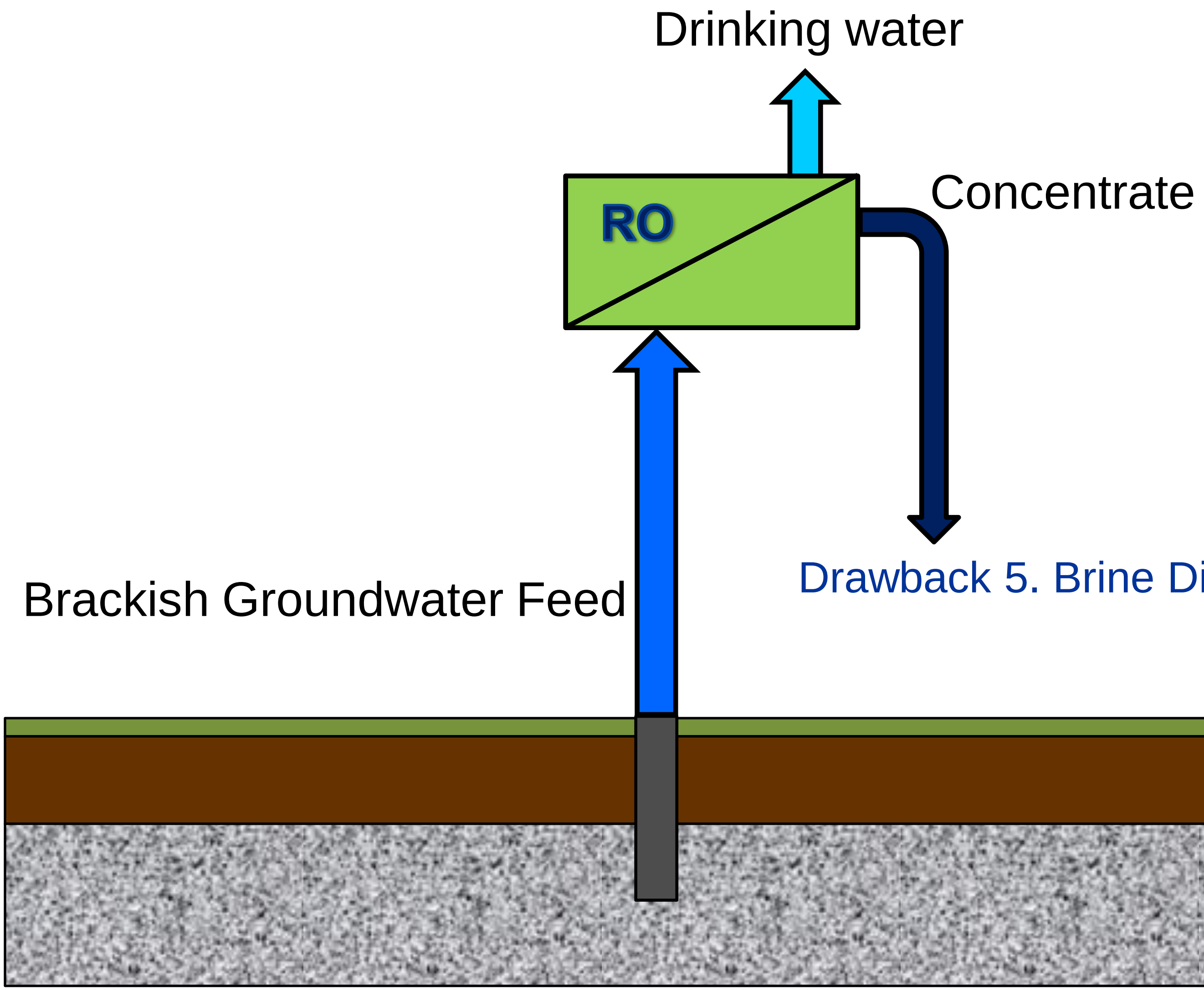
The RO process currently dominates the U.S. and global desalination markets

Current Practice: Reverse Osmosis



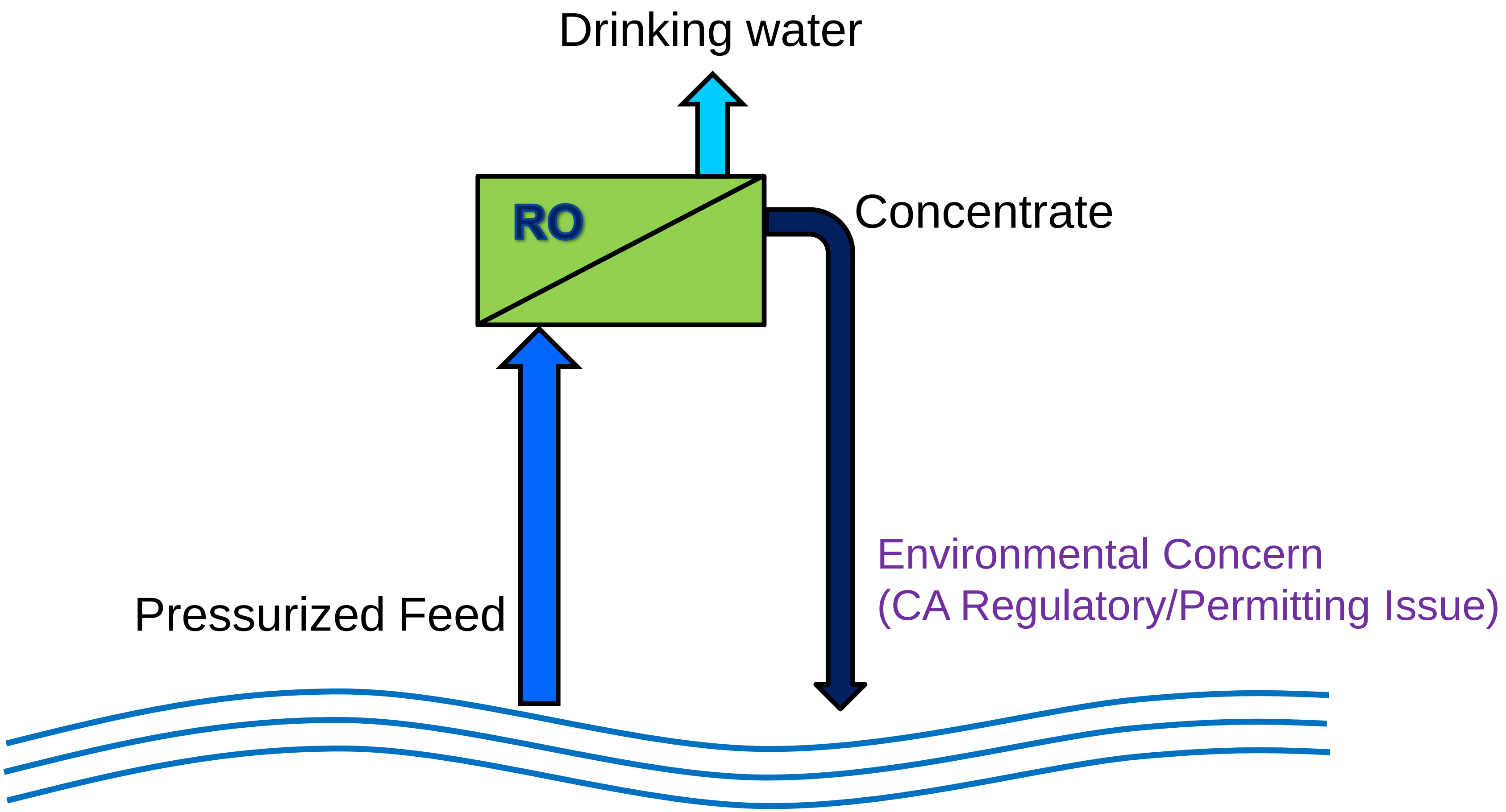
- Produces water with <500 mg/L salts
- Less energy intensive than distillation (~10x less)
- But… does have drawbacks
  1. membrane fouling → FO as pretreatment for RO
  2. passage of some contaminants → FO/RO or MD
  3. reduced driving force at high salt concentrations → osmotic dilution or MD
  4. electricity (work) required → MD (waste heat recovery) or RO-PRO

In-Land Desalination



Drawback 5. Brine Disposal or Treatment

Seawater Desalination



Considering these drawbacks…

Some analysts posit that seawater desalination

1) uses more water to create the energy to run the desal unit than the water that is ultimately produced
2) exposes water utilities to significant energy price risk, and
3) creates a host of environmental impacts

What is the latest thinking on these issues?

