PRO: Should It Stay or Should It Go?

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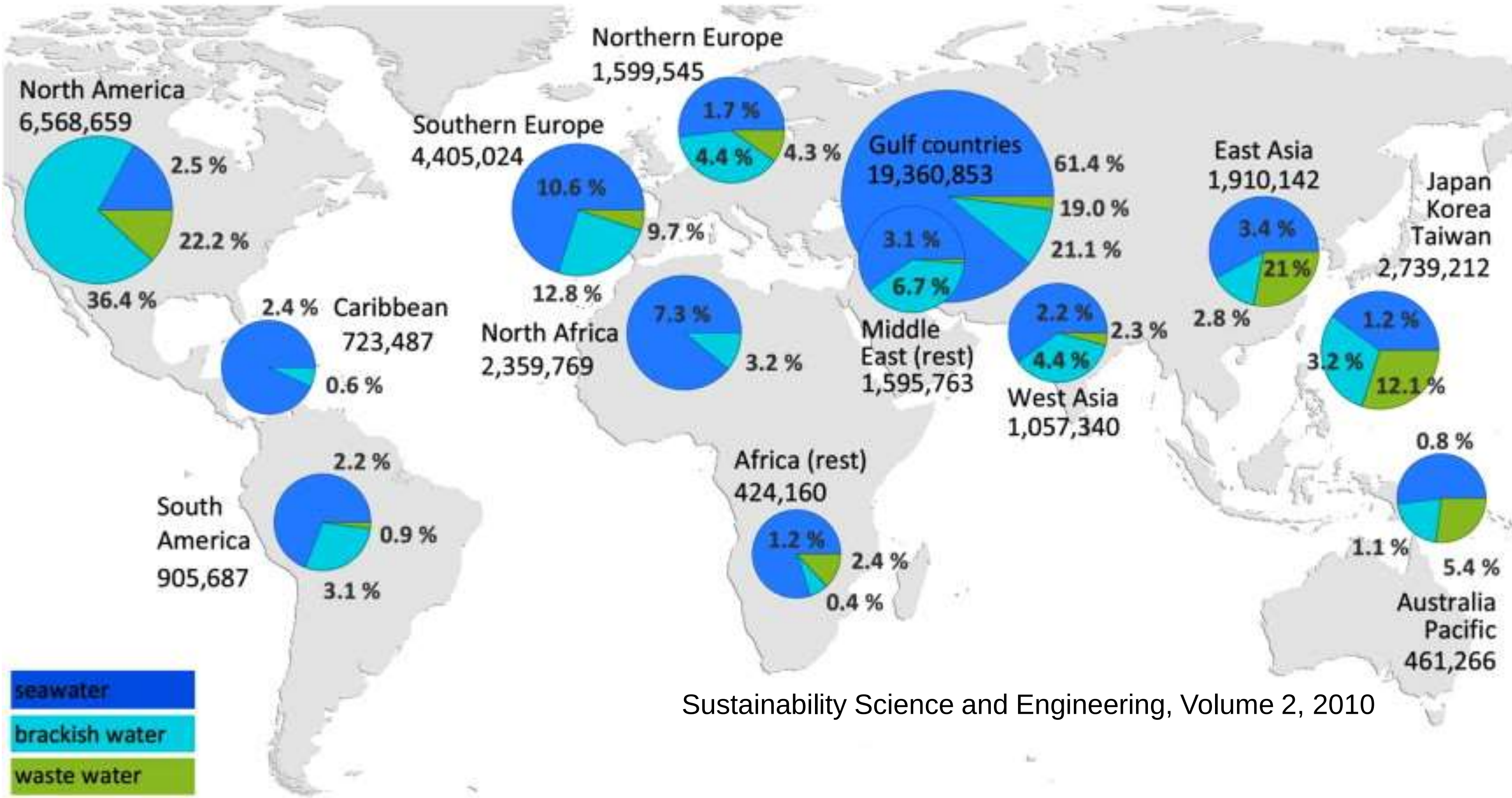
Outline

- Seawater Desalination in the U.S.
- Regulatory and Technical Factors associated with Seawater Desalination
- Osmotic Dilution as a Solution
  - Forward Osmosis
  - Pressure-Retarded Osmosis
  - RO-PRO System
- Future Directions

Waters Being Desalinated



Sustainability Science and Engineering, Volume 2, 2010

California in 4th year of record-breaking drought

Why is US (and California in particular) approaching seawater desalination so reluctantly?

Recent History of CA Seawater Desal

- 2006 data from Cooley et al.
  - Most existing facilities were small systems for industrial/commercial needs
  - 21 proposals for facilities
- 2012 data from Cooley et al.
  - 1 of the 21 proposed facilities was permitted and built (Sand City 0.3 MGD)
  - 17 facilities proposed along California coast + 2 facilities considered in Baja
- 2015
  - Carlsbad 50 MGD – 12 years planning, 6 years State permitting will deliver water in late 2015
  - Huntington 50 MGD – final phases of permitting – targeting 2018
  - Santa Barbara 9 MGD – City Council issued contract to reactivate

Significant regulatory and technical factors facing agencies considering seawater desalination

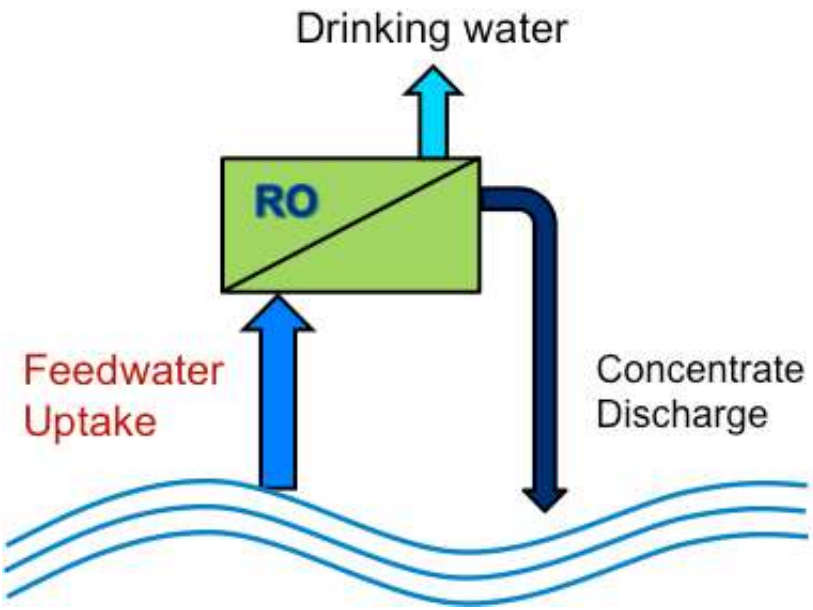
Regulatory Factors

- From regulation and oversight standpoint: desalination is new in the US
- Existing laws and policies do not address unique issues raised by desalination
  - Environmental
  - Public health
- Uncertainty in review and approval
  - in California could involve 9 federal, 13 state, and additional local agencies
- Will regulation streamline the process or hinder technology development?

But Perhaps More Interesting…

Does seawater desalination by reverse osmosis:

1) use too much energy and freshwater to create the energy?
2) expose water utilities to energy price risk and demand risk?
3) create a host of environmental impacts?



1a) How Much Freshwater is Required?

