Advanced, Energy-Efficient Hybrid Membrane System for Industrial Water Reuse

DOE Cooperative Agreement No. DE-EE0005758
RTI International, Duke University,
and Veolia Water Solutions & Technologies North America, Inc.
Project Period: September 1, 2012 to November 30, 2015

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Washington, D.C.
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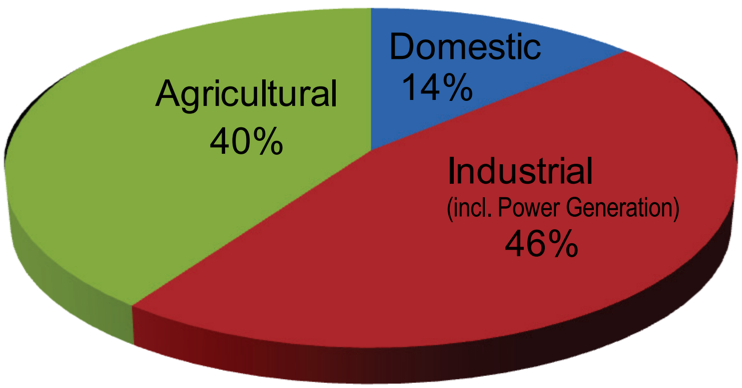
Project Objective

Current State/Challenges of Industrial Water Use

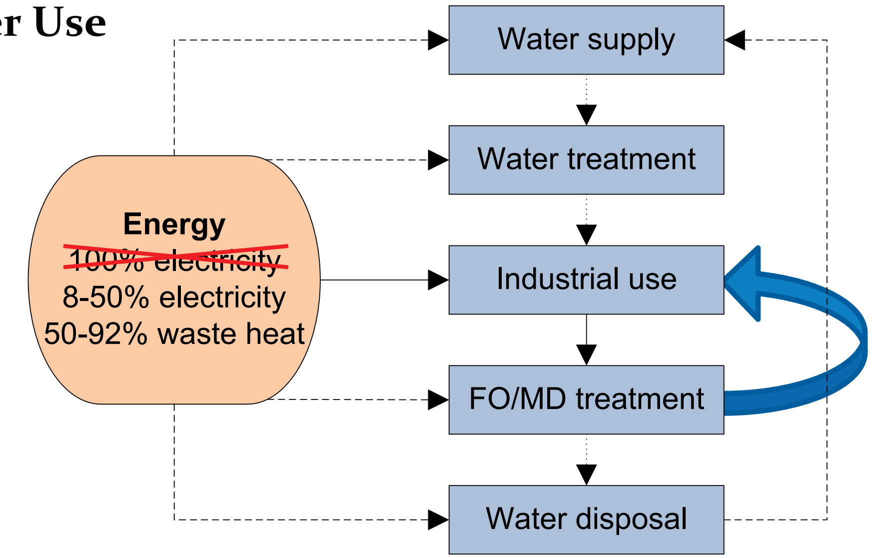
- Heavy industrial water utilization footprint

Freshwater Withdrawals in the U.S. by Sector (2005)



Source: U.S. CIA World Factbook

Total = 478.4 km^3/yr



Water reuse and waste heat can reduce freshwater withdrawal and energy consumption.

- ~5.2 quadrillion BTU* (2010) consumed for water services in U.S. industrial sector
- Minimal to no water reuse
- Wide spectrum of contaminants in industrial wastewaters, making them difficult to treat
- High energy intensity, pretreatment needs, and water-treatment costs
- Unsustainabilit (limited resources, regulatory pressures)