Seawater Desalination Energy and Water

- Liters of fresh water to generate 1 MWh of electricity by coal

  19-280 L/MWh of water to mine the coal
  +
  1,100-1,800 L/MWh for coal-fired electricity* *water consumed
  ----
  1,119-2,080 L/MWh (lifecycle water for a unit of coal-fired electricity)

- Seawater desalination energy requirement (average)

  4 kWh/m^3 of water* *rated energy use under standard, fixed conditions

- Water required for the energy needed in seawater desal
  2,080 L/MWh
  x
  4 kWh/m^3

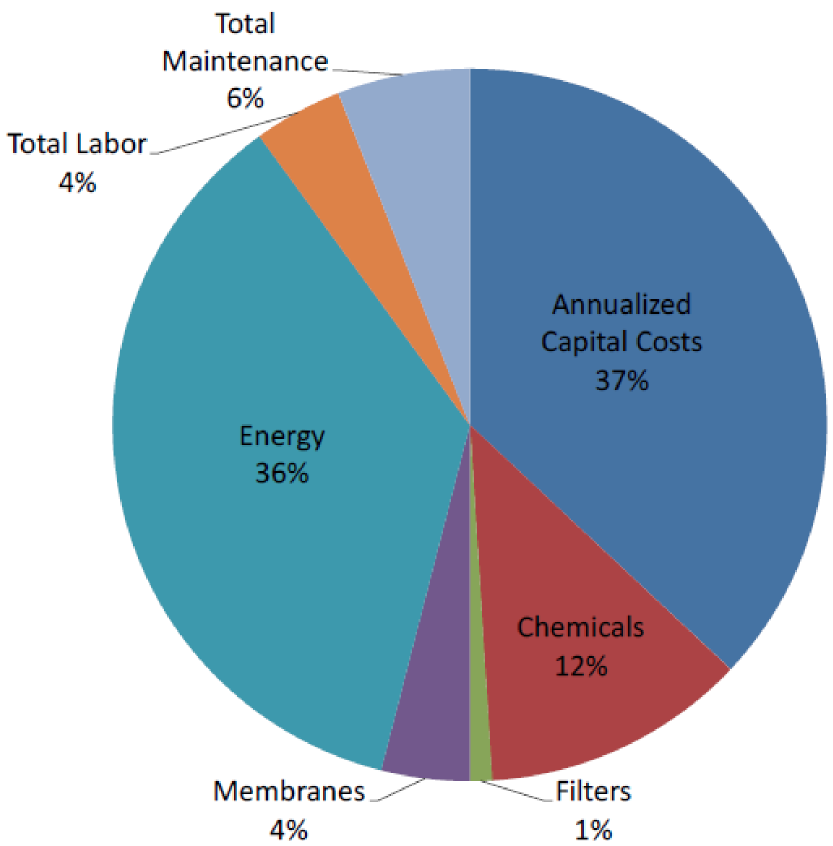
  8,320 L of water required to desalinate 1 million L seawater <1%

"Easier to move electrons than water"

Coal data from: King, Stillwell, Twomey, Webber 2013]

Energy Price Risk

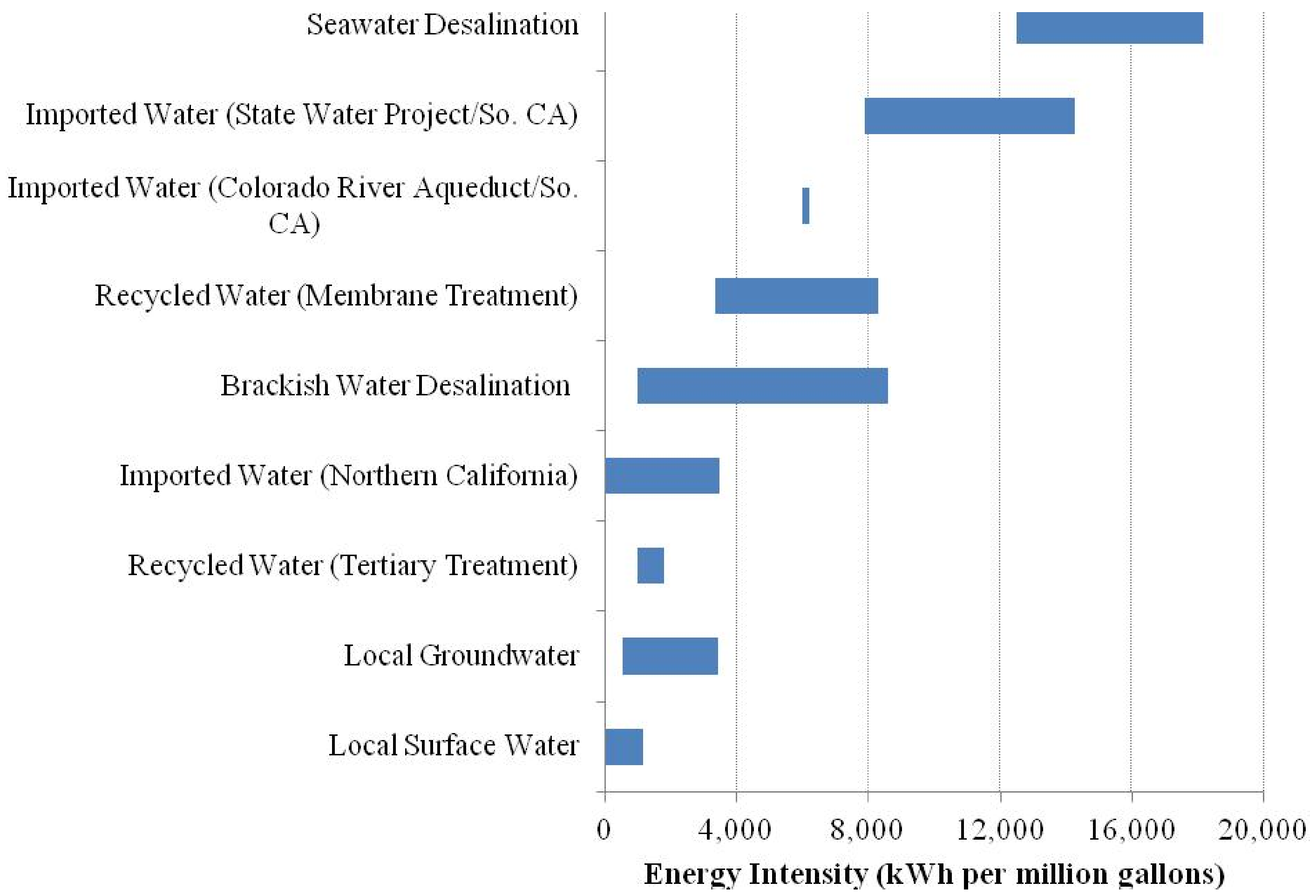
- NRC [2008] reports that energy accounts for 36% of the typical water costs of a reverse osmosis plant.
- Energy is the largest single variable cost for a seawater desalination plant.
- An energy rate increase of 25% increases the cost of produced water by ~ 10%.
- How does this compare to other water supplies?



