



# PROCESS COMMERCIALIZATION LANDSCAPE FOR FORWARD OSMOSIS

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Erik Desormeaux  
erikd@porifera.com  
(510) 648-5767  
3502 Breakwater Court  
Hayward, CA, USA

# Porifera Introduction and Overview

- Founded in 2009 in Hayward, CA, USA.
- Porifera Forward Osmosis (PFO) technology developed for US military
- PFO systems for product concentration, near ZLD, and water reuse
- Sold elements and pilot systems in Europe, Middle East, Australia & the Americas since November 2013 product launch.
- Mass manufacture membrane in Korea; systems in US



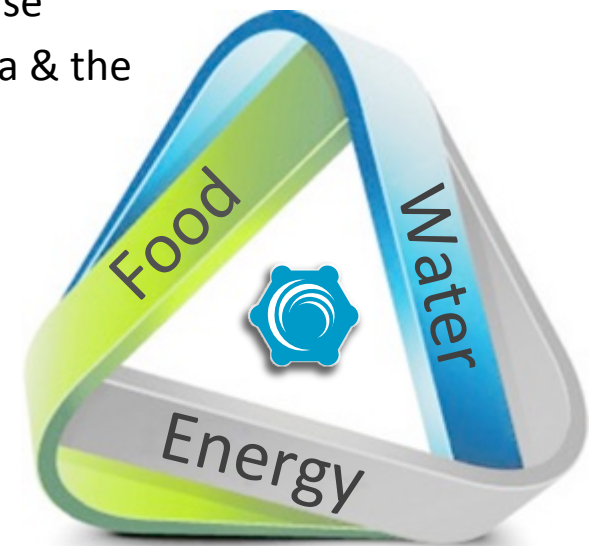
PFO-100 element (7m<sup>2</sup>)



PFO module (42-70 m<sup>2</sup>)



5000-10,000 gpd PFO pilot system (20-40 m<sup>3</sup>/day) (with two 42 m<sup>2</sup> modules)



At the Heart of the  
Water-Energy-Food Nexus

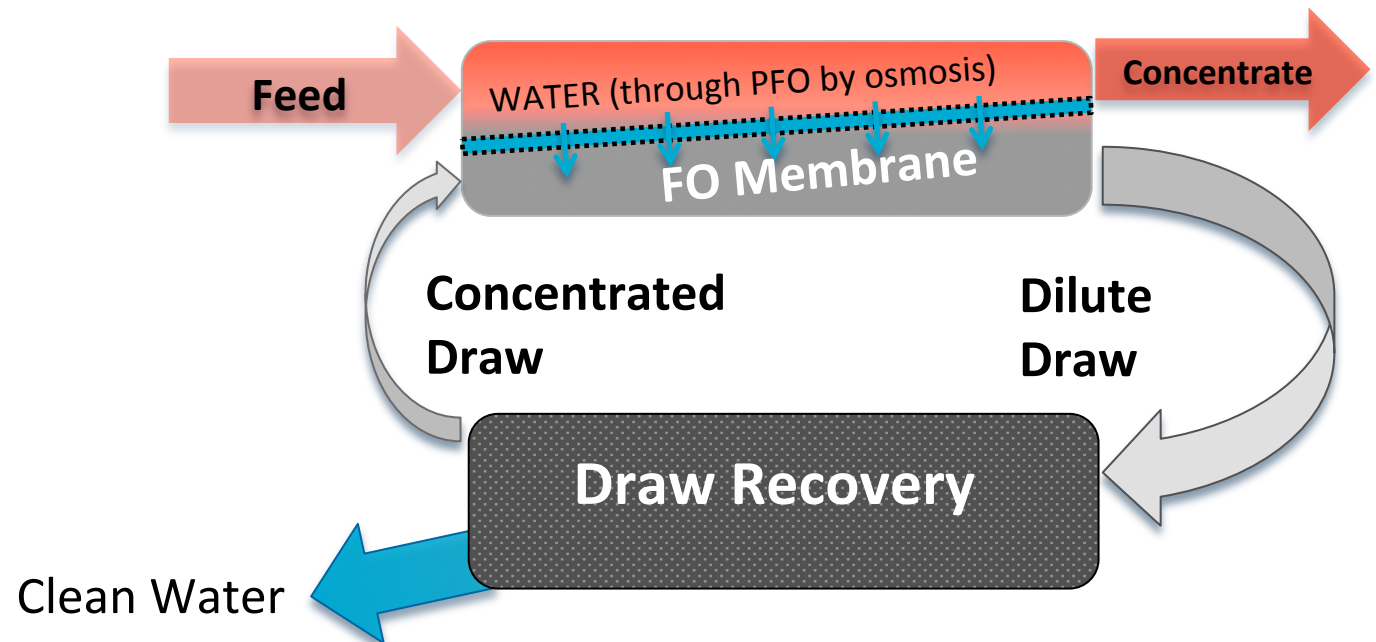
# What are the perceived challenges for FO?

## 1) FO Membrane performance:

- *Cost and footprint*

## 2) Draw chemistry & recovery:

- *Energy use*

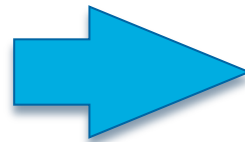


# Perceived Challenges

## Check these off your list!!!!

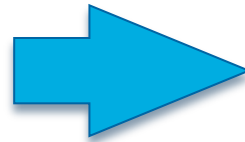
### 1) FO Membrane performance:

- Cost and footprint



### 2) Draw chemistry & recovery:

- Energy use



Over 10 pilot size systems operating successfully worldwide that can compete on cost, footprint & energy use



# Key Remaining Challenges are Market Based

- What is FO good for?
- Is FO ready for broad commercialization?
- What are FO Target markets?