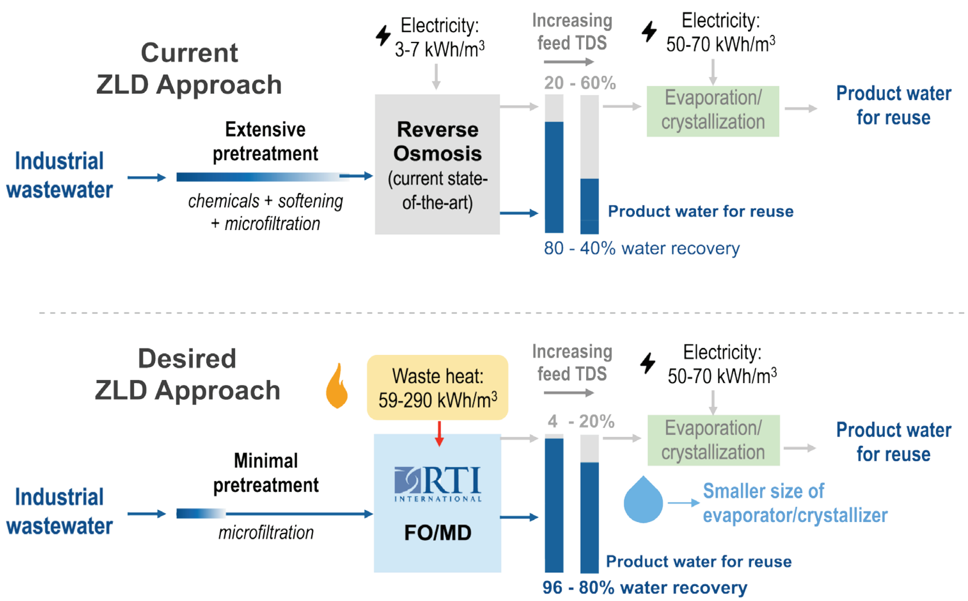
* *Ref.: Sanders and Weber, Environ. Res. Lett., **7**, 1-11 (2012)*

Project Objectiv

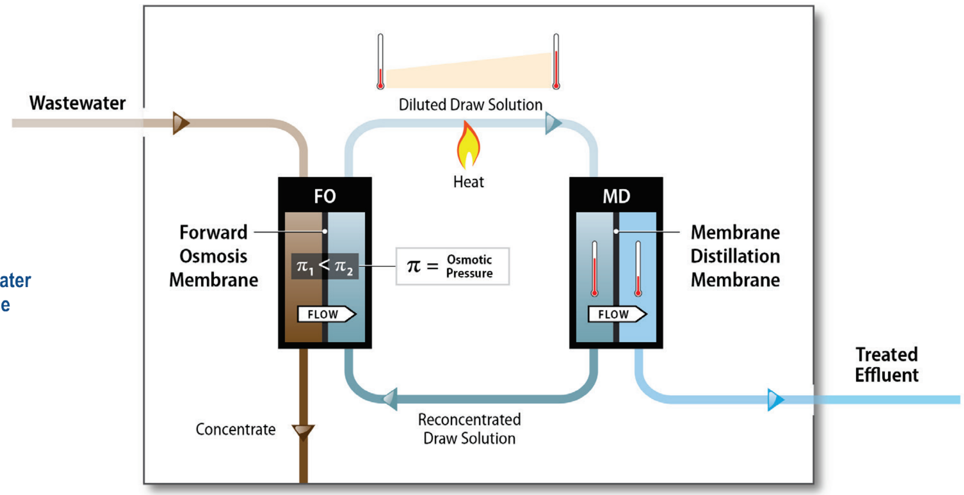
Develop and demonstrate advanced hybrid industrial water treatment system that will…

- Cost-effectively enable at least 50% water reuse efficiency near term toward Zero-Liquid Discharge (ZLD)
- Improve energy efficiency of industrial wastewater treatment by at least 50%, relative to current technology

Technical Approach



Innovative Technical Approach



- Beneficial utilization of waste heat
- Synergistic coupling of FO (forward osmosis) and MD (membrane distillation)
  - FO (osmotically driven process):
    Pretreatment for MD
  - MD (thermally driven process):
    Regeneration of high-osmotic FO draw solution
- Low-pressure operation
  - Reduced energy requirements
- High water recovery/reuse potential
- Broad applicability to different industries

Technical Approach

Strong, Multidisciplinary Project Team:

Basic R&D → Applied technology development → Commercialization

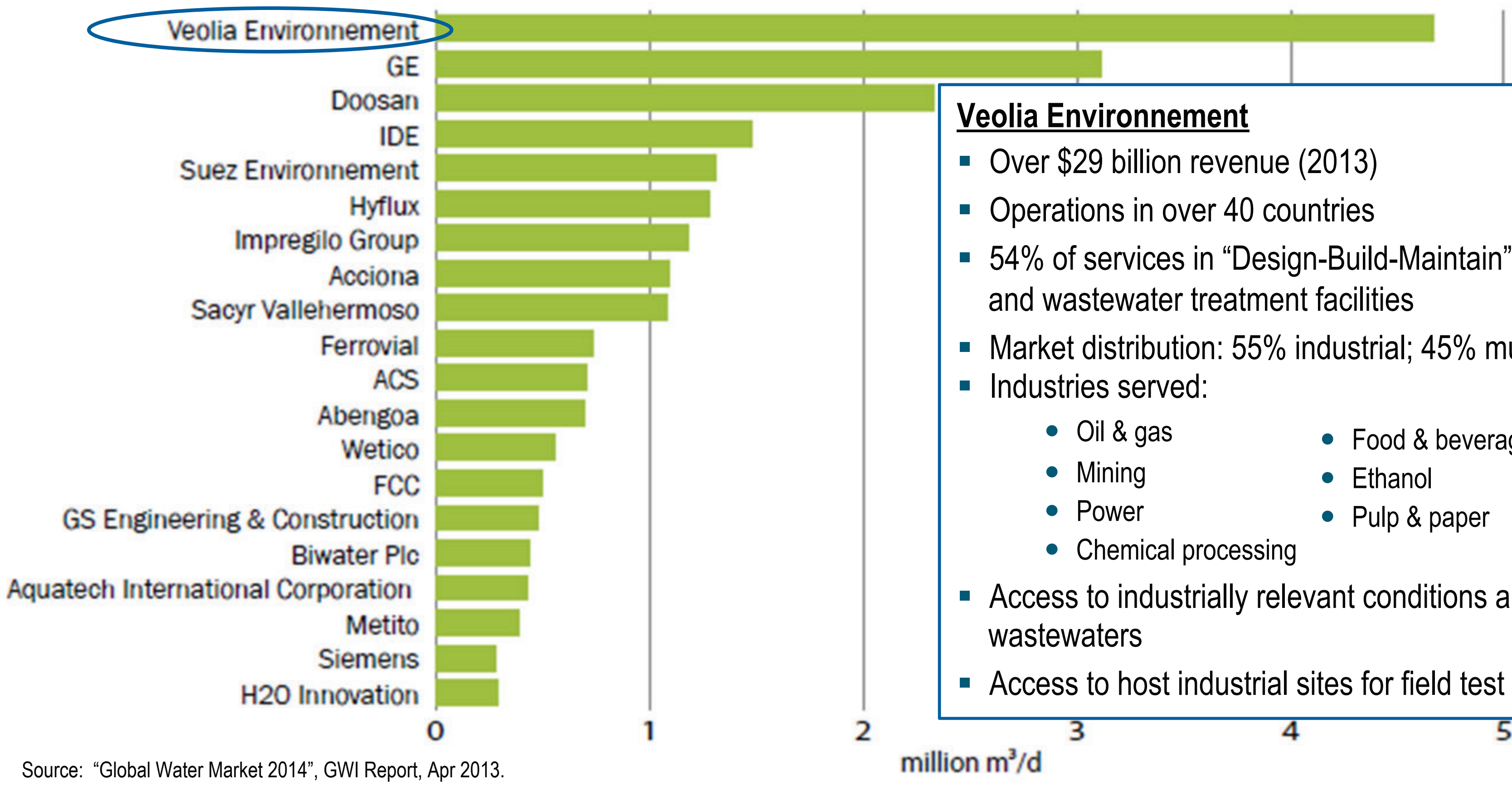
Duke University

RTI International

U.S. Department of Energy — Energy Efficiency & Renewable Energy — Advanced Manufacturing Office

Veolia Water Solutions & Technologies

Top 20 Desalination Plant Contractors by Capacity, 2006-2012



Veolia Environnement

- Over $29 billion revenue (2013)
- Operations in over 40 countries
- 54% of services in "Design-Build-Maintain" of water and wastewater treatment facilities
- Market distribution: 55% industrial; 45% municipal
- Industries served:
  - Oil & gas
  - Mining
  - Power
  - Chemical processing
  - Food & beverage
  - Ethanol
  - Pulp & paper
- Access to industrially relevant conditions and real wastewaters
- Access to host industrial sites for field test

Source: "Global Water Market 2014", GWI Report, Apr 2013.