- Liters of fresh water to generate 1 MWh of electricity

  95 L/MWh of water to produce natural gas
  +
  855 L/MWh for power generation* *water consumed
  ----
  950 L/MWh (lifecycle water for a unit of electricity from natural gas)

- 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

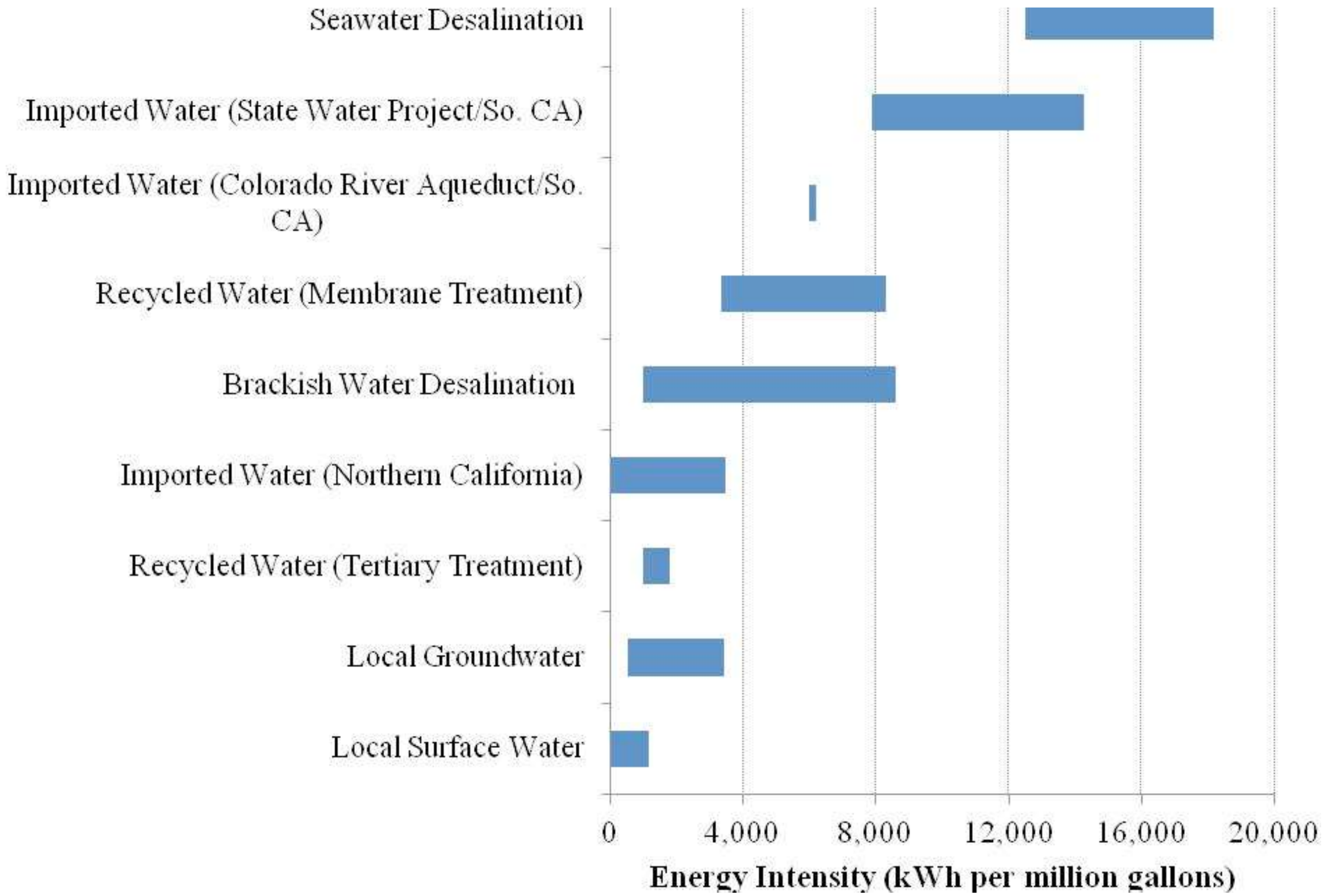
  950 L/MWh
  x
  4 kWh/m^3

  3,800 L of water required to provide energy to desalinate 1 million L seawater

< 0.4 %

Electricity data from: King, Stillwell, Twomey, Webber 2013

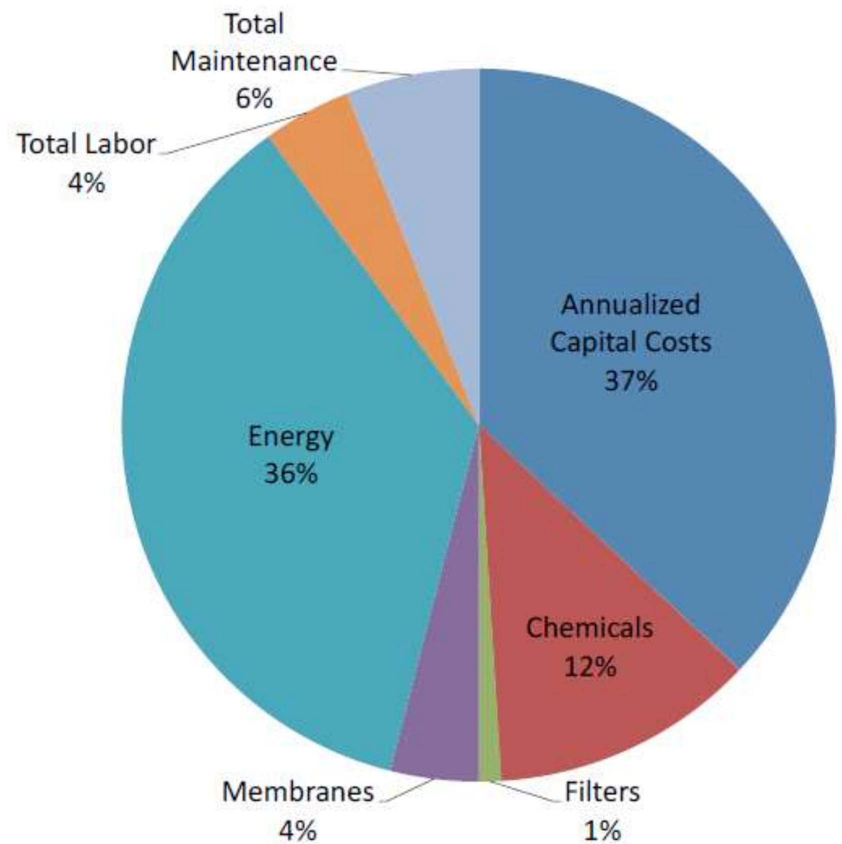
1b) How Much Energy is Required?



Cooley and Heberger 2013

2a) Energy Price Risk

- NRC [2008] reports that energy accounts for 36% of the typical water costs of an RO facility.
- 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%.



Annual Cost Breakdown of a Typical Seawater Desalination Plant

Cooley and Ajami 2012

2b) “Demand” Risk

- If less expensive water supply options are available, then demand for seawater desalination will decrease – “demand risk”

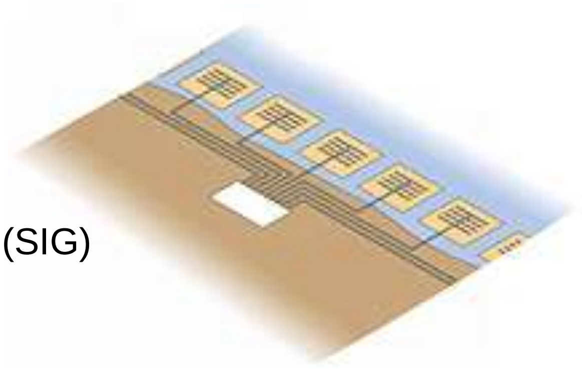
- Examples
  - US: Santa Barbara facility (7 MGD) operated June 1992 then placed in long-term stand-by mode
  - AU: 1997-2009 drought; state governments built SWRO facilities; many in east and south are mothballed

- Other options should be fully exploited before turning to seawater desalination
  - conservation and efficiency
  - stormwater capture
  - water reuse
  - brackish water desalination

3a) Environmental Impacts

- Uptake: impingement and entrainment
  - Similar issue as other coastal industry (e.g., power facilities)
  - CA's Ocean Plan amended earlier this month