Customer operated pilot in Asia



# What does FO do better than other technologies?

Oil Field Waste  
Conc. 4X



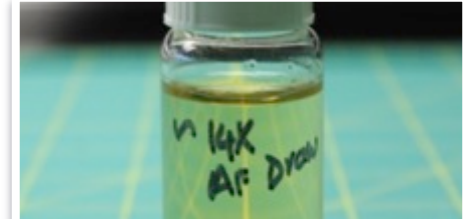
**HIGH FOULING**  
- Fewer treatment steps and  
a new tool to solve difficult  
problems

Tomato Juice to  
Tomato Paste



**HIGH QUALITY**  
- Unprecedented retention  
of flavors, VOC's, and  
PATHOGENS/VIRUS

14 X Concentrated  
RO Brine with Silica



# For Which Industries is FO a Good Fit?



## FOOD & BEVERAGE

Product Concentration  
Waste Concentration  
& Reuse  
Water Recycling

Why consider FO?  
New products, low  
cost, sustainability, &  
higher purity



## OIL & GAS

Unique drilling fluid  
chemistry and reuse  
ZLD concentration of  
oilfield brines  
Small footprint  
offshore treatment

Why consider FO?  
High temperatures,  
reliability, low cost,  
small footprint



## INDUSTRY & MINING

Product concentration  
High purity processing  
Waste concentration  
and reuse

Why consider FO?  
High temperatures,  
new products, low  
cost, small footprint



## WATER & AGRICULTURE

Ultimate technology  
for potable reuse  
Unique water reuse  
solutions for every  
aspect of society.

Why consider FO?  
Purity for POTABLE,  
IRRIGATION, &  
RESIDENTIAL REUSE

**Key Innovations:  
Why is FO more attractive  
now than 2 years ago?**



# PFO Membrane Outperforms Competition

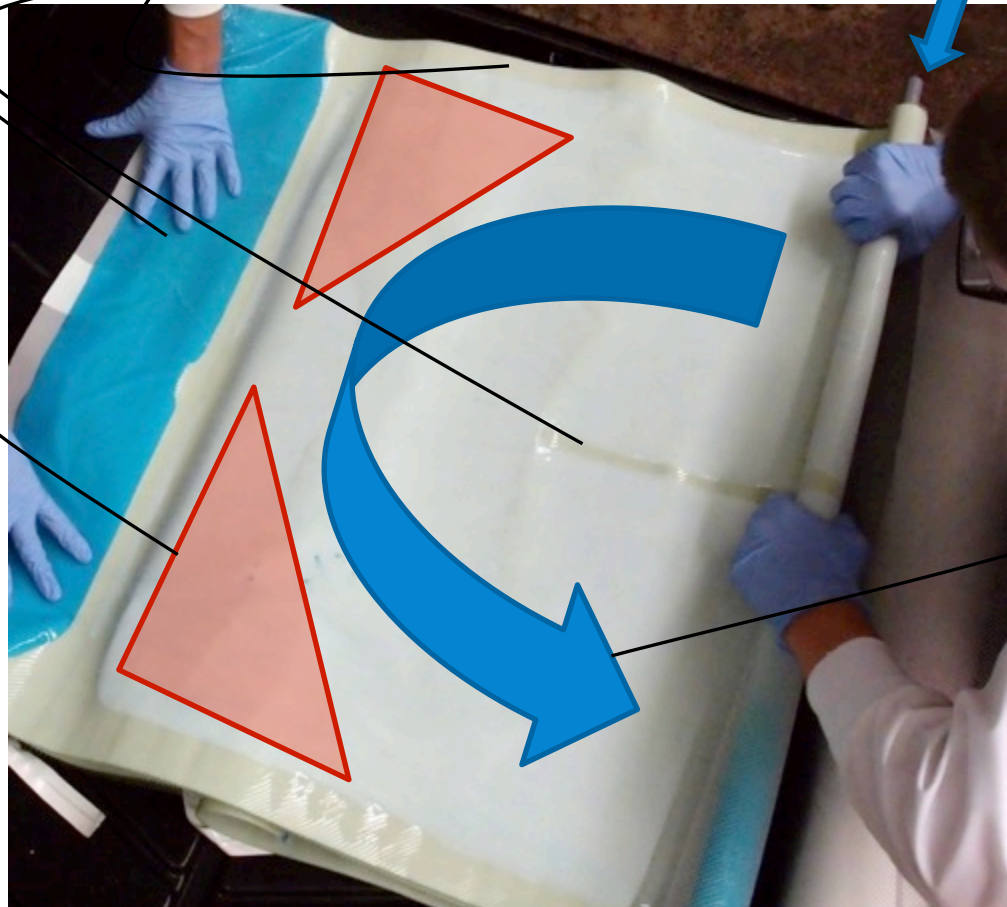
Supplier	flux [LMH]	Specific flux [LMH/bar]	RSF [g/l]	Structural parameter S [um]	Source
Aquaporin Flat Sheet	7	0.15	0.29	N/A	Data Sheet, SIWW 2014
HTI CTA	12	0.26	0.58	500	T. Cath et al. Desalination 2012, doi:10.1016/j.desal.2012.07.005
HTI TFC	17.5	0.37	0.41	N/A	Data sheet, Weftec 2013
Oasys TFC	30	0.64	1.67	375	T. Cath et al. Desalination 2012, doi:10.1016/j.desal.2012.07.005
Porifera	33	0.70	0.40	215	Data Sheet, SIWW 2014

- Highest flux & highest rejection commercial FO membrane according to NASA, customers, and universities
- **Highest Temp., COD, Oil & Grease limits for polymeric membranes:**
  - Up to 80°C
  - Success with feeds >10,000 mg/L COD and >100 ppm oils and greases