Annual Cost Breakdown of a Typical Seawater Desalination Plant

Cooley and Ajami 2012

Energy Intensity of Water Supplies



Cooley and Heberger 2013

Environmental Impacts

- Uptake: impingement and entrainment
  - Very similar issues with coastal power facilities
  - Solution: Subsurface intakes
  - New drilling technologies (e.g., directional drilling) can enable finding pockets with proper geology and sediment conditions
- Brine discharge
  - Unique issue: Density of salt
  - Sinks and spreads along ocean floor - little wave energy to mix brine; benthic community most affected
  - Mitigation: Diffusers
    - Marine impact data have rarely been collected in CA or elsewhere
  - Co-discharge with treated wastewater effluent
    - May introduce nutrients to seafloor where mixing is limited
    - Brine flows are constant; wastewater flows are variable

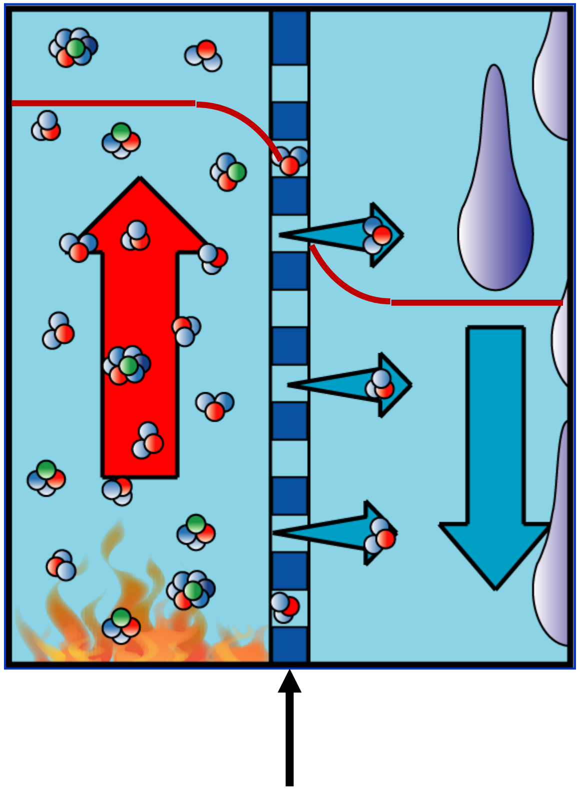
Emerging Technologies:

Membrane Distillation (MD)

Pressure Retarded Osmosis (PRO)

Direct Contact Membrane Distillation

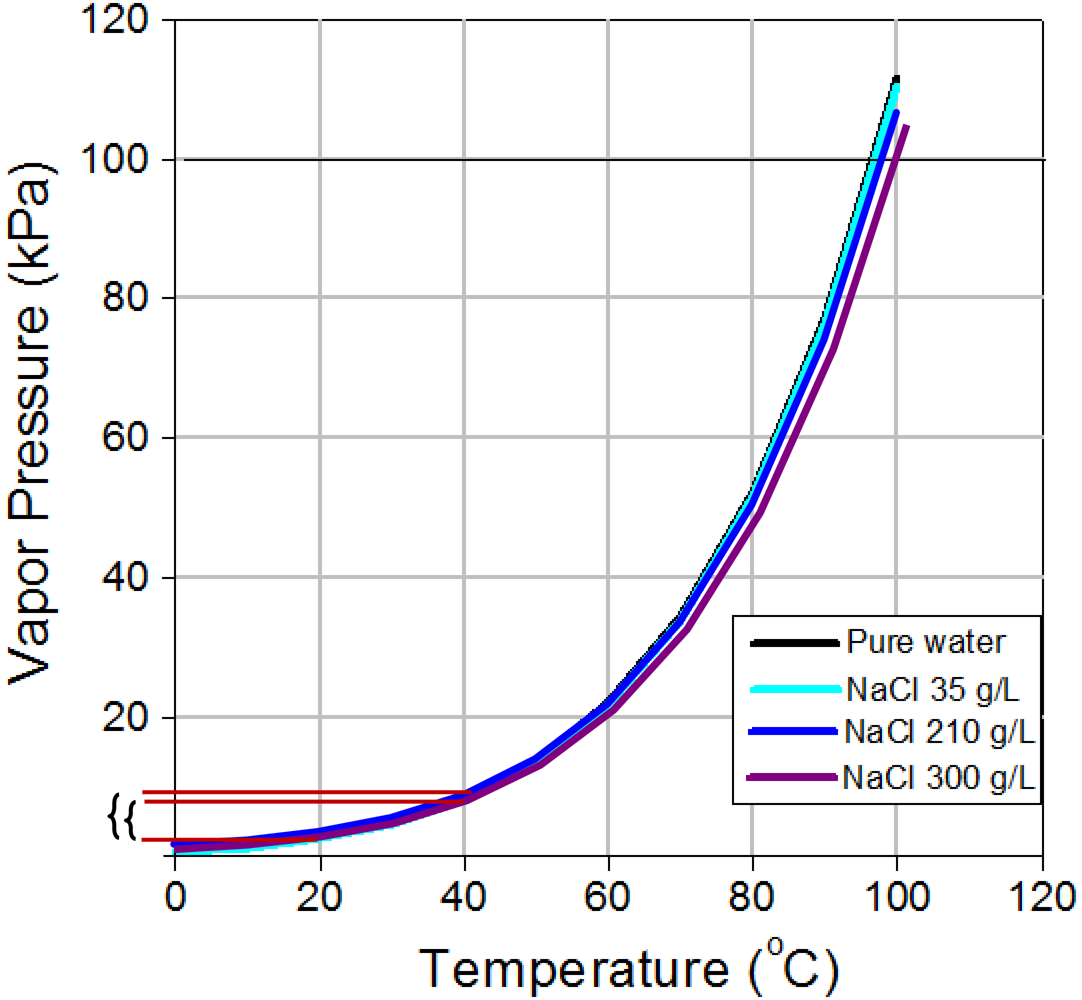
Warmer Feed Stream



Cooler Distillate Stream

Hydrophobic, Microporous Membrane

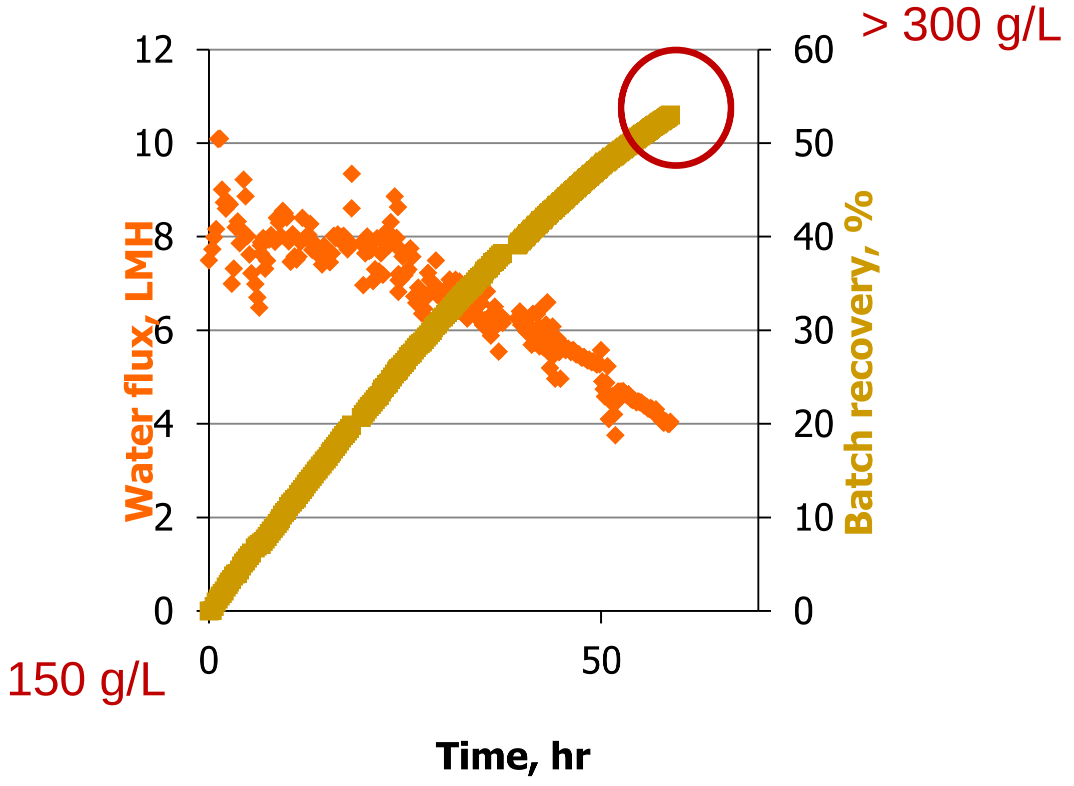
Advantage 1: Vapor Pressure Driving Force