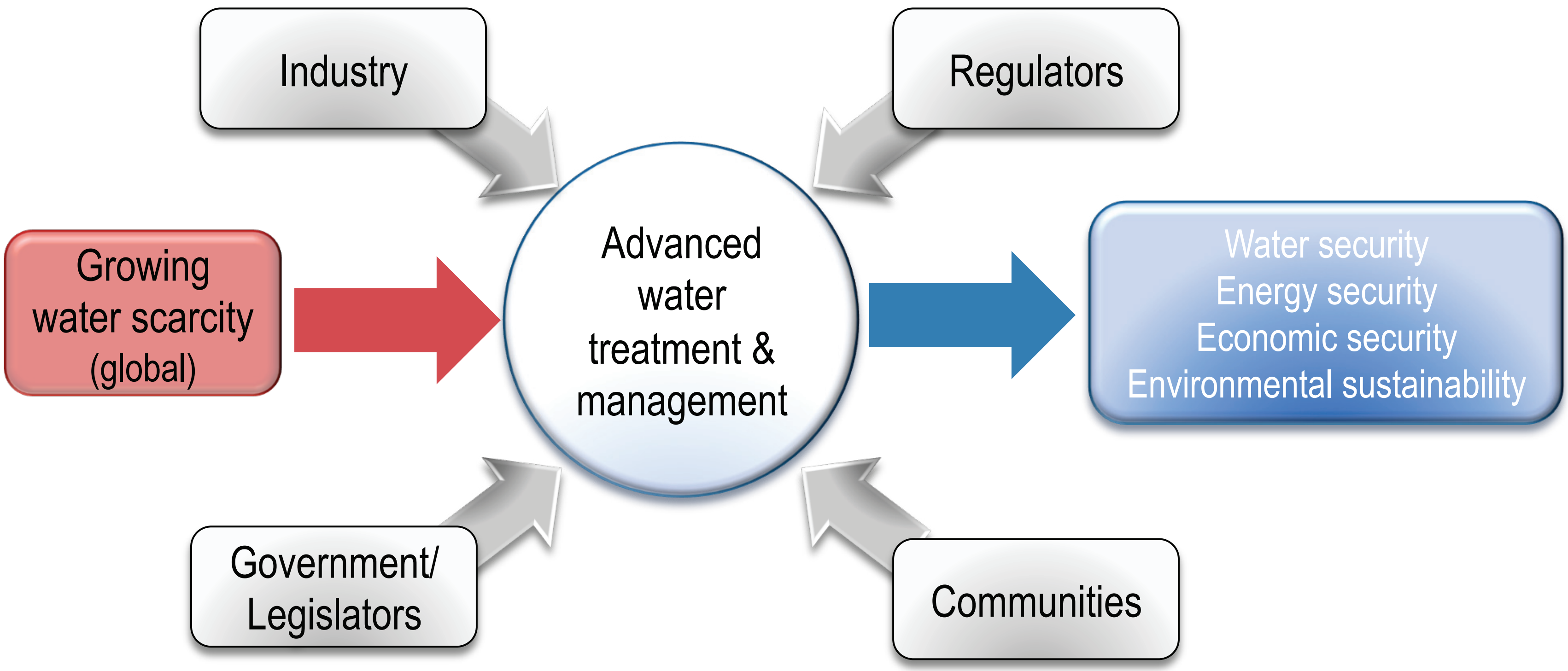
Transition and Deployment

Stakeholders/End Users in This Technology Development

Broad applicability throughout industrial sectors…

- Oil & gas
- Refining/Petrochemical
- Chemical
- Pulp & paper
- Biorefineries/Biofuels
- Power generation

- Environmental protection
- Energy/Water/Carbon footprints
- More stringent regulations
  - Wastewater discharges
  - Air emissions