# Spiral Wound Elements: non-ideal flow paths for FO

Inactive membrane

Low surface velocity  
(dead zones)  
High concentration polarization effects



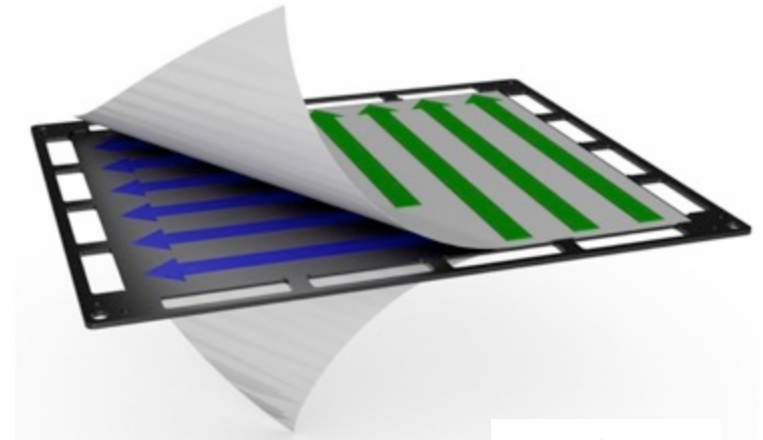
Draw IN

Draw flow path

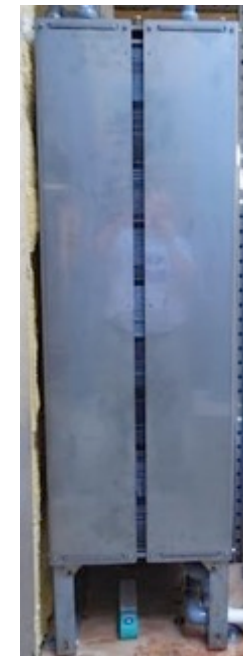
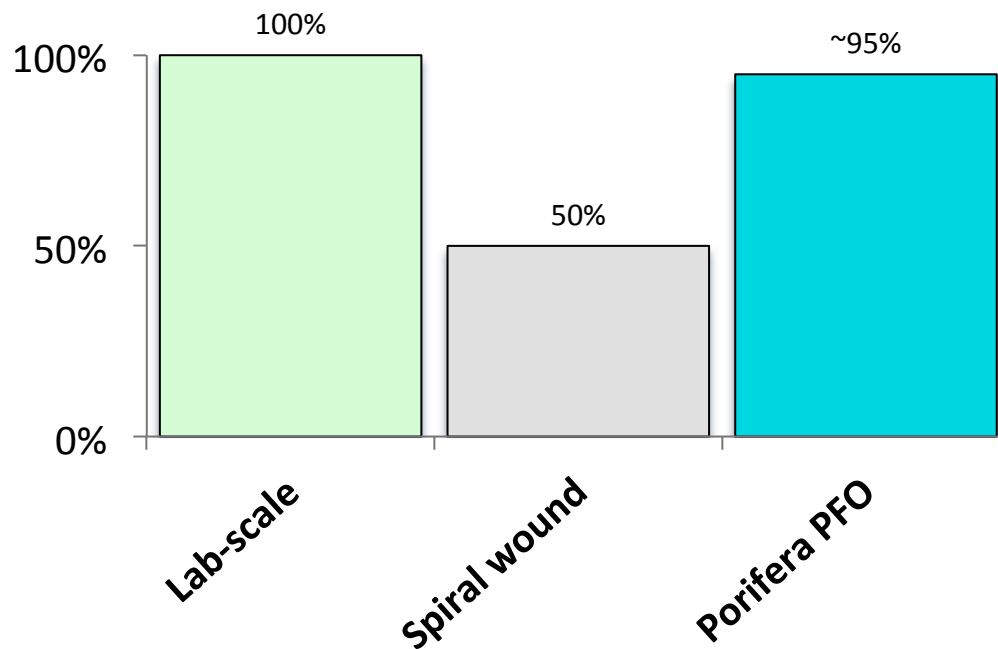
Draw OUT

# Best FO Packaging and Systems

- Ideal flow paths result in >95% system efficiency
- Only spacerless element for high solids & high algae applications
- Only small footprint submersible, flat sheet element for MBR and submerged applications



Element Related Scale Up Efficiency

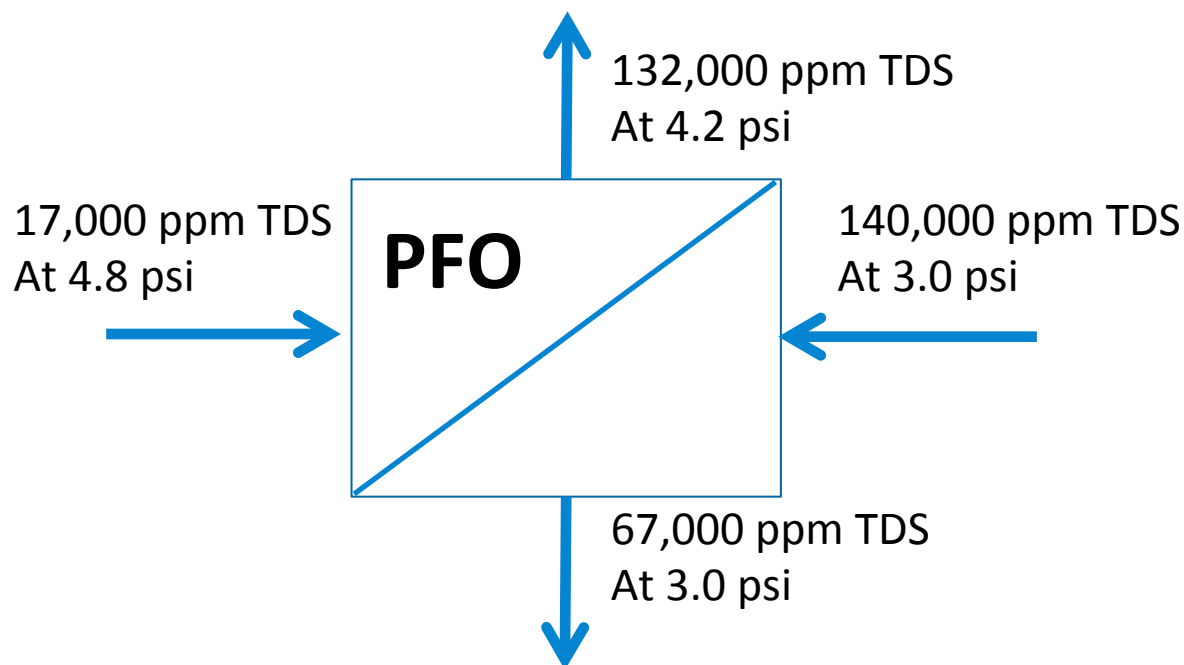


# What can Porifera do with these elements?

Parameter	Spiral CTA FO	Porifera FO
Elements	44	10
Tapered Stages	3	2
Pressure drop	>30 psi	~12 psi
Flow	10-20 times higher	

## Baffled FO Element Stacks:

- Allows constant surface velocity across entire membrane area.
- Engineered to any recovery at high efficiency & low headloss.
- Co-current or counter-current



Porifera's first baffled Stack



# How do recent FO innovations affect the bottom line?

Reduced footprint, CAPEX, OPEX and Life Cycle costs for a 30,000 m<sup>3</sup>/day system.