Driving force not significantly reduced at high salt concentrations

Current Interest in MD

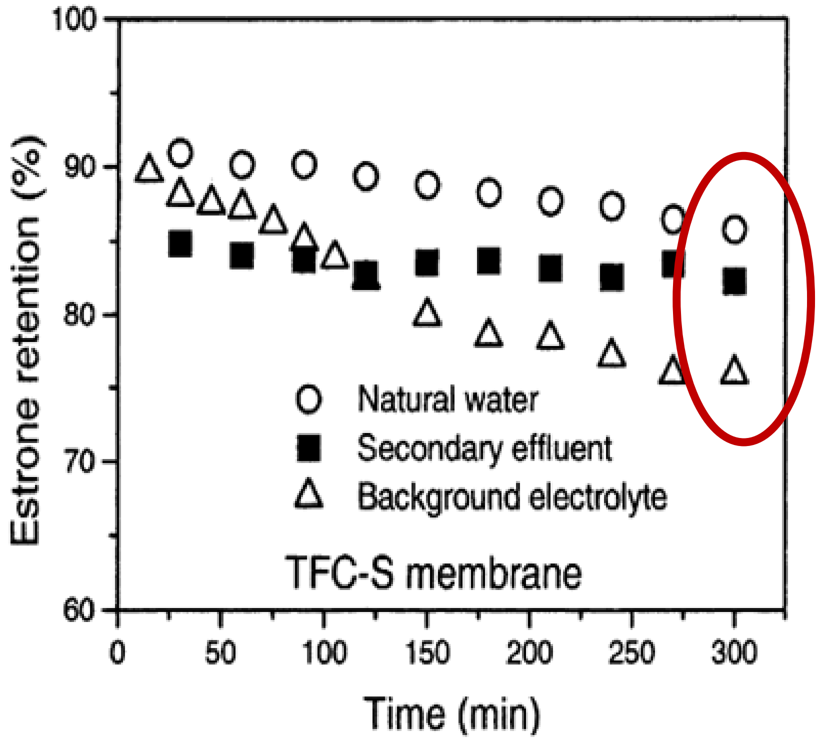
- Treatment of high fouling and scaling feed waters
  - Concentration of brackish water RO brines
  - Valuable metal recovery in mineral harvesting
  - Produced waters in oil and gas industry



Cath et al., 2013

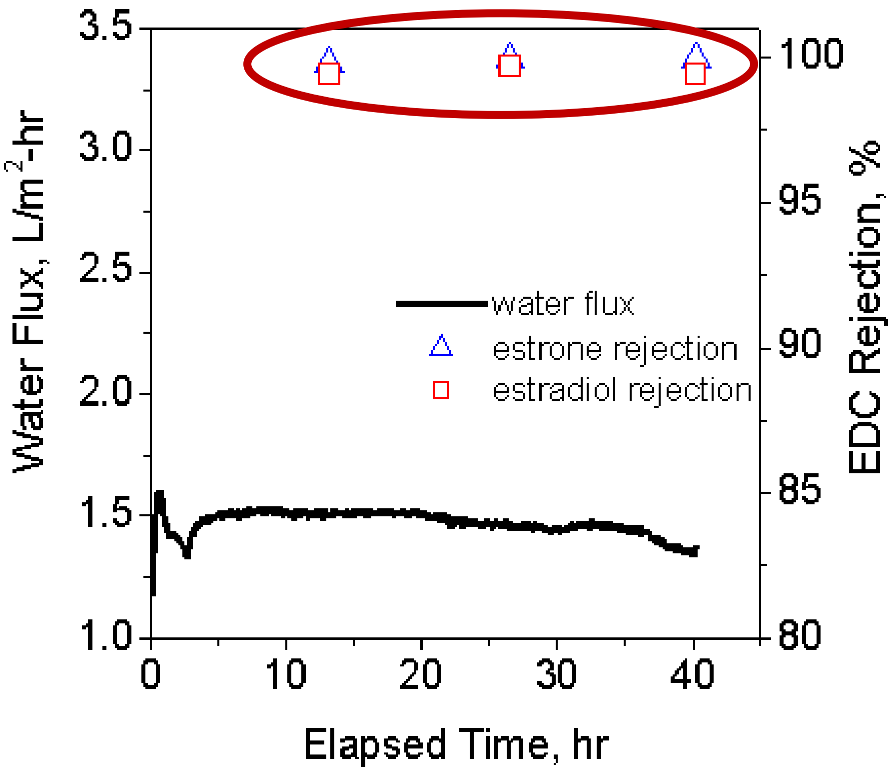
Advantage 2: Distillate-Quality Product

Low pressure RO



Nghiema, et al. 2004

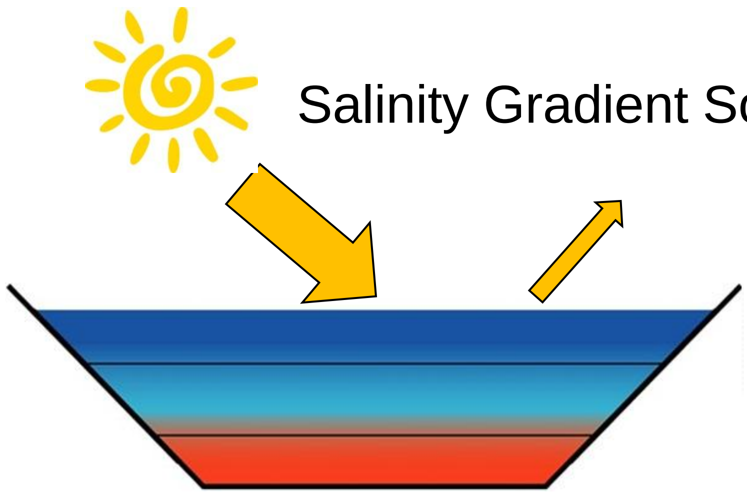
Membrane Distillation



Cartinella, Childress, et al., 2006

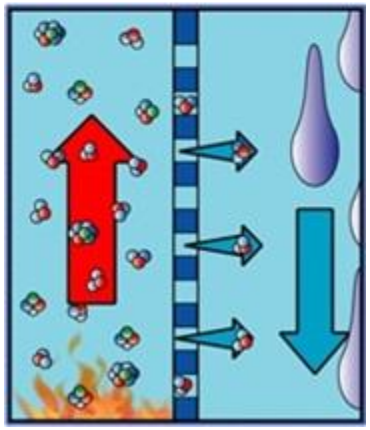
High removal of emerging – and traditional – contaminants

Advantage 3: Compatible w/ Thermal Energy



Salinity Gradient Solar Pond

Membrane Distillation



Solar Thermal, Geothermal

Waste Heat

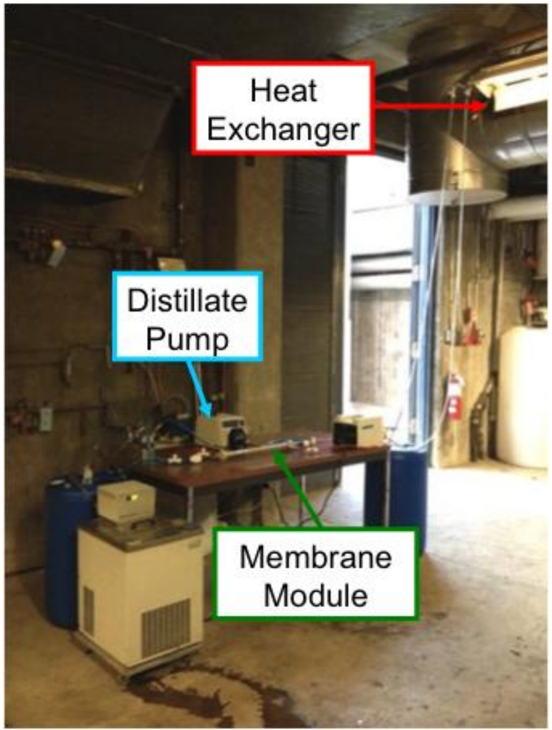
- Machines (e.g., electrical and diesel generators)
- Heat exchangers (e.g., condensers, power plant cooling towers)

