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

Lora Toy (Principal Investigator)
RTI International
Research Triangle Park, NC 27709

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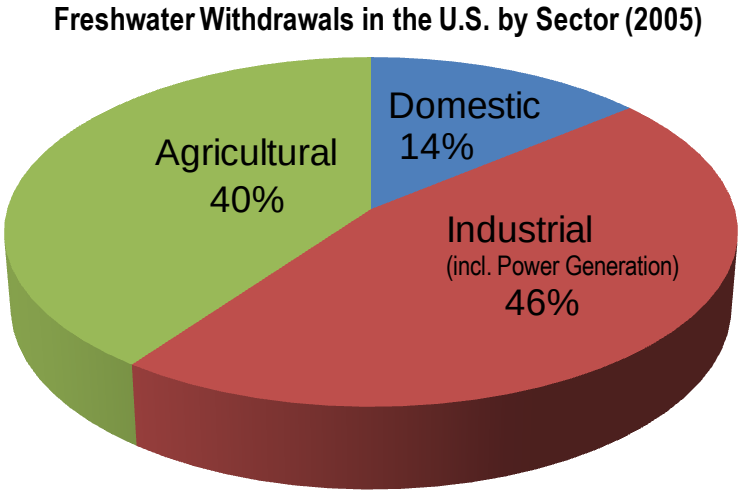
Project Objective

Current State/Challenges of Industrial Water Use

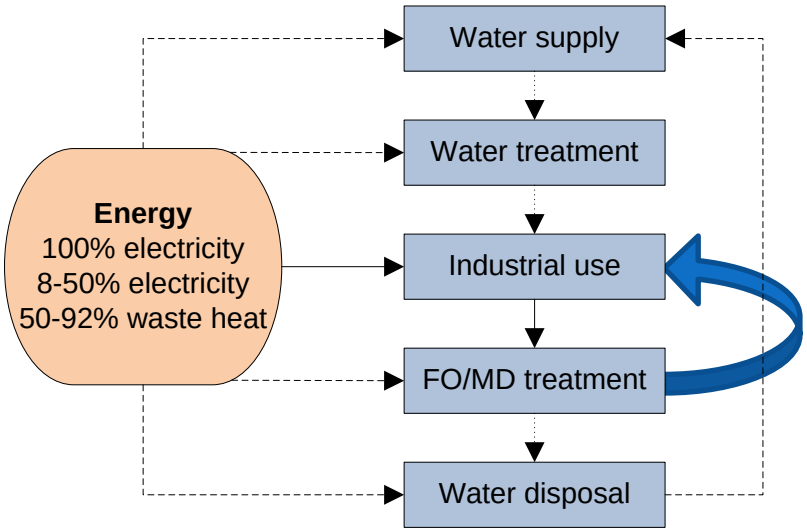
- Heavy industrial water utilization footprint



Source: U.S. CIA World Factbook

- ~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
- Unsustainability (limited resources, regulatory pressures)

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

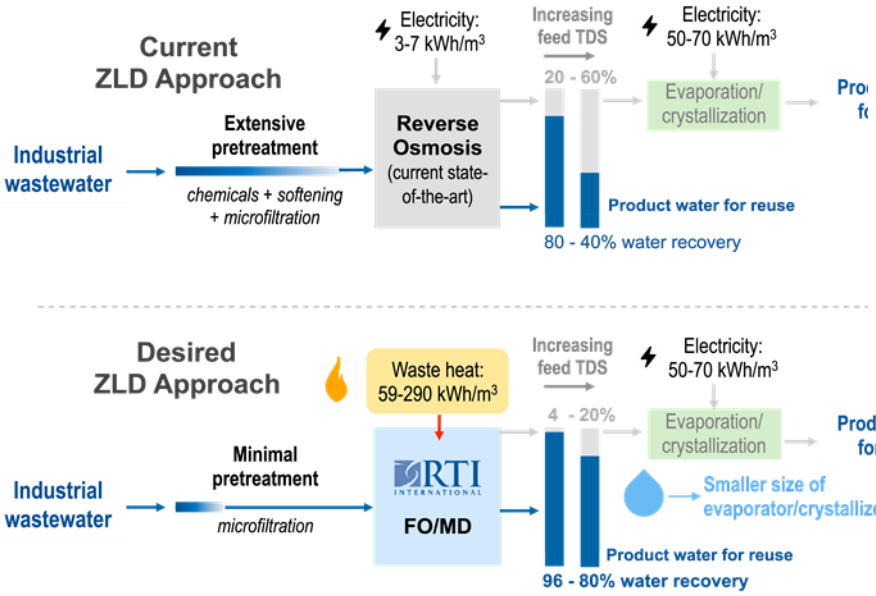


Water reuse and waste heat can reduce freshwater withdrawal and energy consumption.