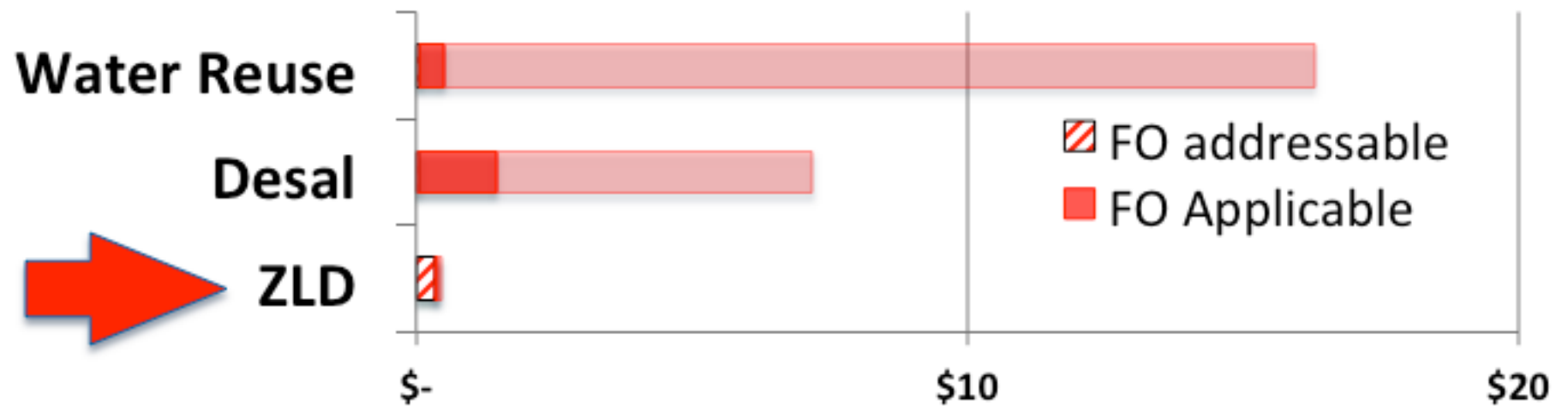
## 3 Years Ago

Spiral wound element  
+ CTA membrane

	CAPEX Footprint & Building	CAPEX Equipment	OPEX	Lifecycle % savings
3 Years Ago Spiral wound element + CTA membrane	\$\$\$\$\$	\$\$\$\$\$\$\$\$\$\$ \$\$\$\$\$\$\$\$\$\$ \$\$\$\$\$\$\$\$	\$\$\$	0%
Membrane Spiral wound element + PFO membrane	\$\$	\$\$\$\$\$\$\$\$\$\$	\$\$	50%
Element PFO element + CTA membrane	\$	\$\$\$\$\$\$\$\$\$\$ \$\$\$\$\$\$\$\$	\$\$	32%
Current PFO membrane + PFO element	\$	\$\$\$\$\$\$\$\$	\$	62%

Note: Compares FO system only; does not include CIP system, containers, strainers, pretreatment or other ancillary systems

# FO Market Today

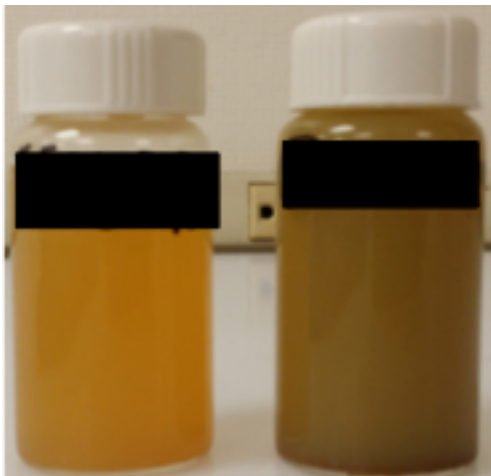


Frost and Sullivan Report of 2009; "Global Water Recycling Equipment Markets"  
BCC, 2013; Global wastewater reuse, recycling markets  
GWI, Global Water Market 2014

Example 1:

## Oilfield Fracking Waste Concentration for minimal liquid discharge

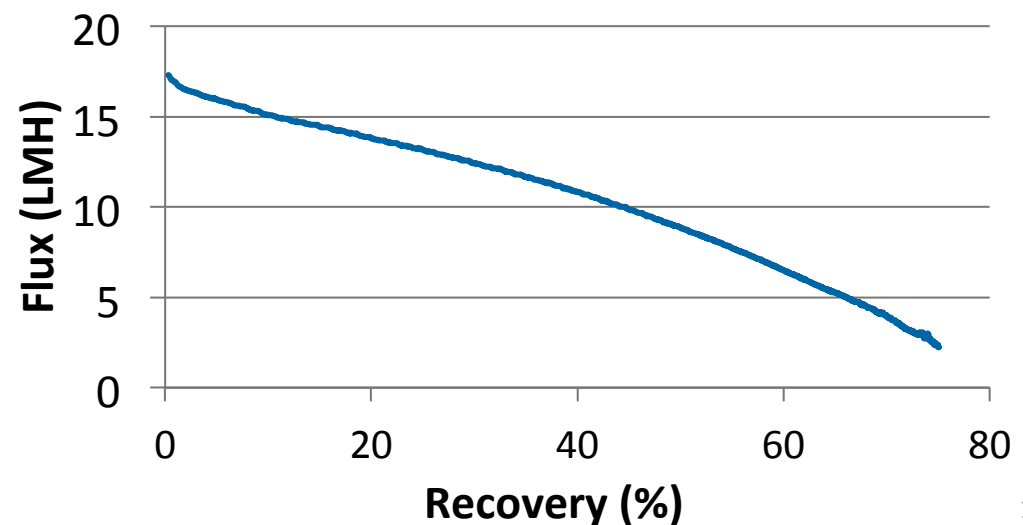
- Feed: mixed oil well waste (~50,000 ppm TDS) with high concentrations of COD, scalants, and inorganic salts
- Demonstrated concentration of challenging feed to 200,000 ppm TDS without irreversible membrane degradation