Newer Applications of MD

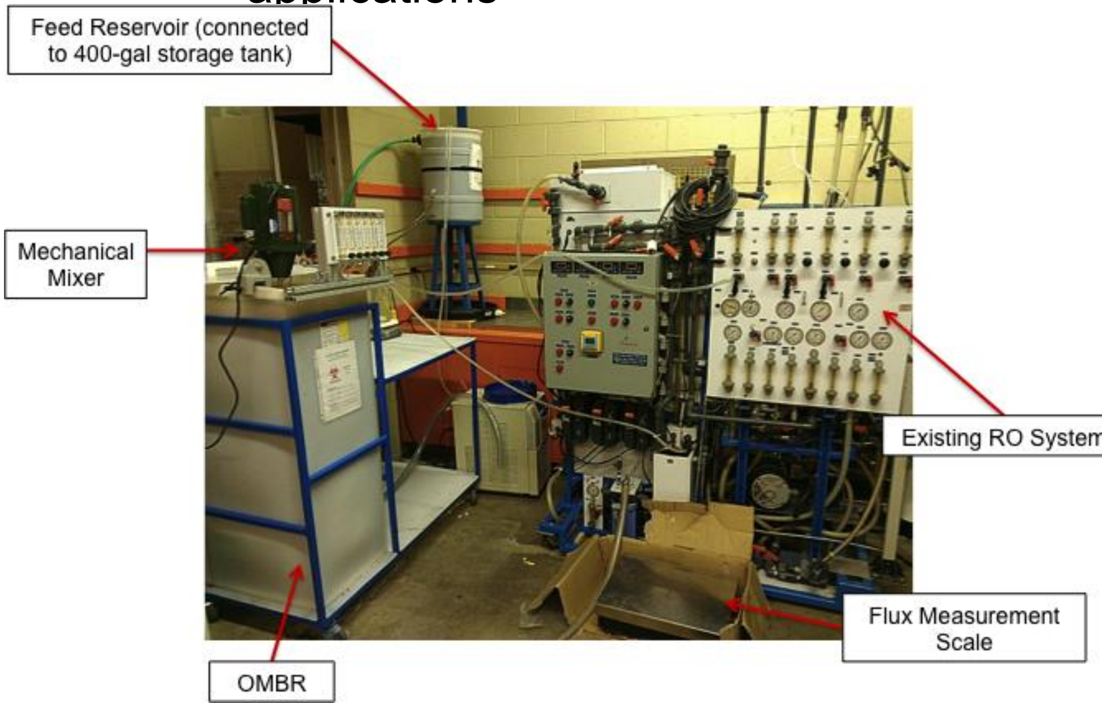
- Treatment of low fouling and scaling feed waters
  - Water "polishing"

    Removal of low-molecular-weight organics, urea, boron, arsenic
  - Reconcentration of forward osmosis draw solution using waste heat

EPA project: "Contaminant removal using membrane distillation for small water systems"



SERDP project: "A fully integrated membrane bioreactor system for wastewater treatment in remote applications"

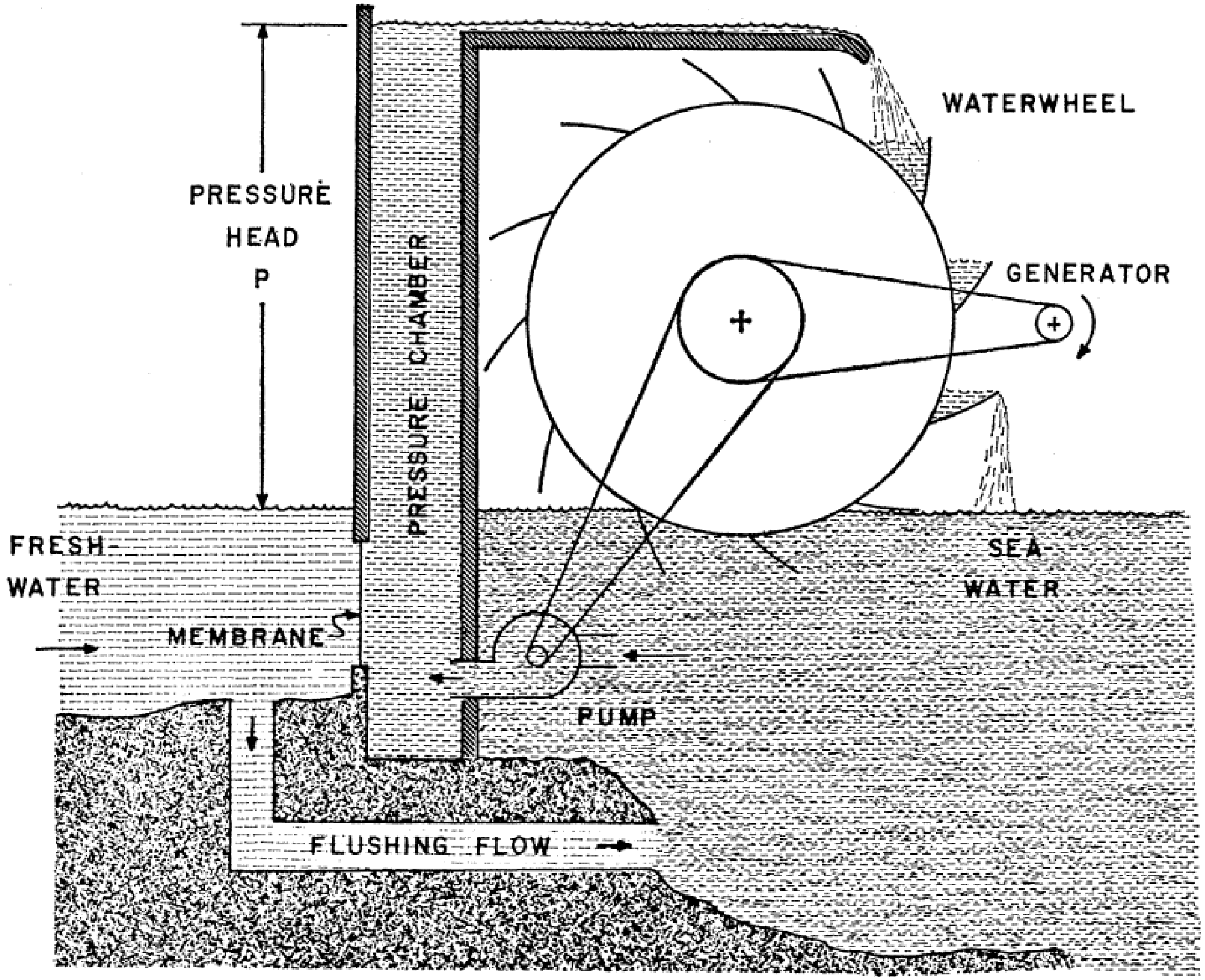


Emerging Technologies:

Membrane Distillation (MD)

Pressure Retarded Osmosis (PRO)