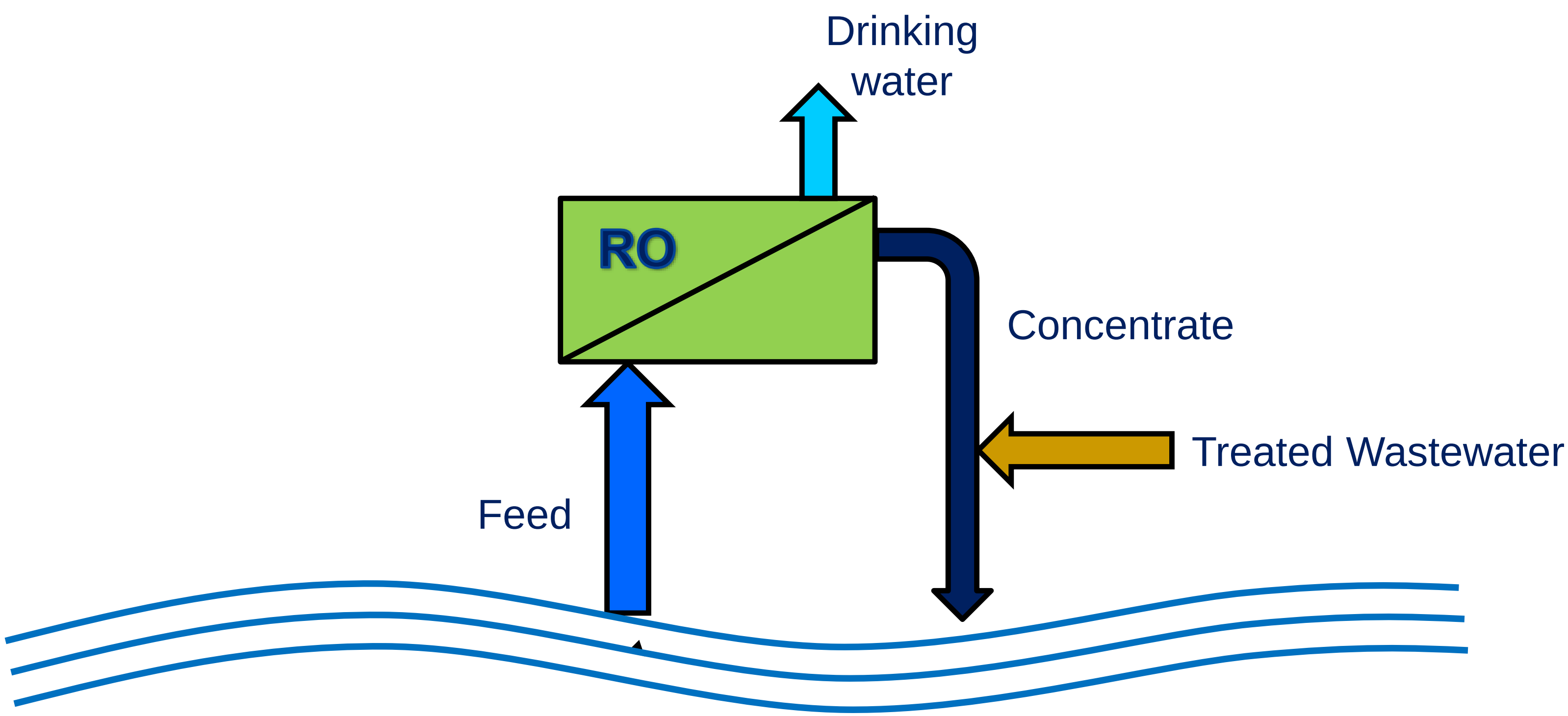
    Requires use of subsurface intakes when feasible
      - Protects marine life
      - Provides pretreatment of seawater
      - May double cost and construction time for facilities



From WDR Aug 17
Seafloor infiltration gallery (SIG)
with multiple offshore cells

- Brine discharge
  - Unique issue: density of salt
  - Sinks and spreads along ocean floor - benthic community most affected
  - Mitigation
    - Diffusers
    - Diluting

Reducing Environmental Impact (1)

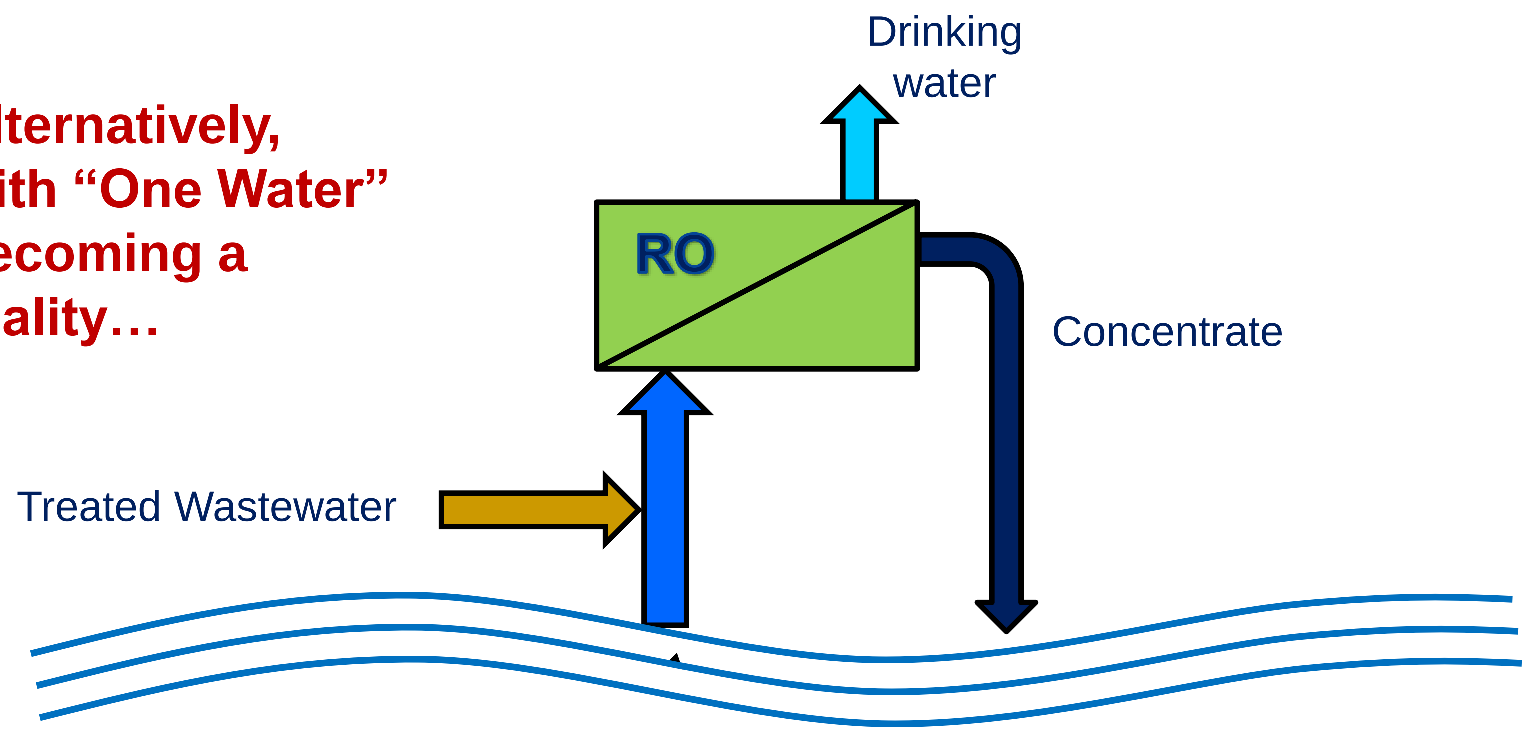


Co-discharge with treated wastewater effluent

Dilution of concentrate stream
But may introduce nutrients to seafloor where mixing is limited

Reducing Environmental Impact (2)

Alternatively, with "One Water" becoming a reality…



Mix treated wastewater with seawater uptake

Reduces uptake volume requirements; Reduces energy requirements (dilutes feed)
But will require wastewater to be highly treated

“The lines between wastewater and drinking water have been fading...”