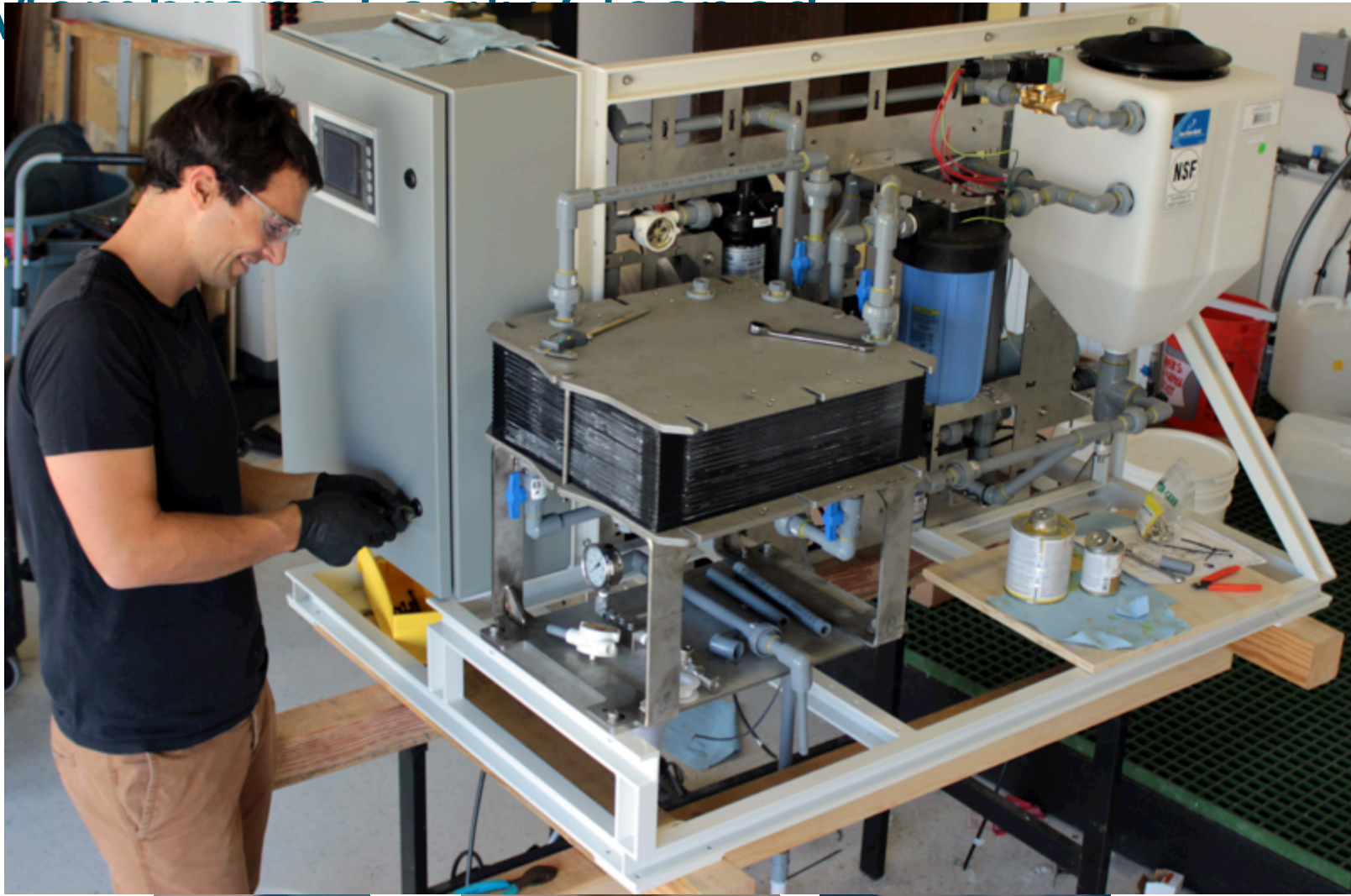
Initial Feed

~4x Concentrate

### Flux vs Recovery



# Membrane Fouling Control



sh.