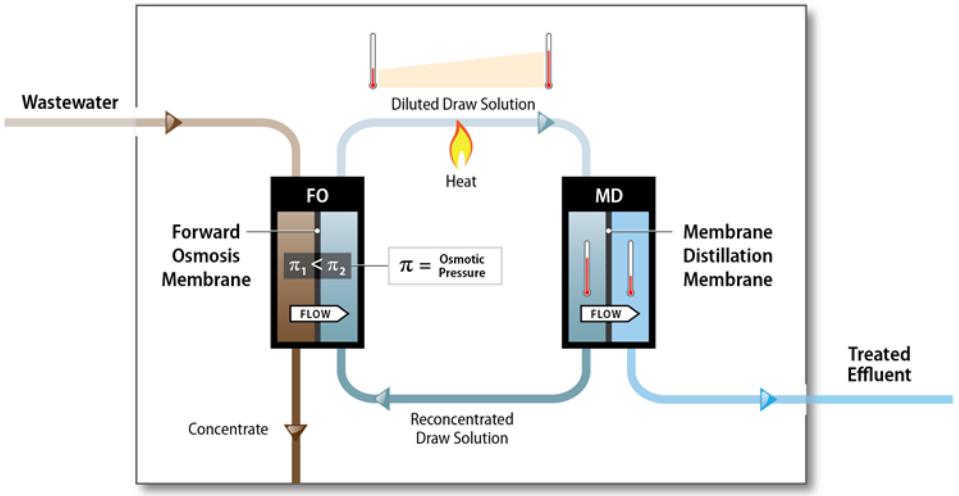
Project Objective

- 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



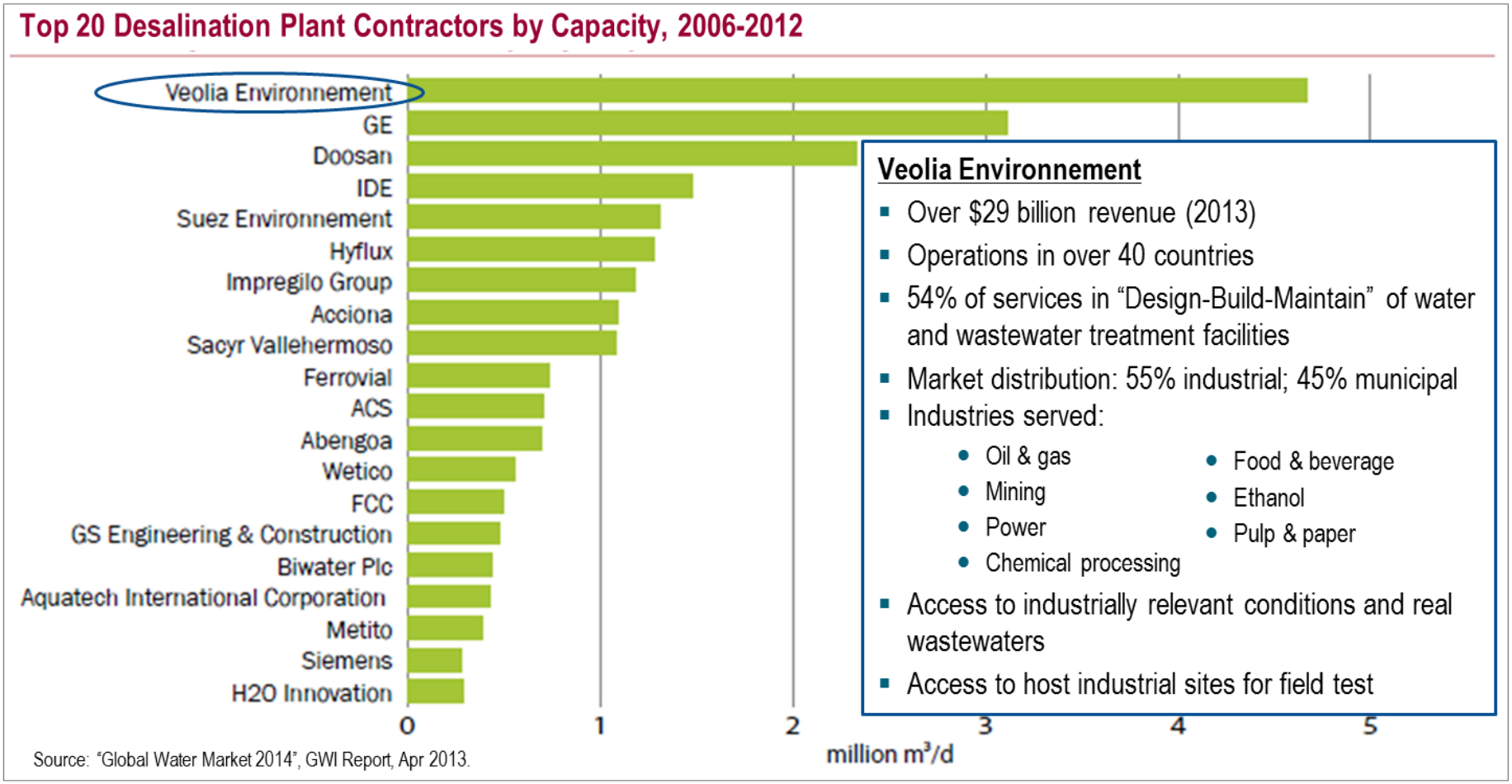
- Beneficial utilization of waste heat
- Synergistic coupling of FO (forward osmosis) and MD (membrane distillation)
  - FO (osmotically driven process): Pretreatment for MD
  - MD (thermally driven process): Regeneration of high-osmotic FO draw solution
- Low-pressure operation
  - Reduced energy requirements
- 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