Quote from consolidation of
Water Research Foundation (WRF) and
Water Environment Research Foundation (WERF)

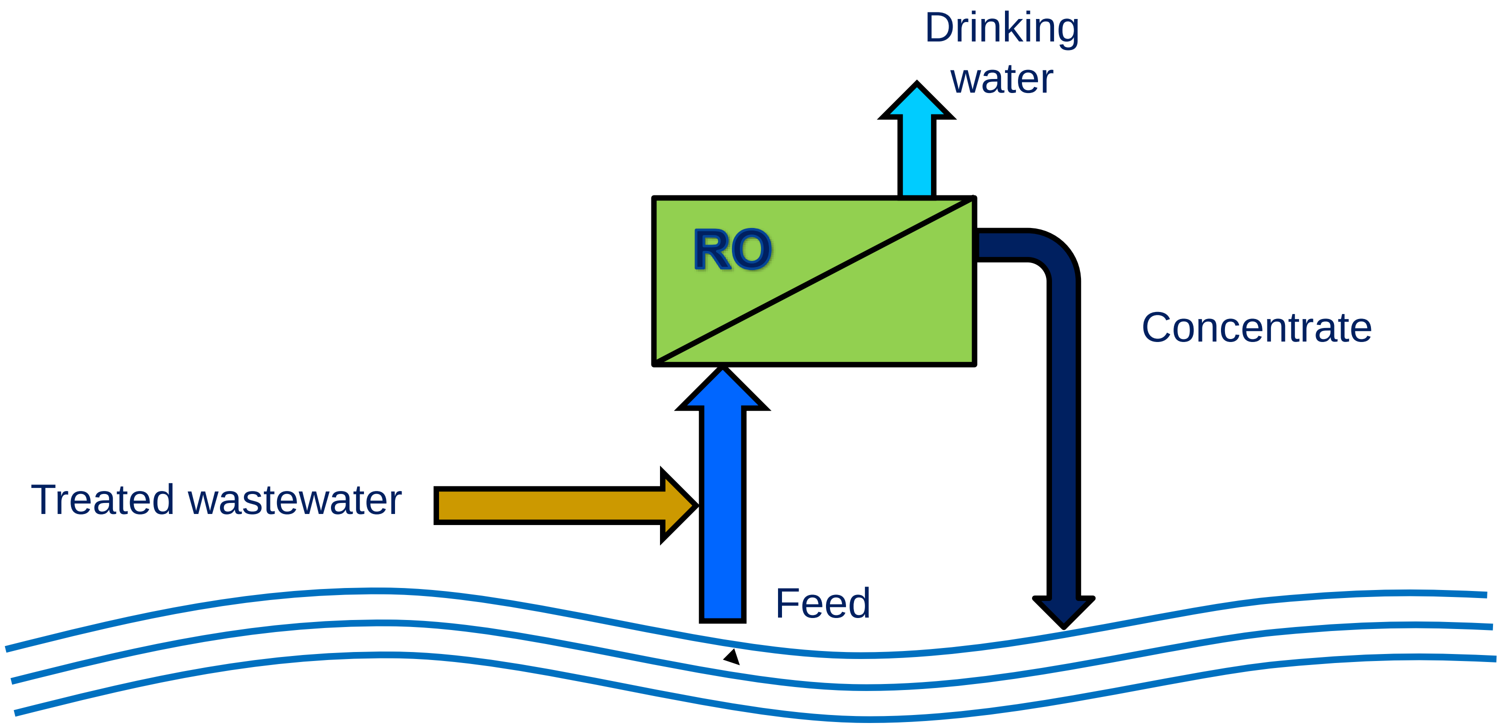
One Water

Wastewater. Stormwater. Groundwater. Drinking water. It's all One Water.

How can seawater and treated wastewater be combined to optimize water supply in arid regions?

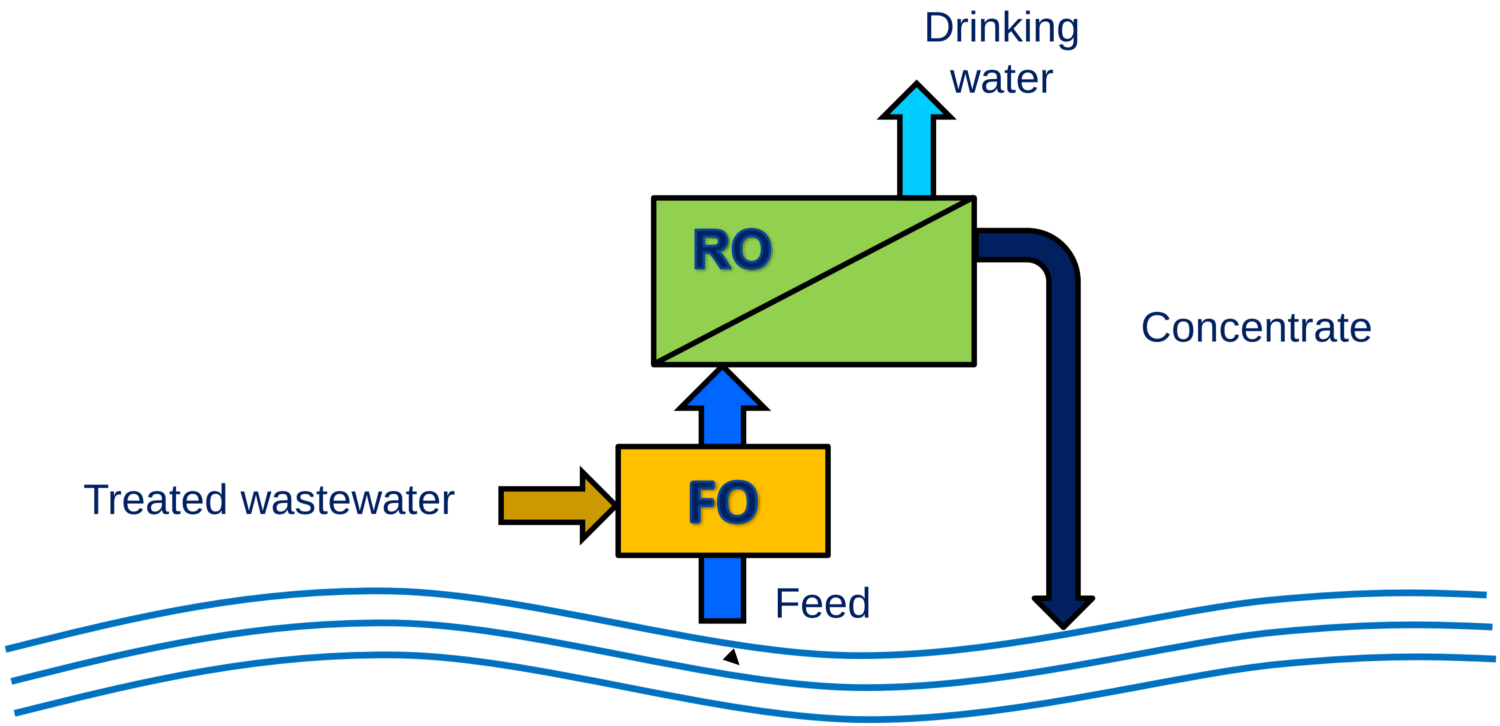
Can we do better than simply mixing them?