**Membrane coupon  
before testing**

**Membrane coupon  
after testing**

**Membrane coupon  
after osmotic backflush**

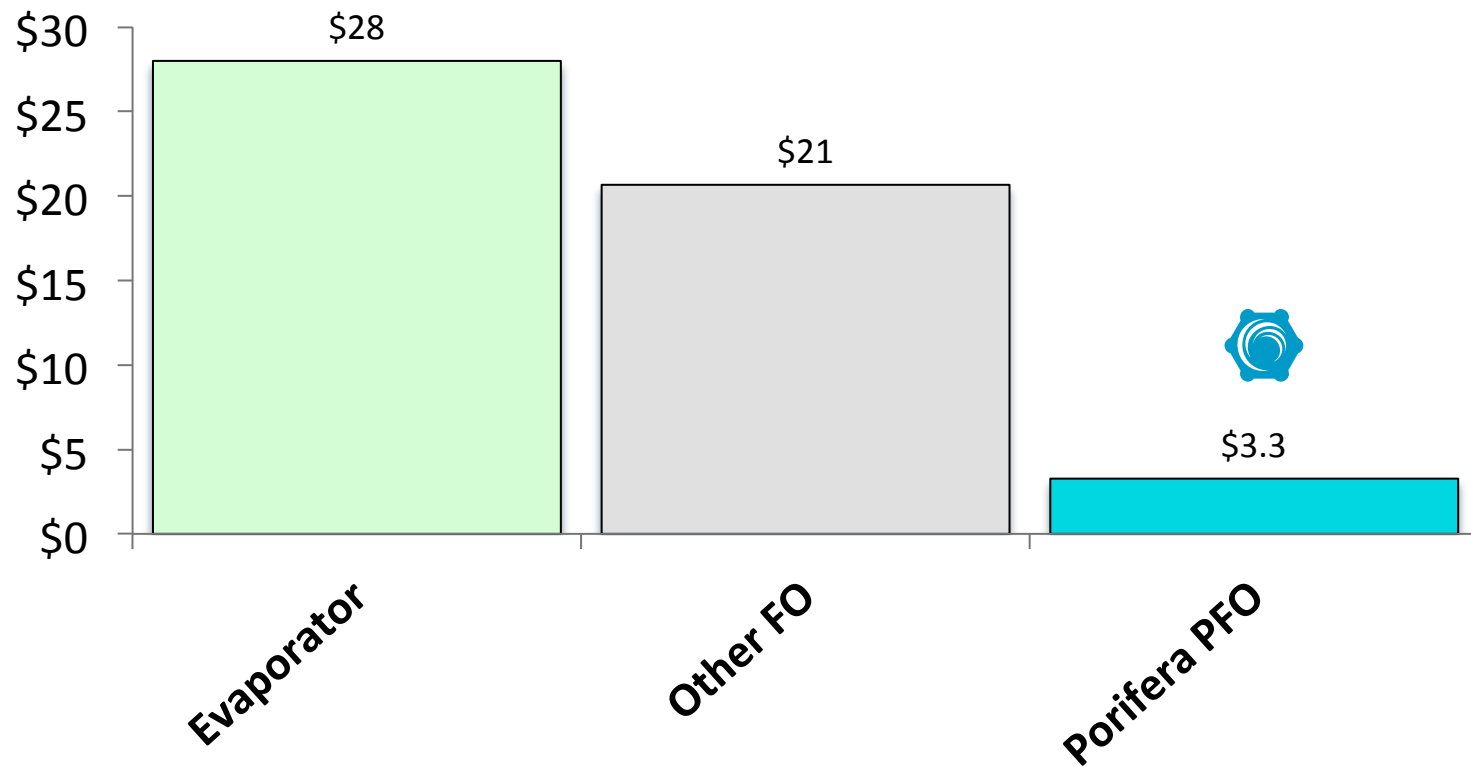


Advantage 1

Advantage 2

# Lowest Cost for High TDS Applications that RO Cannot Treat

Life Cycle Cost per m3 of clean water reused (\$)

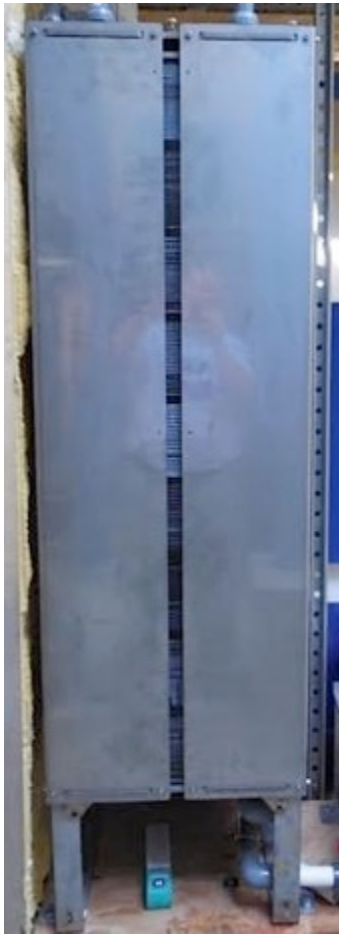


Assumes 20 Year Analysis & 7% interest rate for Oil Field Waste Concentration, Disposal, and Water Reuse via a turn-key solution including containers, pretreatment, & ancillary systems