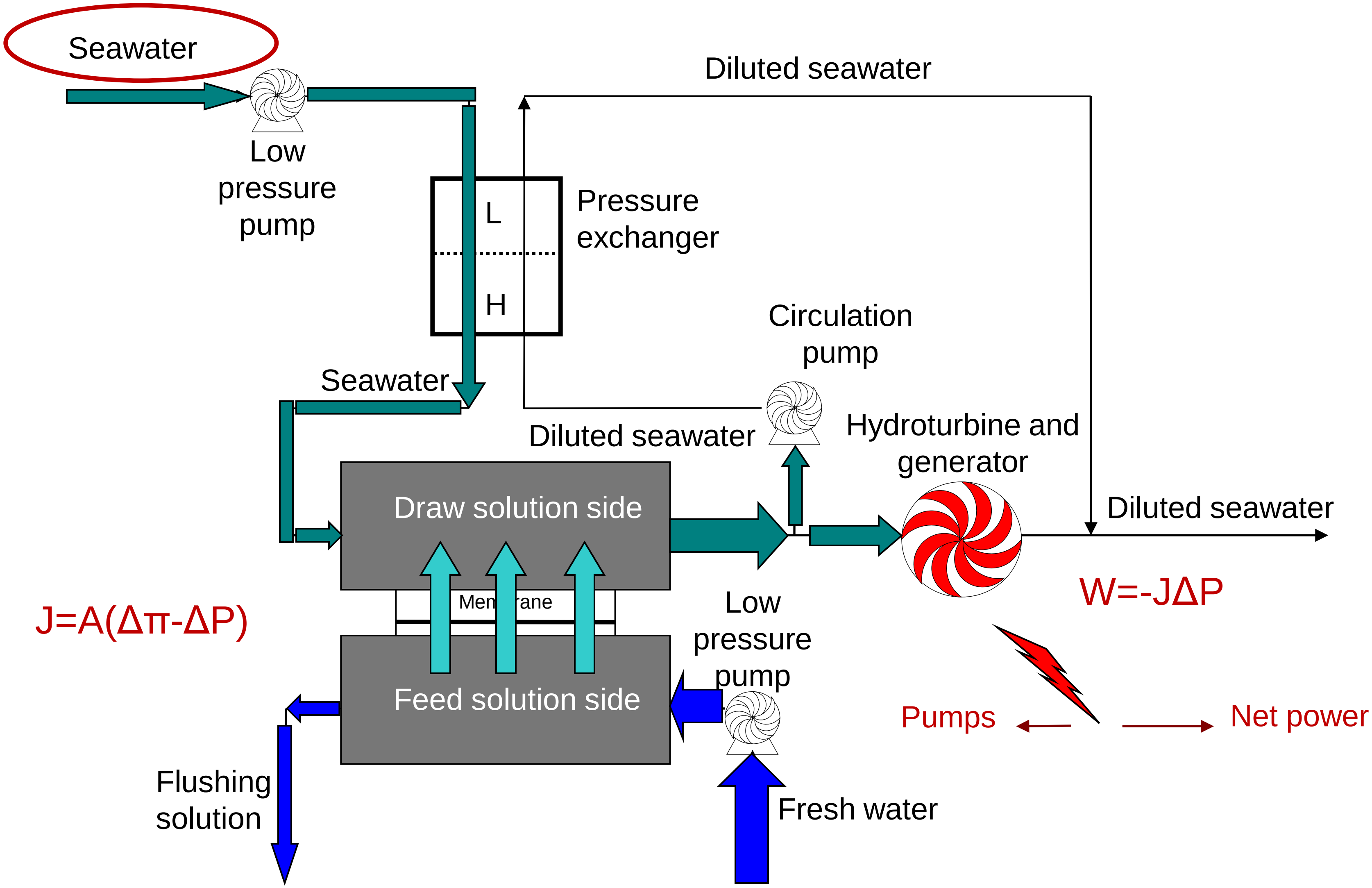
Pressure-Retarded Osmosis



Norman, 1974

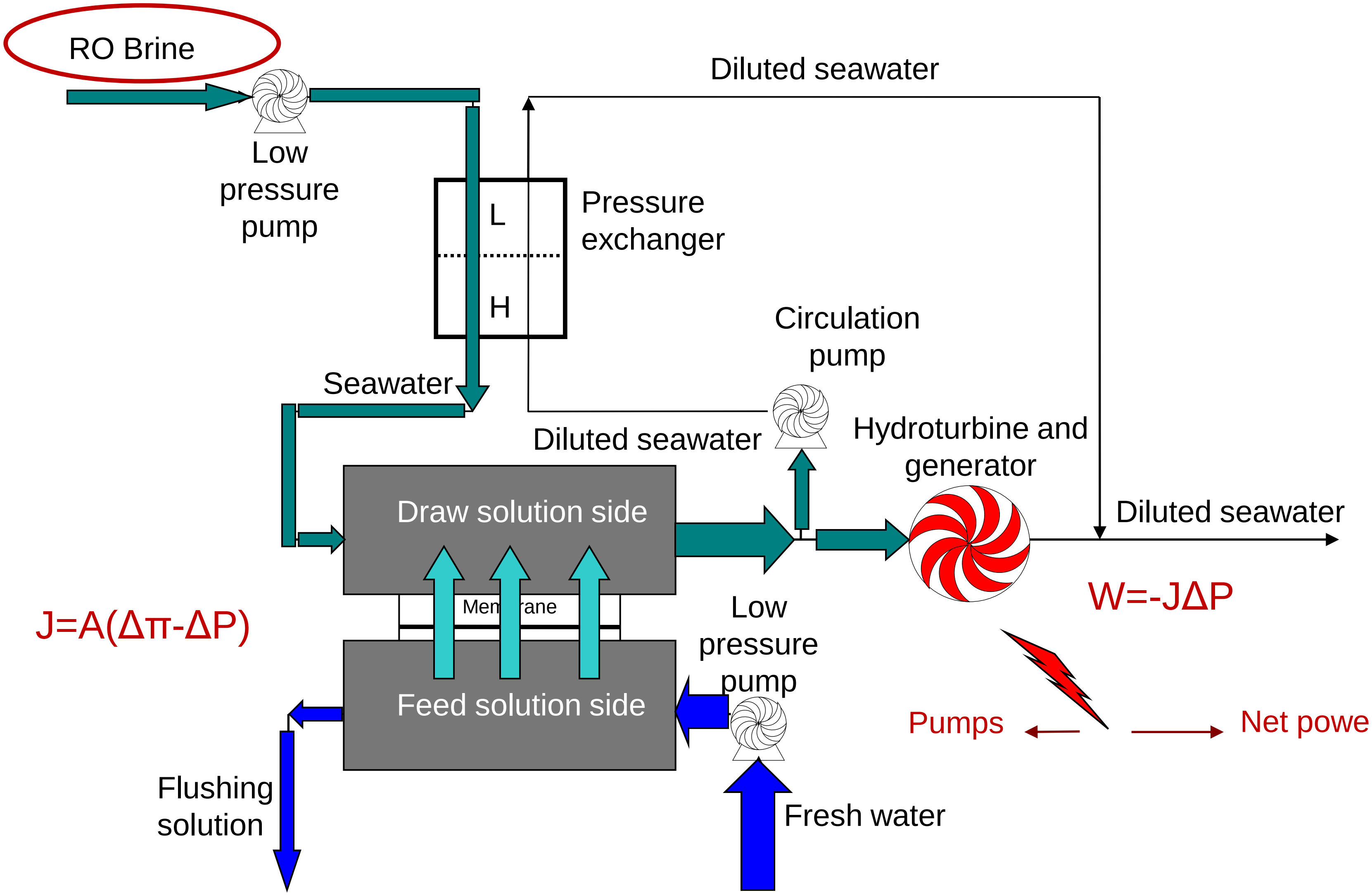
Transformation of chemical potential to hydraulic potential

Power Generation with PRO



River-to-Sea PRO: $\Delta\pi$=350 psi (2413 KPa)