Osmotic Dilution



Reduces uptake volume requirements; Reduces energy requirements (dilutes feed)

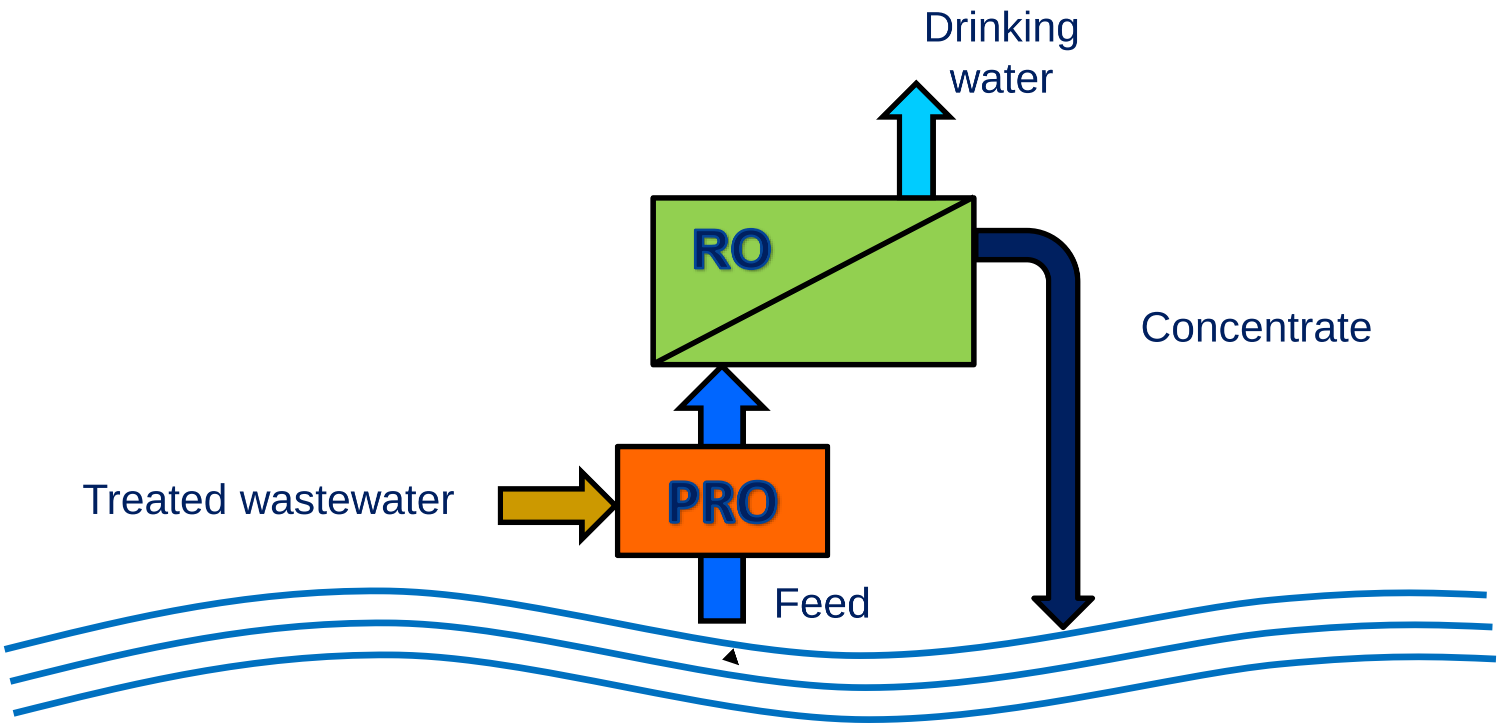
Osmotic Dilution



Reduces uptake volume requirements; Reduces energy requirements (dilutes feed)
High-quality pretreatment of wastewater stream

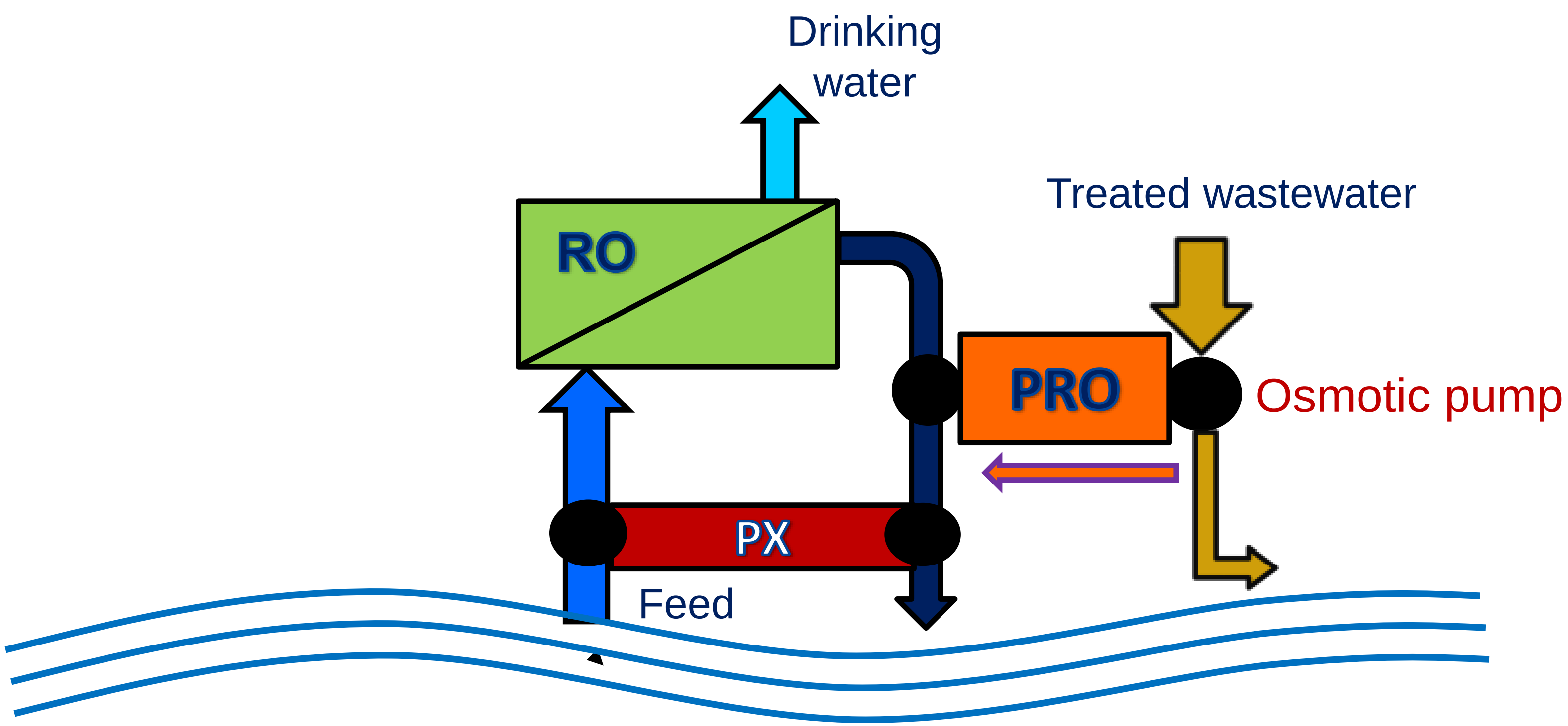
Cath and Childress 2011-2012
US Patents 7,914,680; 8,216,474; 8,083,942

Osmotic Dilution



Reduces uptake volume requirements; Reduces energy requirements (dilutes feed)
High-quality pretreatment of impaired water stream
Reduced energy consumption – Feed pre-pressurization