Advantage 1

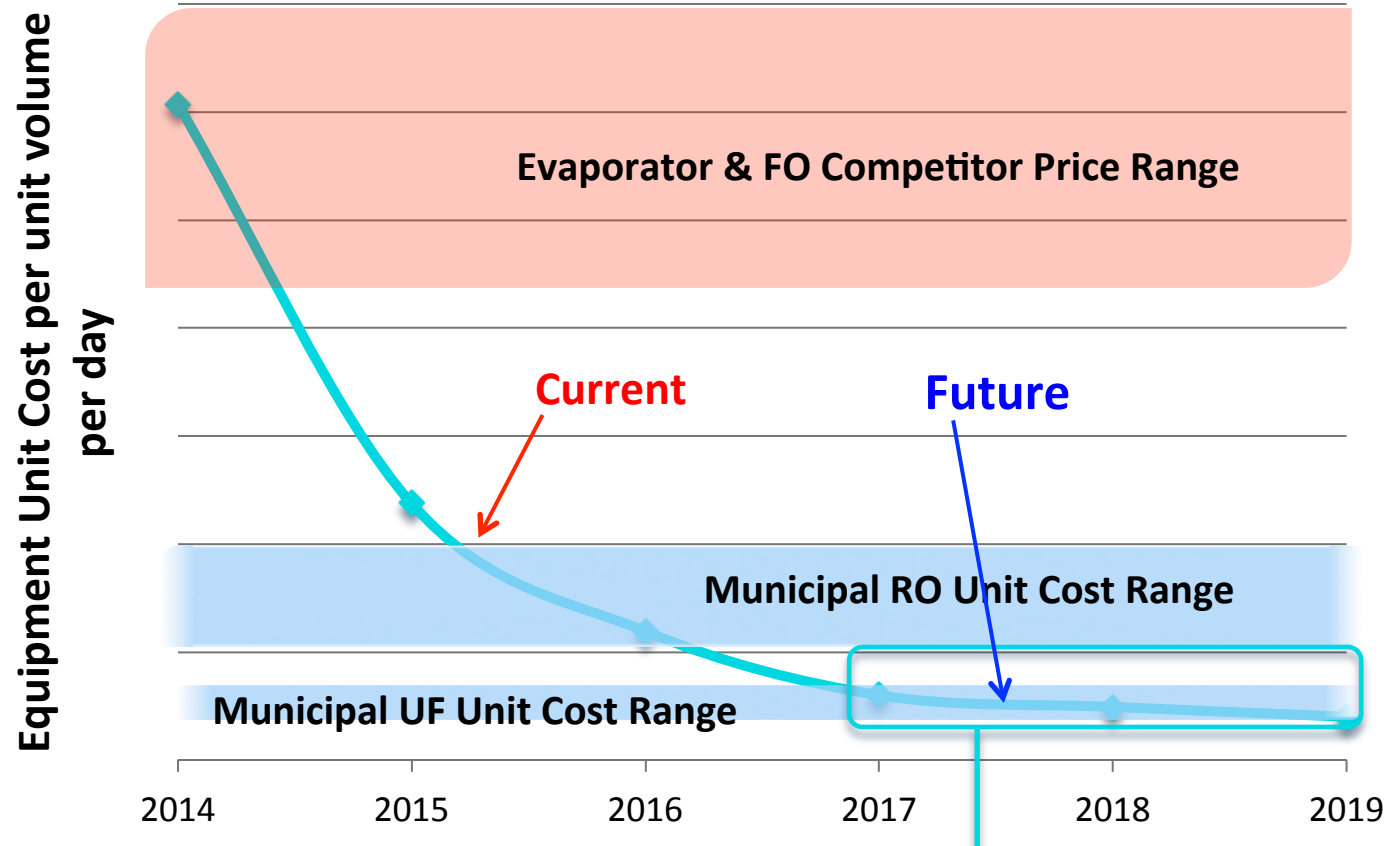
Advantage 2

# Broad Market Commercialization? FO+RO will compete with UF+RO



63 m<sup>2</sup> PFO modules  
480 m<sup>2</sup> modules in development

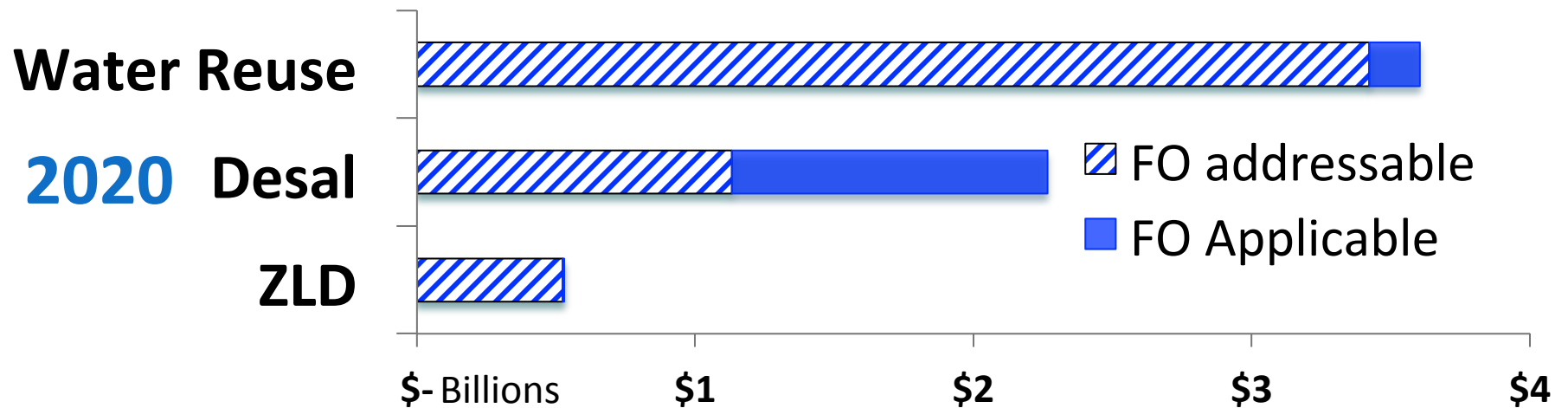
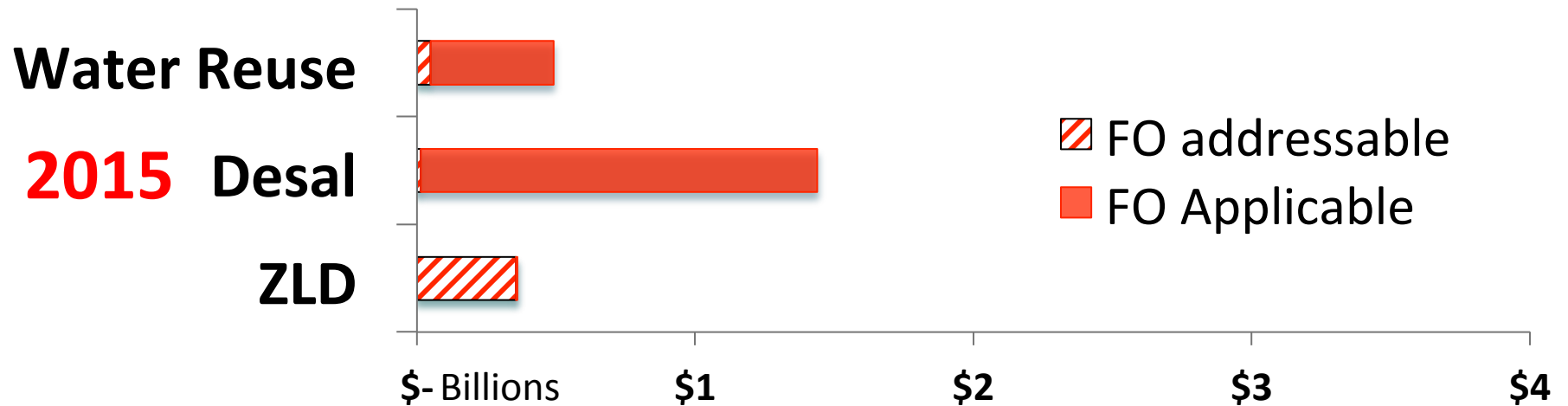
Equipment Only Unit Cost Comparison



PFO brings FO to mainstream municipal projects

## Target Markets:

# ZLD NOW, REUSE TOMORROW



# Conclusions

- What is FO good for?
  - High fouling
  - High quality
  - High TDS
- Is FO ready for broad commercialization:
  - Yes. Recent innovations greatly reduce cost and footprint:
    - *PFO membranes and elements most efficient on the market*
    - *Use of salt as the draw achieves low energy*
- What are FO target markets?
  - Best bang for your buck:
    - *TODAY: Near ZLD*
    - *TOMORROW: Water reuse*



## Why is FO ideal for Direct Potable Reuse?

IDA Conference Presentation

S-06 Emerging Technologies: Forward Osmosis and Osmotic Processes [Part 2]

Wednesday, September 02, 2015 @ 2:30 PM - 3:00 PM



Questions?