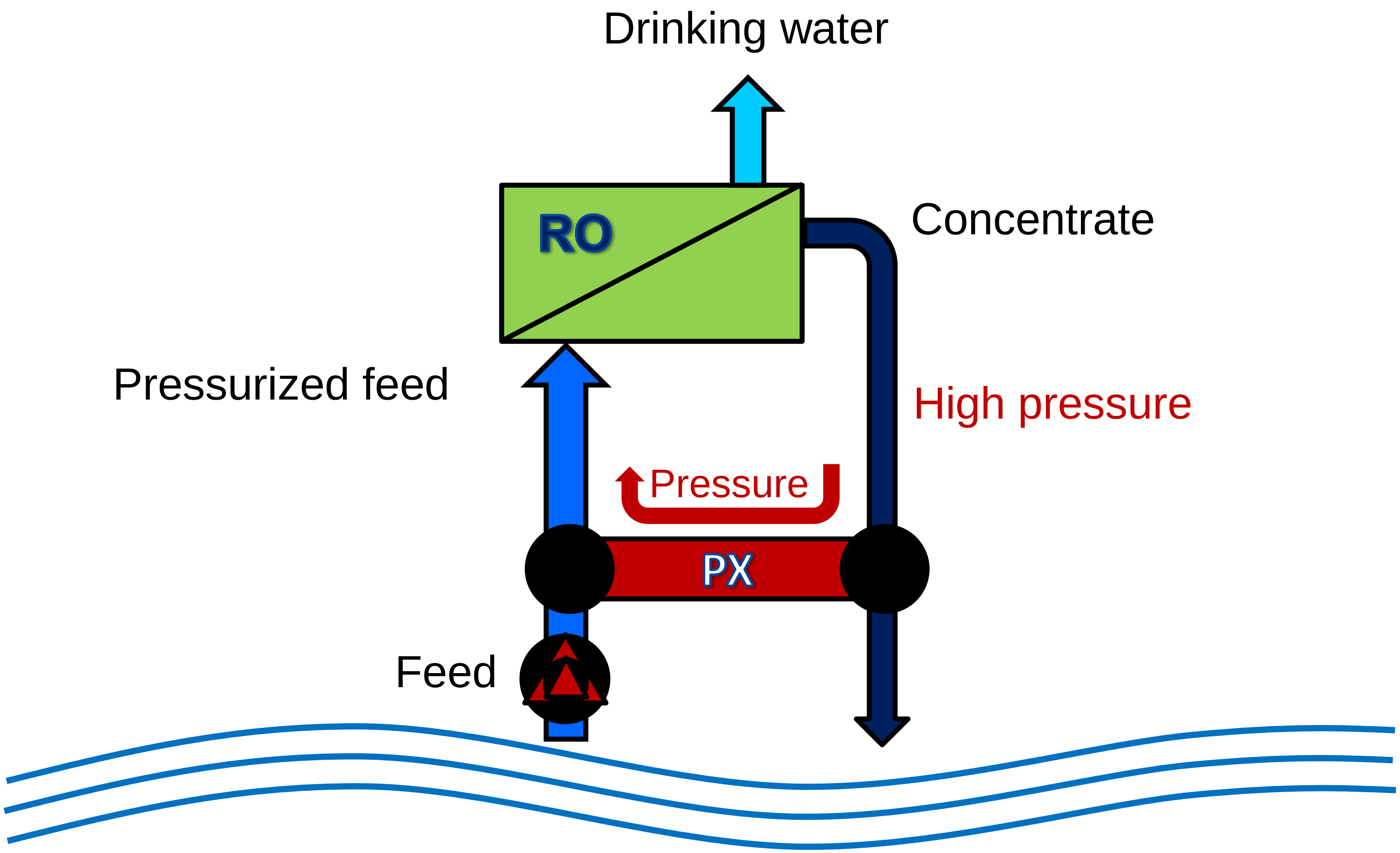
Power Generation with PRO



River-to-Sea PRO: $\Delta\pi$=350 psi (2413 KPa)

RO-PRO: $\Delta\pi$=600 psi (4137 KPa)