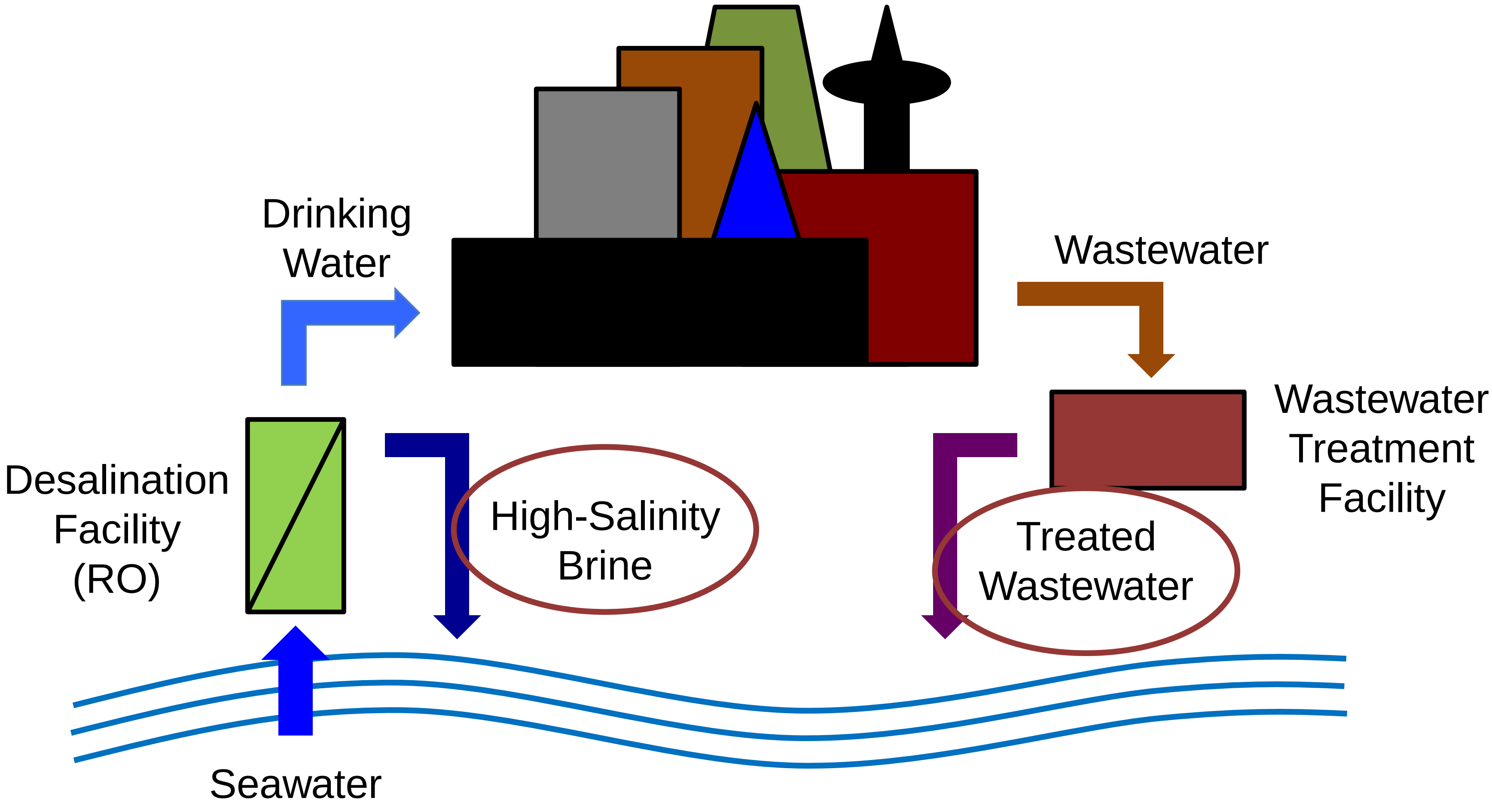
RO-PRO System



Dilution of concentrate stream
Reduced energy consumption

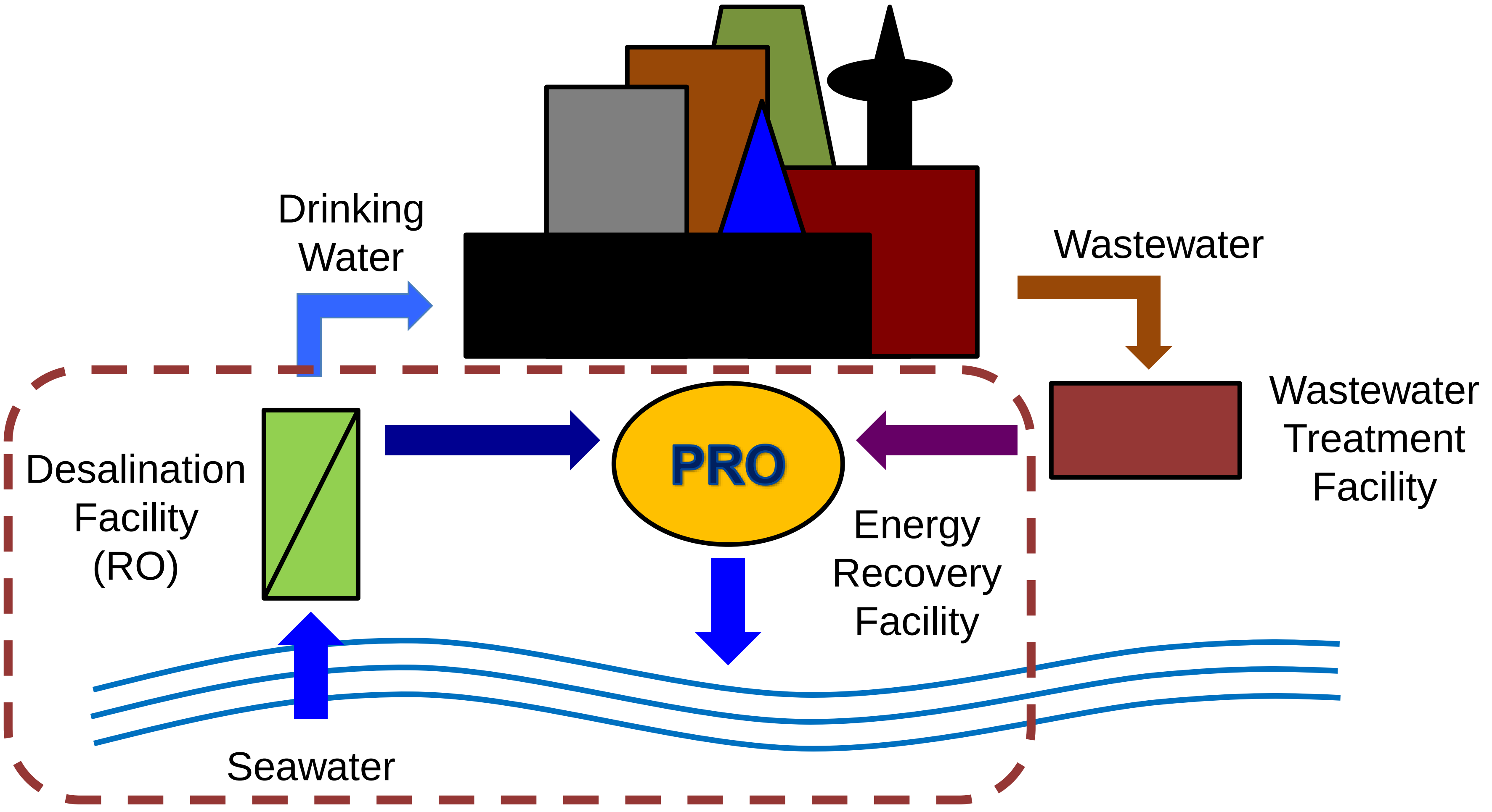
Achilli, Childress, Cath
US Patents 8801934 B2