# Appendix

# Porifera FO for Water Reuse



**Aerospace and Valuable Graywaters**  
– simple, high purity , high recovery,  
low maintenance solution



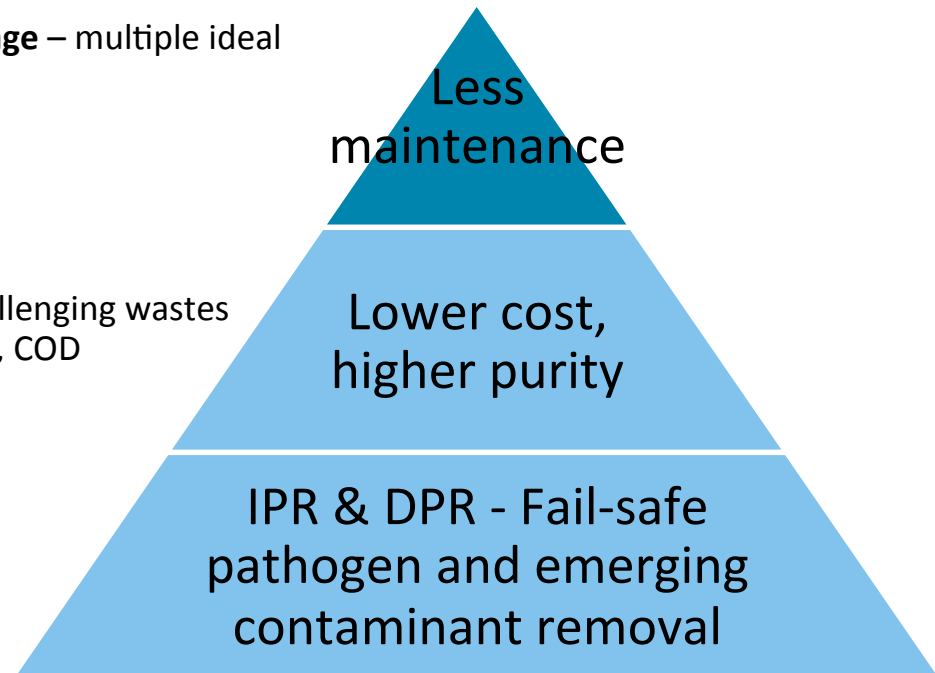
**Food and beverage** – multiple ideal applications



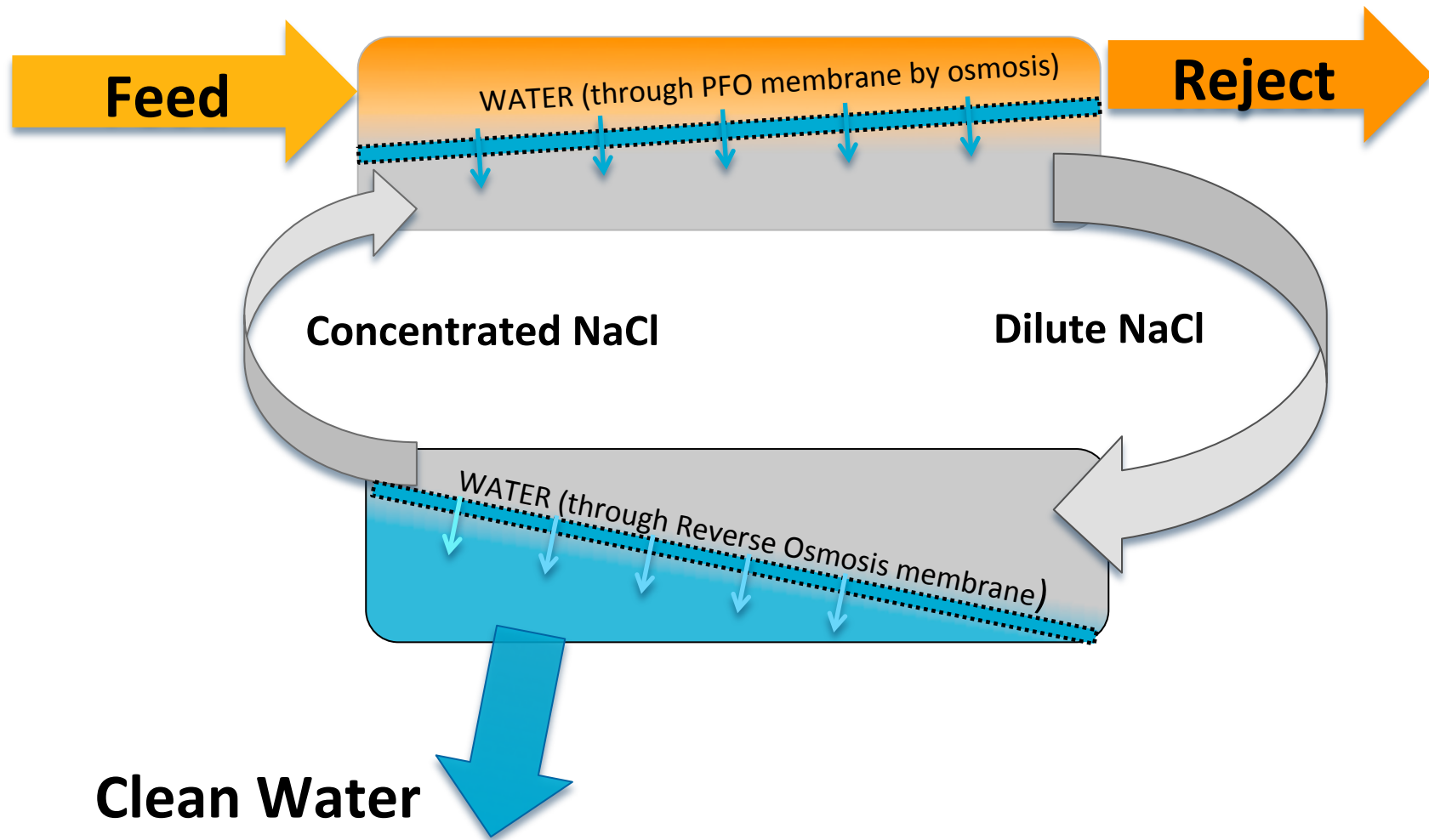
**Industrial** – challenging wastes  
with oils, VOC's, COD



**Municipal** – Indirect and Direct  
Potable Reuse



# PFO Recycler: FO+RO System for Low TDS



# PFO Concentrator: Standard FO+RO System with NaCl Draw for High TDS and Near ZLD