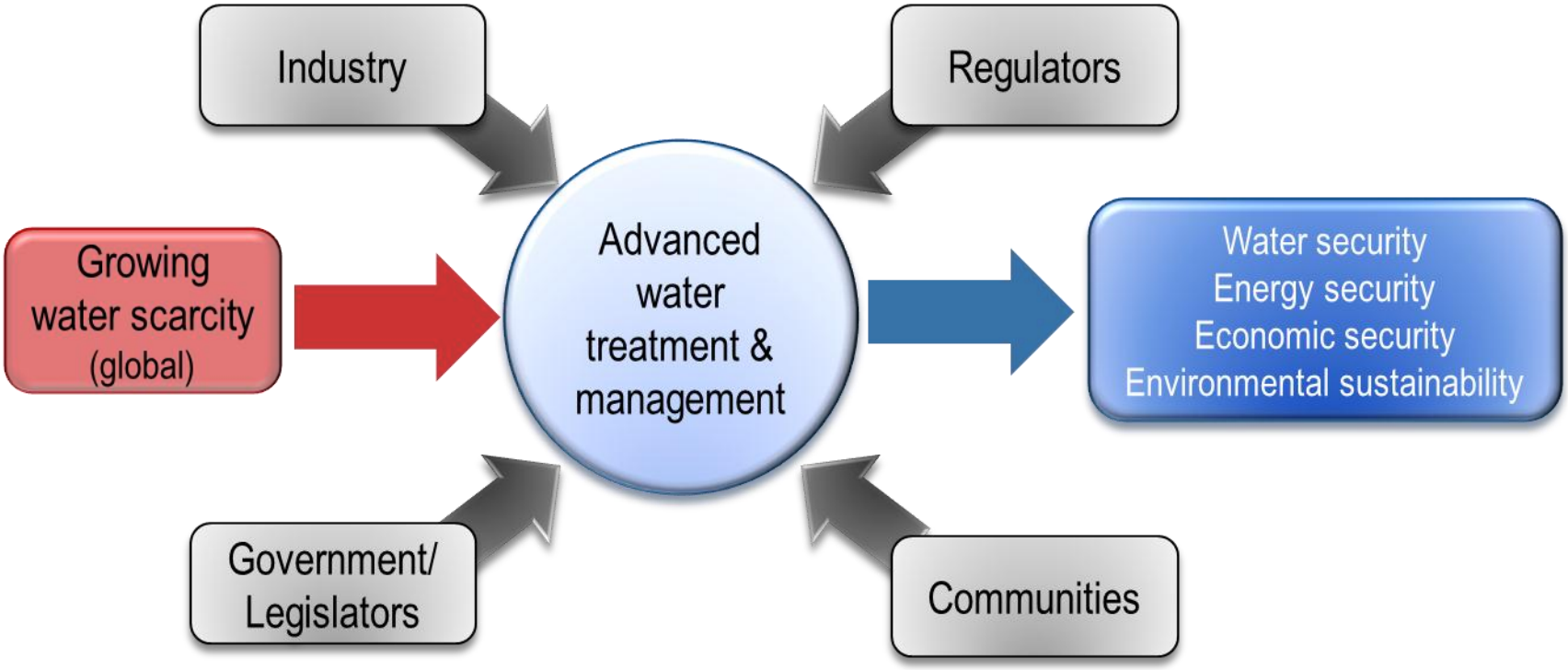
Transition and Deployment

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

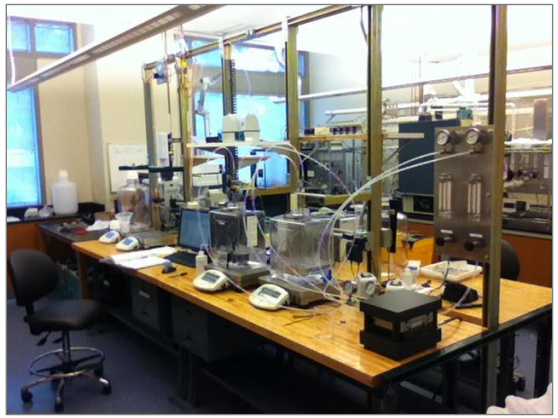
- Water availability & quality
- Public health
- Quality of life
- Job creation

Transition and Deployment Roadmap

	Previous Work	Current Project: RTI / DOE-AMO (Partners: Veolia, Duke)		Future Development/Sustainment	
Yr	**→2011**	**2012-14**	**2015-2016**	**2017-19**	**2020+**
TRL	2-3	3-5	5-6	7-8	9
Proof-of-Concept / Feasibility		<u>Laboratory Validation</u> ✓ Membrane screening & evaluation ✓ Process development, modeling, & integration ✓ Preliminary techno-economic assessment ✓ Bench integrated system (25-gpd) testing with real wastewaters ✓ Updated techno-economic analysis	<u>Relevant Environment Testing</u> • Installation & commissioning of field prototype • <u>Field prototype (500-gpd) demonstration</u> 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

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



Laboratory water test-bed systems

Bench, integrated FO/MD system (25-gpd)