Coastal Water System



Courtesy of Andrea Achilli

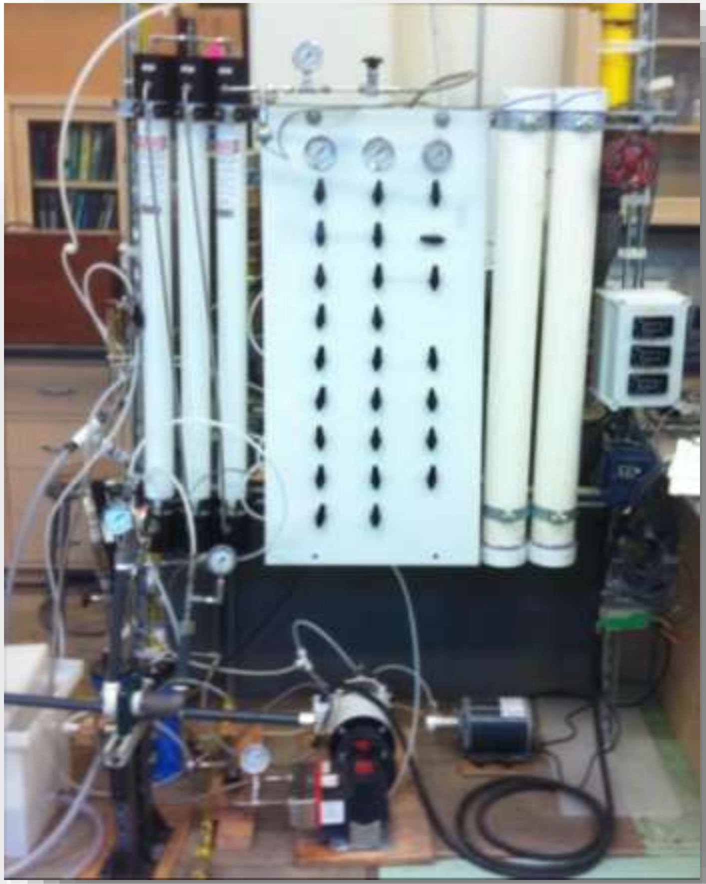
Coastal Water System



Courtesy of Andrea Achilli

Gen 1 RO-PRO System

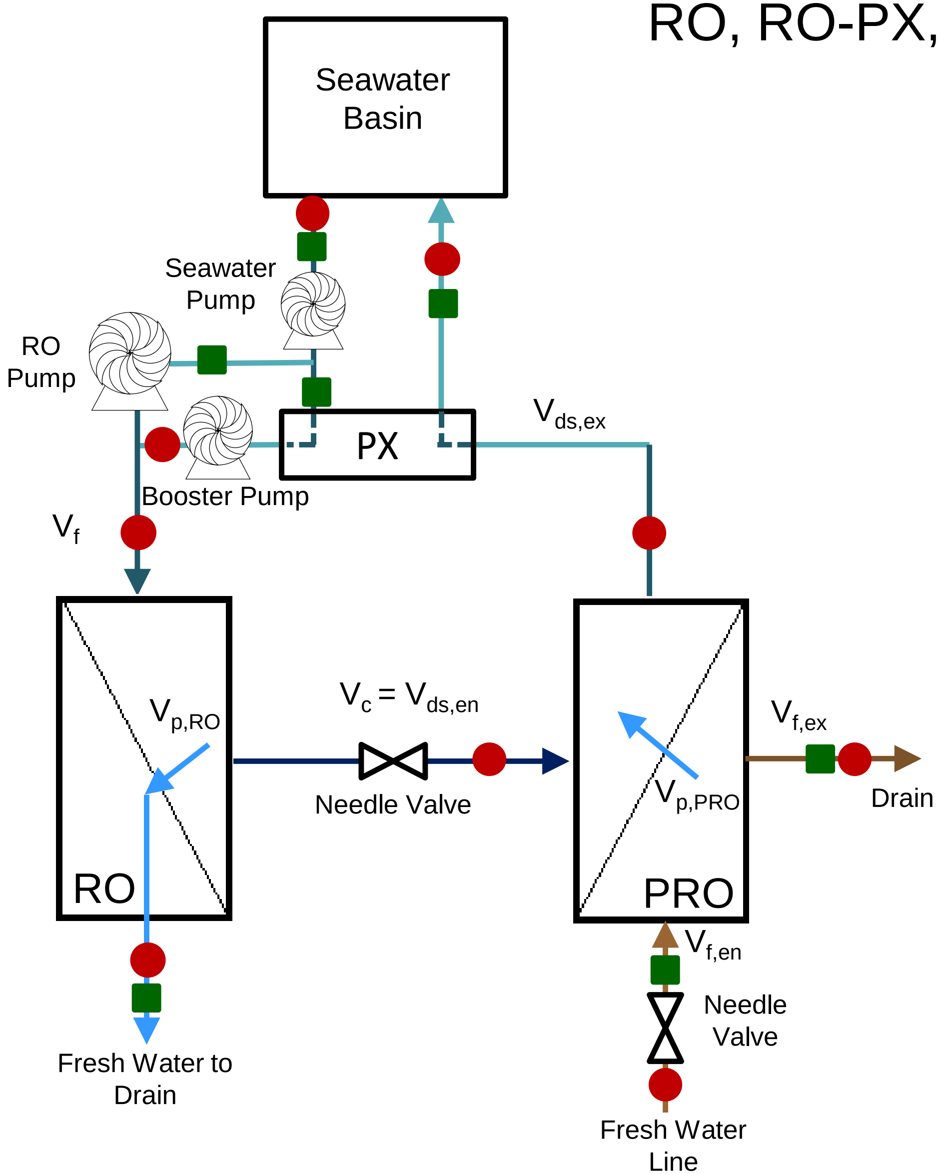
BGNDRF, Bureau of Reclamation
Alamogordo, NM
Summer 2012



UNR Fluids Lab
Fall 2012 - Spring 2013

Experimental Setup

RO, RO-PX, RO-PRO



$$SE = \frac{\sum(Q * \Delta P * \eta_p) - Q * \Delta P * \eta_{PX}}{Q_{p,RO}}$$

Q = Flow Rate through Device
ΔP = Pressure Difference Across Pump
η_p = Pump Efficiency
η_{px} = Pressure Exchanger Efficiency
$Q_{p,RO}$ = RO Permeate Flow Rate

■ = Flow Meter
● = Conductivity Port

Assumed pump efficiencies of 80%

Membranes

- System designed for:
  Cellulose triacetate (CTA) from Hydration Technology Innovations (HTI)
  A = 1.87 E-9 m/s/kPa B = 1.11 E-7 m/s S = 6.78 E-4 m

- System operated with:
  Thin film composite (TFC) membrane (early generation) from Oasys Water
  A = 1.42 E-8 m/s/kPa B = 2.41 E-8 m/s S = 3.10 E-4 m

Operational Challenges

unable to operate at high flowrates and fully utilize RO and PRO membranes

Gen-1 Results

Specific Energy Consumption (kWh/m^3)	20% Recovery	30% Recovery
RO Alone	6.51	5.25
RO-PX	3.73	3.38
RO-PRO	6.11	4.75

Achilli, Prante, Hancock, Maxwell, Childress 2014

- Proved that the energy from a volume of water transferred from atmospheric pressure to elevated pressure across a semi-permeable membrane can be utilized to pre-pressurize RO feed water.
- Published the first experimental PRO power density data for a RO-PRO system (1.1 to 2.3 W/m^2).
- But not able to achieve projected energy reductions…