Current Practice: Seawater Desalination



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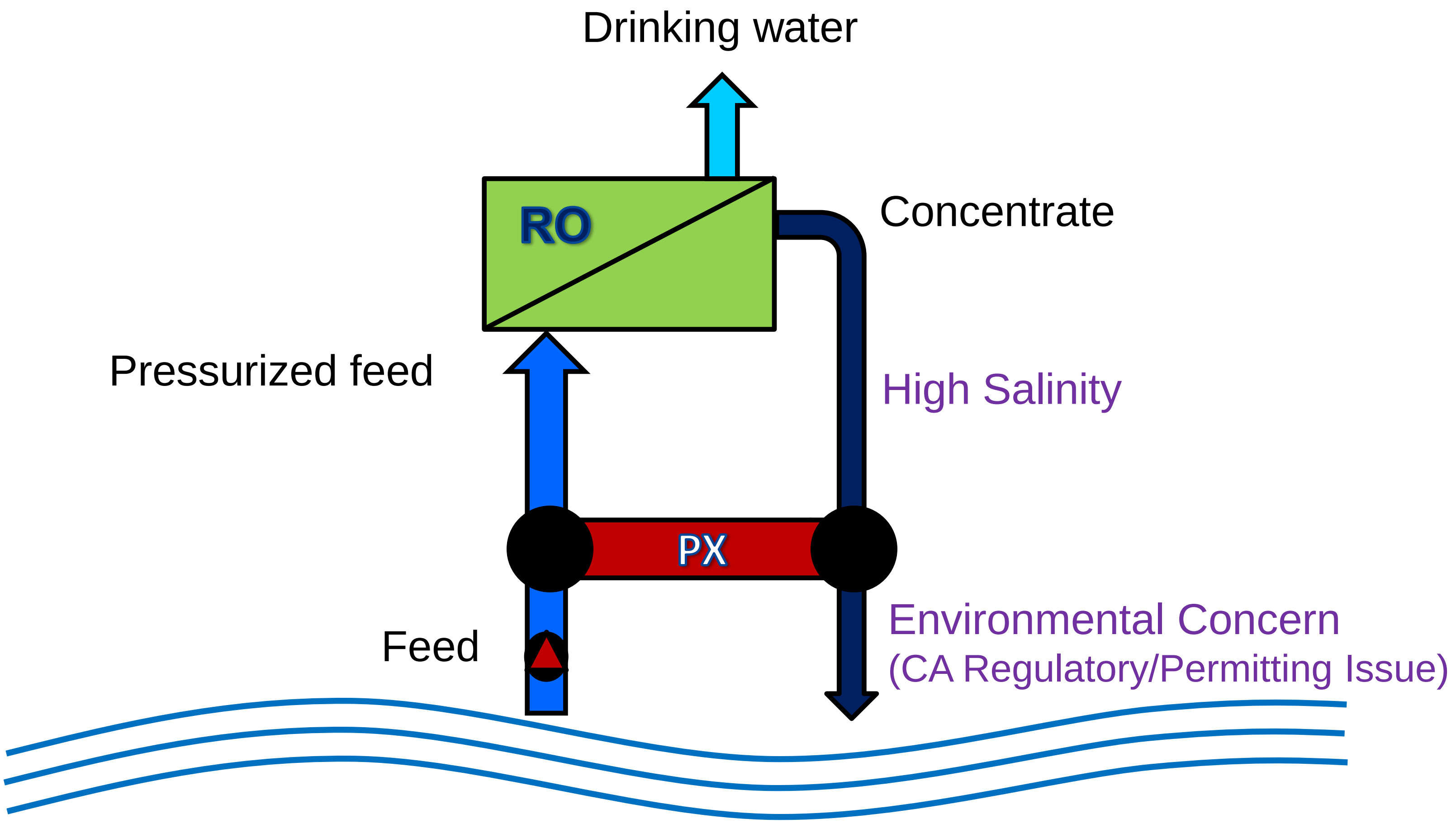
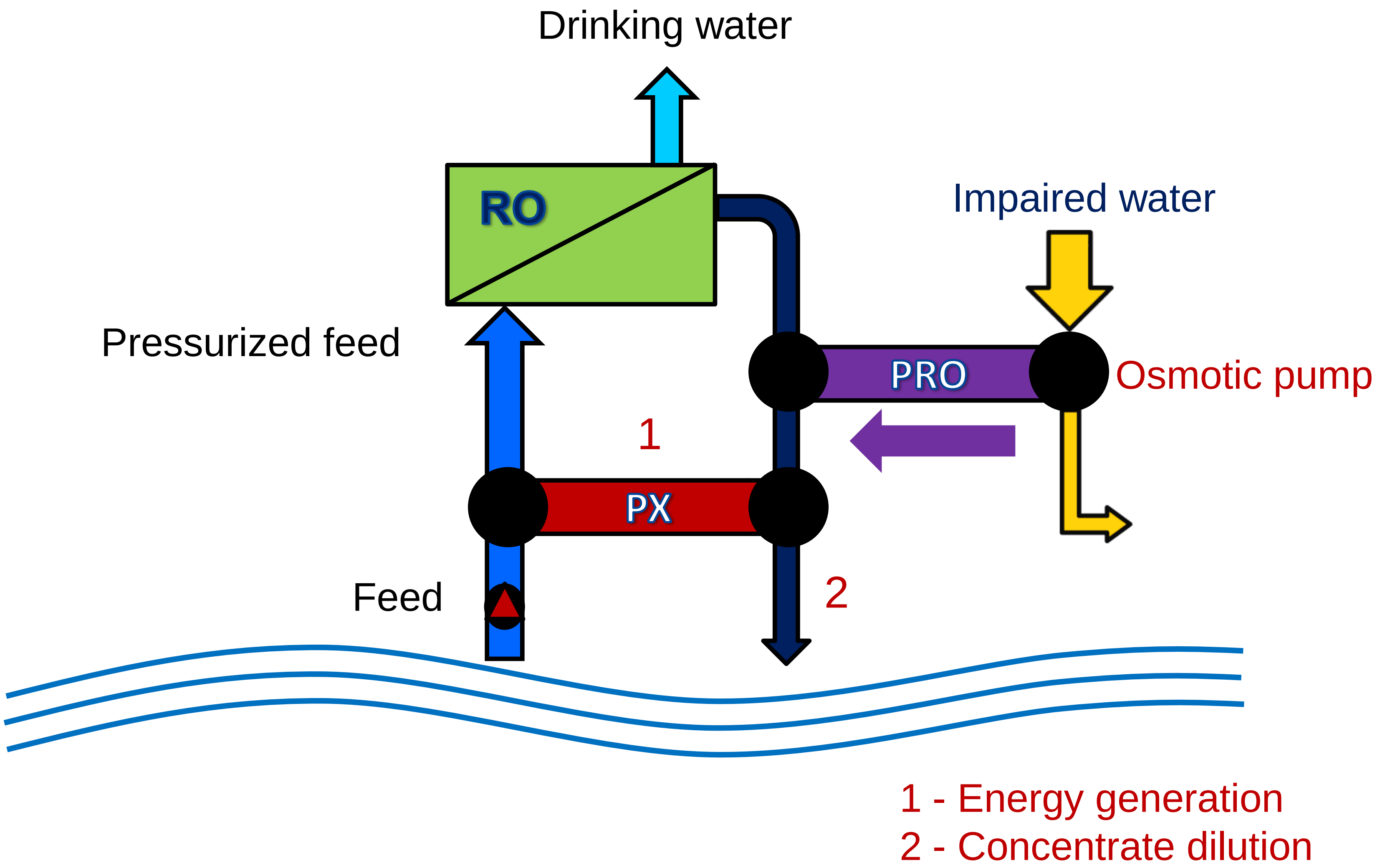
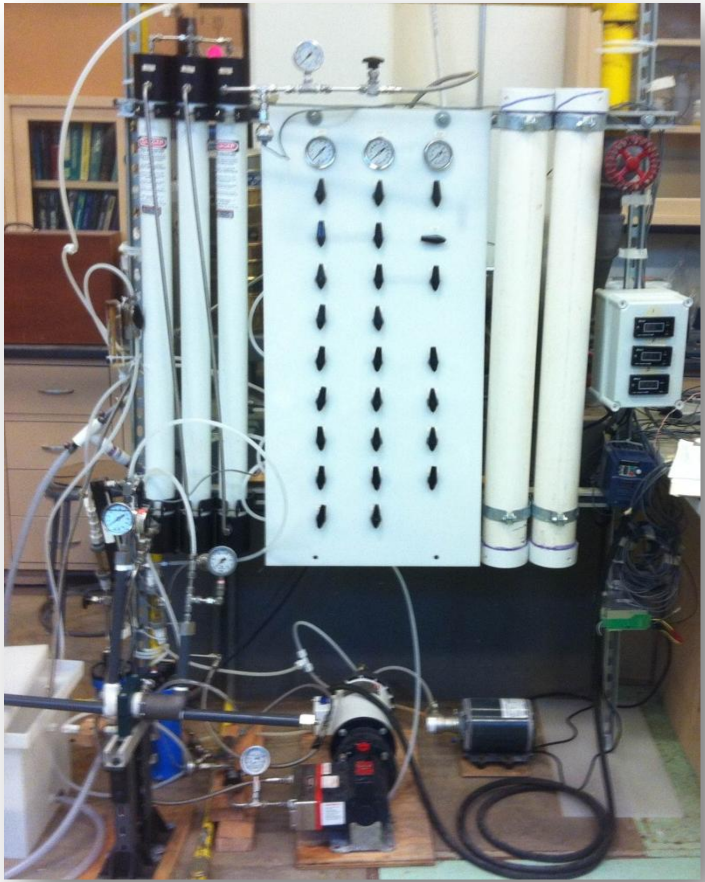


RO-PRO System



USBR Project Pilot System

BGNDRF, Bureau of Reclamation
Alamogordo, NM
Summer 2012



UNR Fluids Lab
Fall 2012 - Spring 2013

Concluding Remarks

- Innovative and hybrid processes can expand the portfolio of technologies for both seawater and wastewater treatment.
- Other options should be fully exploited before turning to seawater desalination
  - If less expensive water supply options are available, then seawater desalination demand will decrease – “demand risk”
- Wastewater reclamation vs seawater desalination
  - Consideration of cost

    Compared to seawater desal, wastewater recycling requires 50% less energy and produces water at 30% less cost to the consumer
  - Consideration of public opinion (MENA, AU, vs CA)
- In 2006, Dr. Peter Gleick of Pacific Institute said: “Desalination will be part of California’s water future, but the future’s not here yet.”…

Acknowledgements

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  - US Bureau of Reclamation
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- Students
  - Jeri Prante, Ally Freitas, Tom Stroud, Vahid Vandadi, Austin Krater, Ryan Gustafson, Tianlin Song, Guiying Rao

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From West Basin Municipal Water District…

“Southern California is facing increasing demands on a shrinking water supply. Imported water is becoming increasingly less reliable due to droughts, environmental restrictions, and other factors. As a result West Basin has initiated a program called Water Reliability 2020 that will reduce the area’s dependence on imported water from 66% today to 33% by 2020. Ocean-Water desalination is a key part of that program.”

- Since 2002, operated 10 gpm pilot facility in El Segundo for extensive research and water quality testing; > 500 monthly tests indicate that quality meets or exceeds federal standards.

- Since 2010, operated demonstration facility using full-scale equipment to perform additional water quality testing, evaluate environmentally-protective source intake methodologies, and assess energy efficiency.

- By 2020 or earlier, asserting cost will be competitive with cost of importing water and energy requirements will be only 10% > importing. Plans to offset the energy difference with green energy sources.

Concluding Remarks

- Need clarification on what applies broadly to major infrastructure projects and what is specific to seawater desalination
  - Energy and energy price risk
  - Environmental considerations – uptake and discharge issues

- "… current water prices often fail to include costs for adequately maintaining and improving water systems. As a result, the public often has a somewhat distorted perception of the cost of reliable, high-quality water, making it difficult for water utilities to justify their investment in more expensive water-supply options, such as desalination." [Cooley and Ajami 2012]