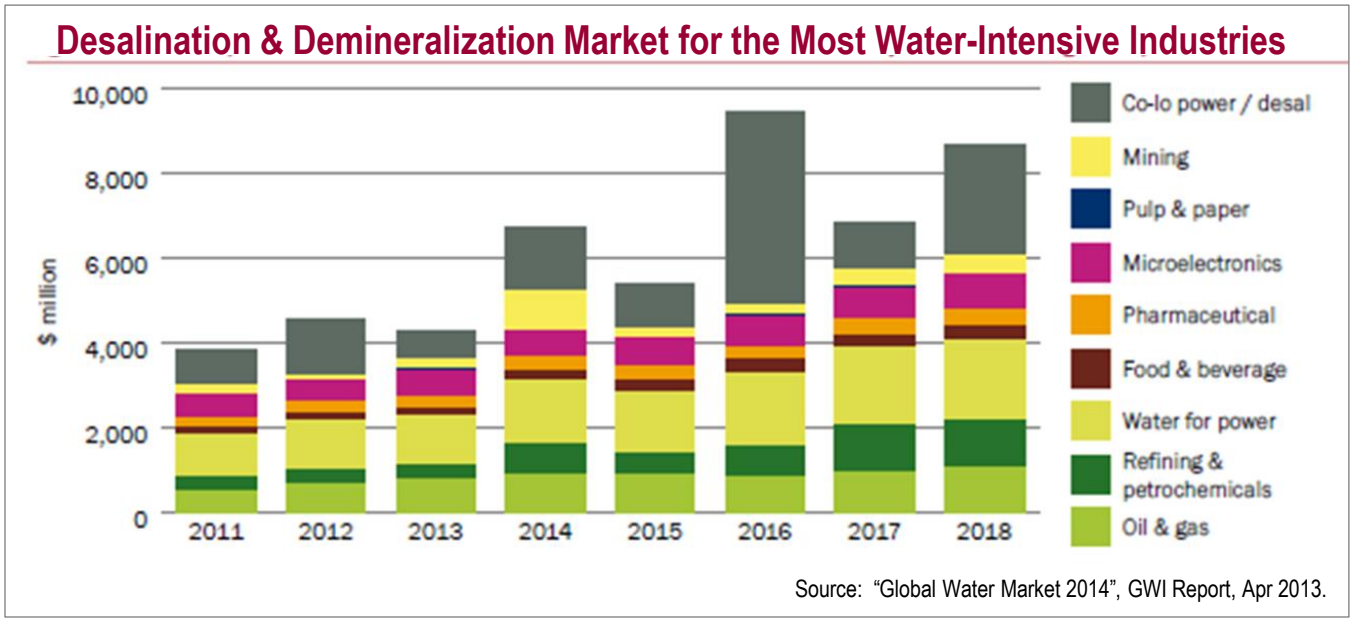
Veolia produced water treatment plant

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
  - 60% to >90% lower electricity costs*
  - Up to 40% reduction in water treatment costs of briny (high-TDS) wastewaters*
- Carbon emissions reduction (60 to >90%*)
- Broad applicability to different industries

* Based on project's updated 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***: ~45 mos. (3.75 yrs.) (anticipated)

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

* Project currently in continuation application review phase

	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 (18-19 mos.)*	✓	Q6 – Preliminary draft engineering design package for prototype, integrated FO/MD unit
	✓	Q7 – **Selection of at least one MD membrane having >95% rejection of dissolved solids in complex wastewater feeds** ***[Go/No-Go]***
	✓	Q8 – **Fully operational bench, integrated FO/MD test system (25-gpd)** ***[Go/No-Go]***
	✓	Q9 – Development of hierarchal, omniphobic surface for MD membranes
	✓	– **Hybrid FO/MD process model validation** ***[Go/No-Go]***
	✓	Q10 – **Selection of host test site** ***[Go/No-Go]***
	✓	– Final engineering design package for field prototype, integrated FO/MD unit
BP3 (~12 mos.)		Q13 – Field prototype, integrated system (500-gpd) installation/ commissioning
		Q14 – Hybrid FO/MD process modeling tool fully validated
		Q15 – Final techno-economic and environmental analysis

Results and Accomplishments

Project Status / Accomplishments Since May 2014 Peer Review

- Currently in Month 33 of project (end of Budget Period 2)
- All Budget Period 2 milestones achieved
- Bench, integrated FO/MD operation (synthetic & real wastewater feeds), demonstrating continuous FO draw-solution regeneration by MD
- Concentration of feeds up to very high TDS (>260,000 ppm) achieved
- Hybrid FO/MD model refinement and validation
- Updated techno-economic analysis showing advantage of hybrid FO/MD technology is the treatment of briny (high-TDS) wastewaters
- Oil & gas production facility selected as host field-test site

Ability of FO/MD Technology To Concentrate To Very High TDS Levels

Initial TDS of Feed	Final TDS of Concentrated Feed	Volume Reduction Factor (feed-side)	Water Recovery
78,000 ppm*	262,750 ppm	3.3	70%
57,620 ppm*	202,250 ppm	4.1	72%
12,960 ppm**	60,350 ppm	5.1	78.5%

* Synthetic feed with NaCl as TDS; ** Real RO brine from oil production facility

Planned Future Work

- Demonstration of field integrated prototype at industrial site
- Final techno-economic and environmental analyses

Updated Techno-economics*