Policymaking to protect…

- Human health
- Ecosystems
- Economic growth

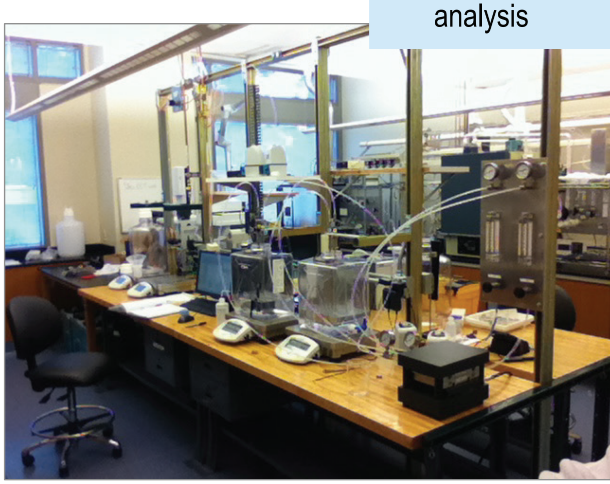
- Water availability & quality
- Public health
- Quality of life
- Job creation

Transition and Deployment Roadmap

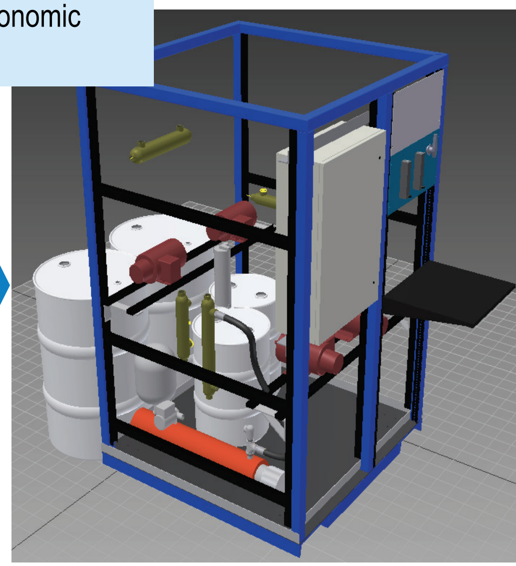
	Previous Work	Current Project: RTI / DOE-AMO (Partners: Veolia, Duke)		Future Development/Sustainment	
Yr	**→2011**	**2012-14**	**2015**	**2016-18**	**2018+**
TRL	2-3	3-5	5-6	7-8	9
	Proof-of-Concept / Feasibility	Laboratory Validation ✓ Membrane screening & evaluation ✓ Process development, modeling, & integration ✓ Preliminary techno-economic assessment • Bench integrated system (50-gpd) testing with real wastewaters • Updated techno-economic analysis	Relevant Environment Testing • Installation & commissioning of field prototype • Field prototype (500-gpd) demonstration at industrial site treating slipstream of real effluent • Final techno-economic assessment	• Membrane / module manufacturing • Pre-commercial demonstration	Deploy-ment

Ongoing membrane, module, and process refinements to increase market relevance and economic competitiveness

Potential technology owners:
- Veolia (JDA / option agreement in place)