Gen-1 Results

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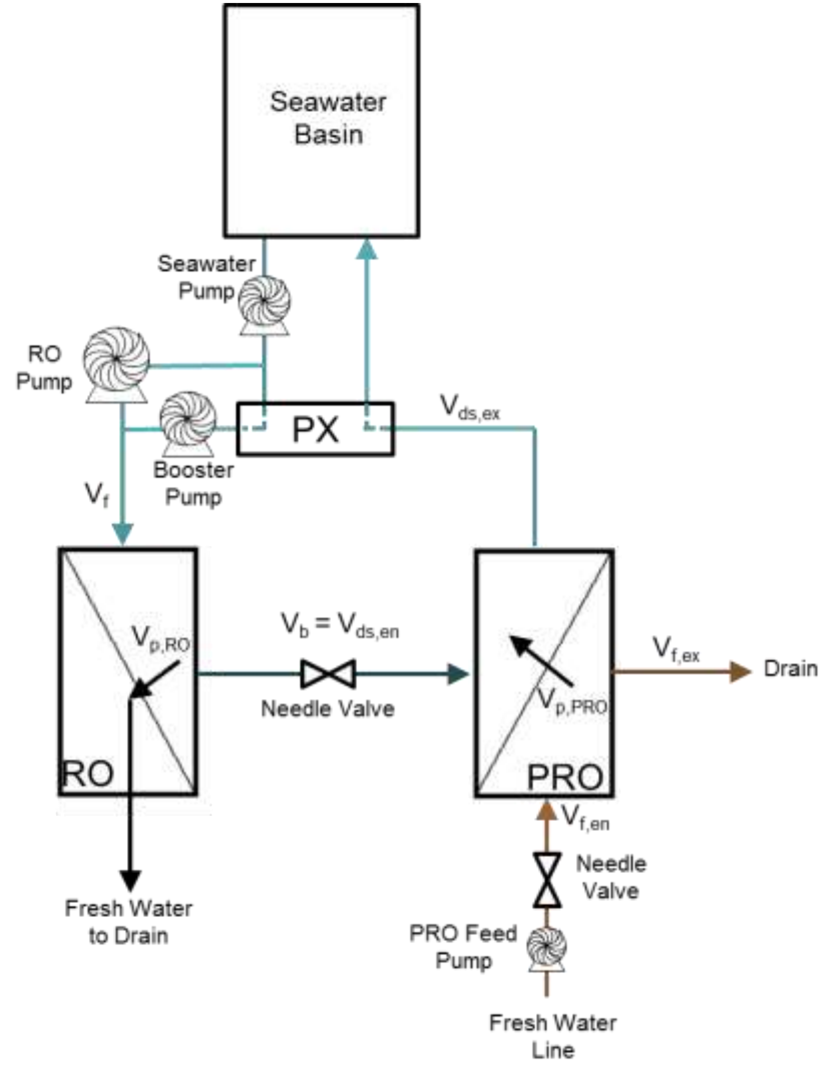
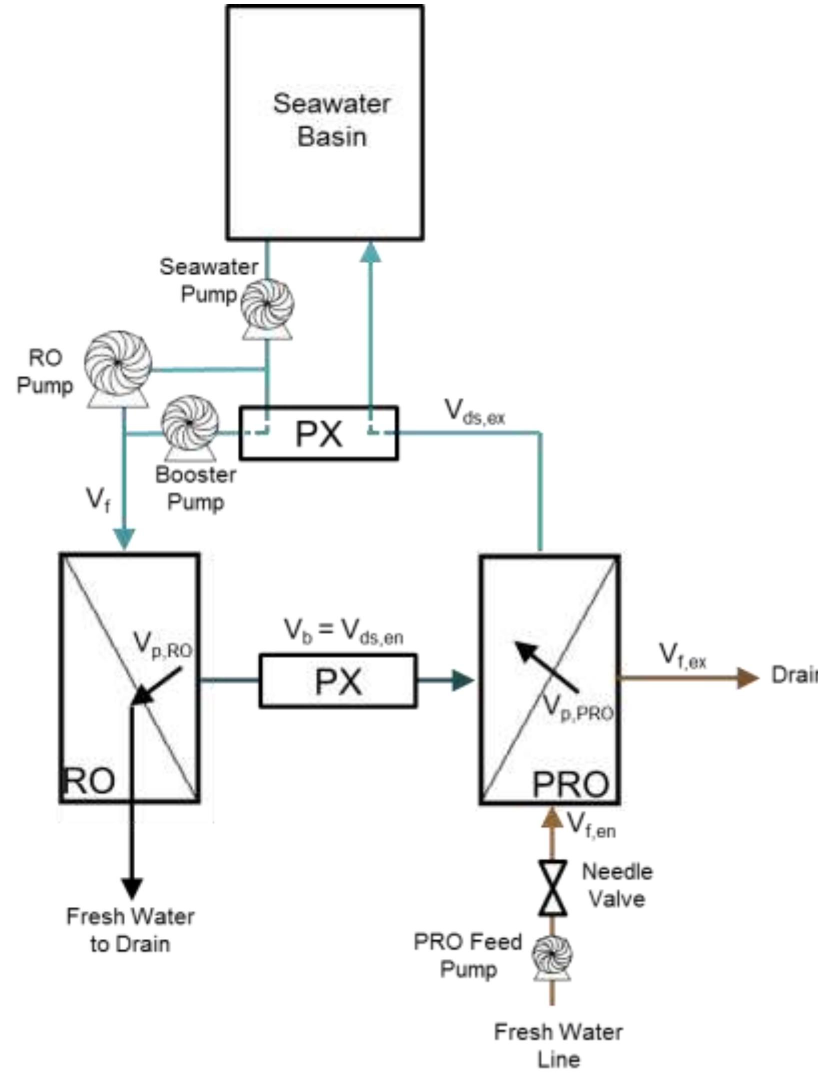


RO-PRO Gen-2

Empirical Results (kWh/m^3)	20% Recovery	30% Recovery
RO Alone	6.51	5.25
RO-PX	3.73	3.38
RO-PRO	*3.08*	*2.64*

Achilli, Prante, Hancock, Maxwell, Childress 2014



Gen-2 Pilot System

- Implementation of 2nd pressure exchanger
  - Completes system design to recover all waste energy

RO-PRO Gen-2

Specific Energy Consumption (kWh/m^3)	20% Recovery	30% Recovery	50% Recovery
RO Alone	6.51	5.25	?
RO-PX	3.73	3.38	?
RO-PRO	*3.08*	*2.64*	?

Achilli, Prante, Hancock, Maxwell, Childress 2014

Gen-2 Pilot System

- Implementation of 2nd pressure exchanger
  - Completes system design to recover all waste energy
- Design for higher flowrates
  - fully utilizes RO and PRO membranes
  - allows 50% RO recovery

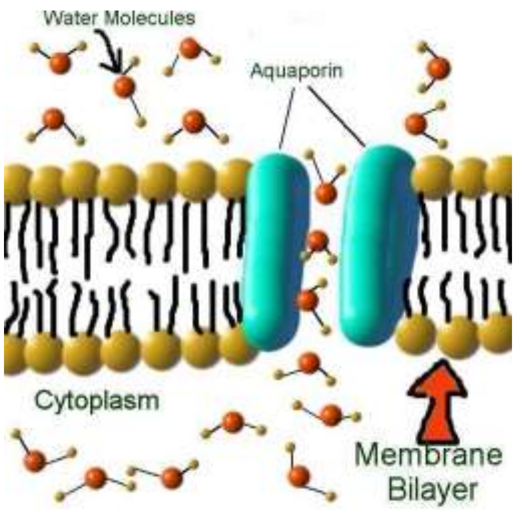
Membranes

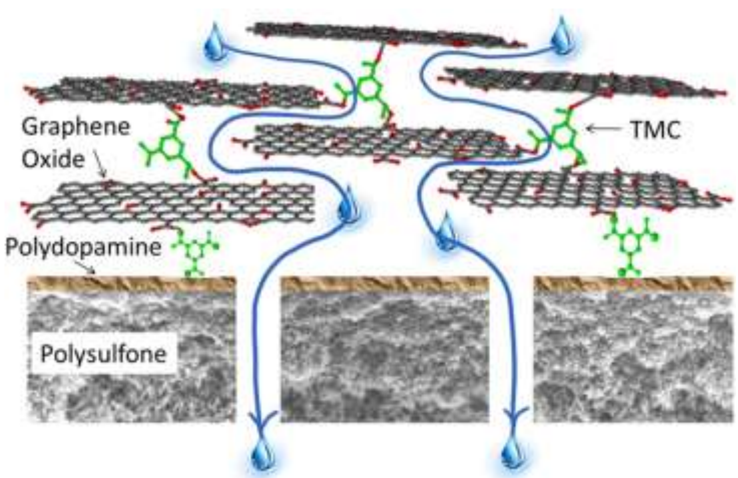
- Cellulose triacetate (CTA) from Hydration Technology Innovations (HTI)
  A = 1.87 E-9 m/s/kPa   B = 1.11 E-7 m/s   S = 6.78 E-4 m

- Thin film composite (TFC) membrane (early generation) from Oasys Water
  A = 1.42 E-8 m/s/kPa   B = 2.41 E-8 m/s   S = 3.10 E-4 m

- More recent membranes
  - PRO: Toyobo (Japan), Woongjin (South Korea)
  - FO: Porifera, Oasys, HTI

- "Game-Changing" Membranes…





Acknowledgements

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