Laboratory water test-bed systems



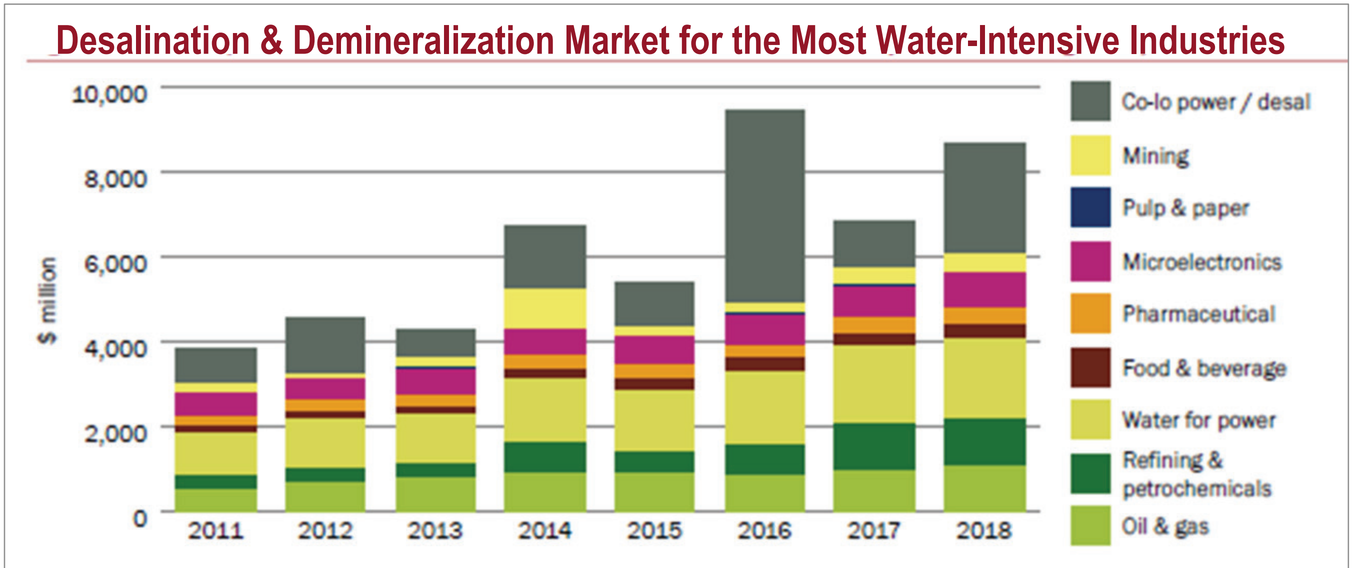
Bench, integrated FO/MD system
(50-gpd)

Veolia produced water treatment plant

Measure of Success

Benefits Throughout U.S. Manufacturing Supply Chain

- Enabling cost-effective water reuse toward ZLD
  - Up to 94% reduction in wastewater discharge volumes*
- More than doubling of energy efficiency of industrial water treatment
  - >90% lower electricity costs*
  - 20% or more reduction in water treatment costs*
- Carbon emissions reduction (>90%*)
- Broad applicability to different industries



Source: "Global Water Market 2014", GWI Report, Apr 2013.

* Based on project's preliminary techno-economic analysis and relative to Reverse Osmosis [RO]

Overall Impacts

- Revitalization and strengthening of the U. S. manufacturing base for existing and emerging industries
  - Domestic job creation
  - Increased U.S. manufacturing economic competitiveness & sustainability
  - Support of President's "Plan To Win the Future by Investing in Advanced Manufacturing Technologies"
- U. S. clean energy and water technology leadership

Project Management & Budget

- **Project Duration**: 39 mos. (3.25 yrs.)

Total Project Budget	
DOE Investment	$4,800,000 [80%]
Cost Share	$1,200,000 [20%]
Project Total	$6,000,000

Project Task Structure (Simplified)
1 – MD membrane development
2 – FO membrane process evaluation and optimization
3 – Bench, integrated FO/MD System performance testing
4 – Hybrid process model development and validation
5 – Field demonstration of prototype, integrated system
6 – Hybrid process design integration/Techno-economic analysis

	Status	Milestones
BP1 (15 mos.)	✓	Q3 – Successful hydrophobic surface modification of ceramic MD membranes
	✓	Q5 – Bench-scale, integrated FO/MD system design
	✓	**– Optimized FO membrane process with FO draw solution formulation(s) *[Go/No-Go]***
	✓	**– Preliminary techno-economic and environmental analysis *[Go/No-Go]***
BP2 (12 mos.)		Q7 – Fully operational bench, integrated FO/MD test system (50-gpd) ***[Go/No-Go]***
	✓	– Preliminary draft engineering design package for prototype, integrated FO/MD unit
		Q8 – Selection of at least one MD membrane having >95% rejection of dissolved solids in complex wastewater feeds ***[Go/No-Go]***
		– Hybrid FO/MD process model validation ***[Go/No-Go]***
		– Selection of host test site ***[Go/No-Go]***
		– Final engineering design package for field prototype, integrated FO/MD unit
		Q9 – Successful development of hierarchal, omniphobic surface for MD membranes
BP3 (12 mos.)		Q11 – Field prototype, integrated system (500-gpd) installation/ commissioning
		Q12 – Hybrid FO/MD process modeling tool fully validated
		Q13 – Final techno-economic and environmental analysis

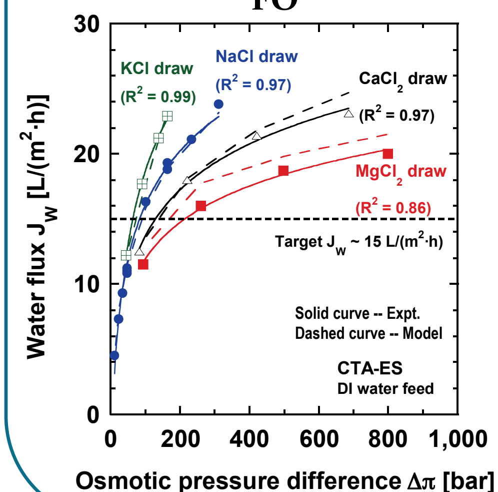
Results and Accomplishments

Project Status

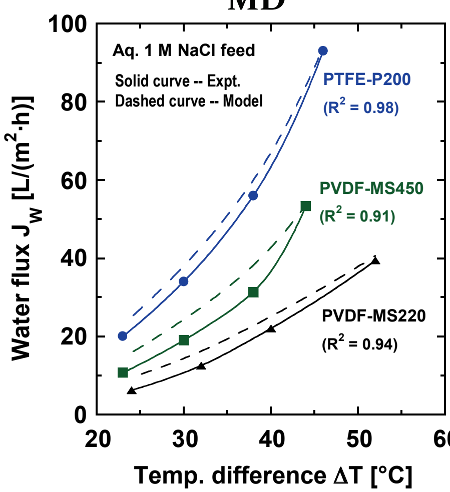
- Currently in Month 21 of project (halfway through Budget Period 2)
- Accomplishments to date include
  - All Budget Period 1 milestones achieved
  - FO & MD membrane experimental screening/performance evaluation
  - FO & MD model development
  - Preliminary techno-economic analysis (Class 4 estimate)

Model Validation with Experimental Data

FO



MD

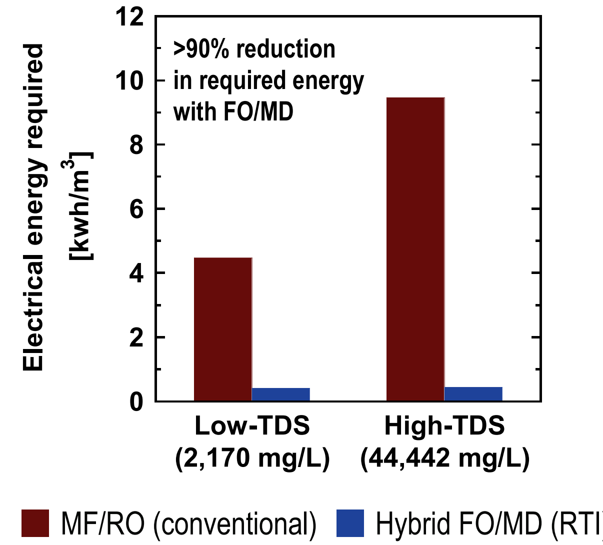


Planned Future Work

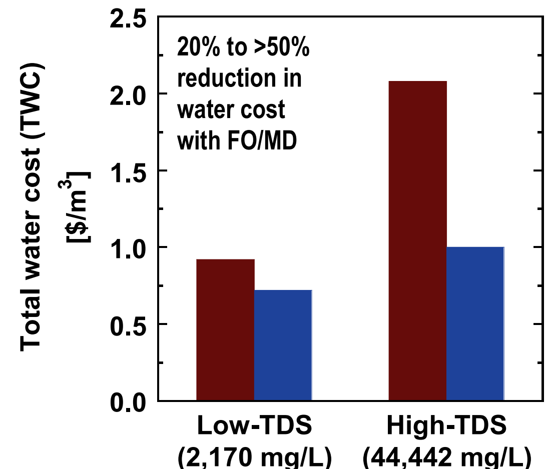
- Bench, integrated FO/MD testing with real wastewaters
- Demonstration of field integrated prototype at industrial site
- Final techno-economic and environmental analyses

Preliminary Techno-economics*

Energy Requirement



Total Water Cost



* Single-pass RO with no energy recovery devices