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

DOE Cooperative Agreement No. DE-EE0005758

RTI International, Duke University, and Veolia Water Technologies, Inc.

Project Period: September 1, 2012 to December 31, 2016

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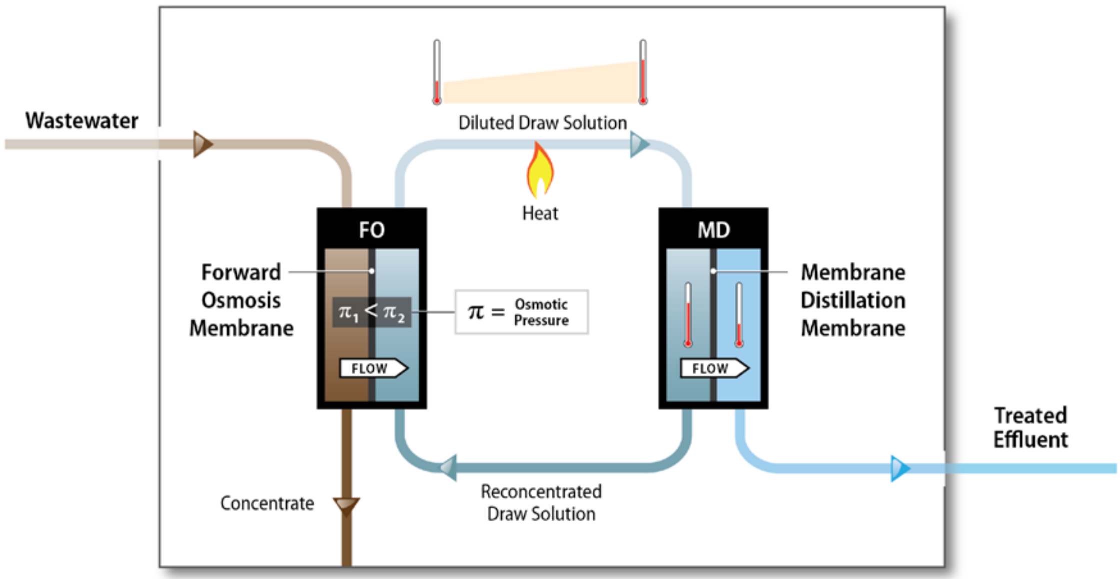
Project Objective

- What are you trying to do?
  - To develop integrated FO-MD technology for high TDS water
- What is the problem?
  - Current RO Technology is not capable of producing clean water if the feed water TDS level exceeds 60,000 ppm
  - There has not been any new technology developed for high TDS water
- Why is it difficult?
  - RO is generally low energy desalination method. But at high TDS, RO cannot handle the water. Also it takes a significant amount of electrical energy.

Technical Innovation

- How is it done today, and what are the limits of current practice?
  - Up to 60,000 ppm TDS (seawater in the Middle East) feed water can be treated by RO
  - Higher than 60,000 ppm TDS requires thermal evaporator which is very expensive to construct due to the high cost of exotic alloys
- What's new in your approach, and why do you think it will be successful?
  - Use waste heat instead of electricity for the major part of the energy required
  - Use plastic material instead of high alloys

Technical Innovation



- 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

- What is the technical approach for the project?
  - Forward Osmosis uses the salinity gradient, so that the water is collected without energy input
    - Current practice is to use high pressure to filter only water through semi-permeable RO membrane
  - Membrane Distillation uses low grade waste heat and uses mostly plastic material for construction
    - Current practice is to use thermal evaporator which is made of high alloys due to corrosion at high temperature
    - High energy consumption is due to the osmotic pressure of saline water

  - Potential project risks and unknowns:
    - The membrane needs to be further developed for this process to be successful.
    - Development and manufacturing of new type of membrane for high TDS membrane has been led by European and Asian firms.

Technical Approach

Strong, Multidisciplinary Project Team:

- Duke: Basic membrane properties research, and modeling approach of the system
- RTI: Overall process concept and design. Pilot design and operation.
- Veolia: One of the largest water and desalination companies in the world. Advice on field testing

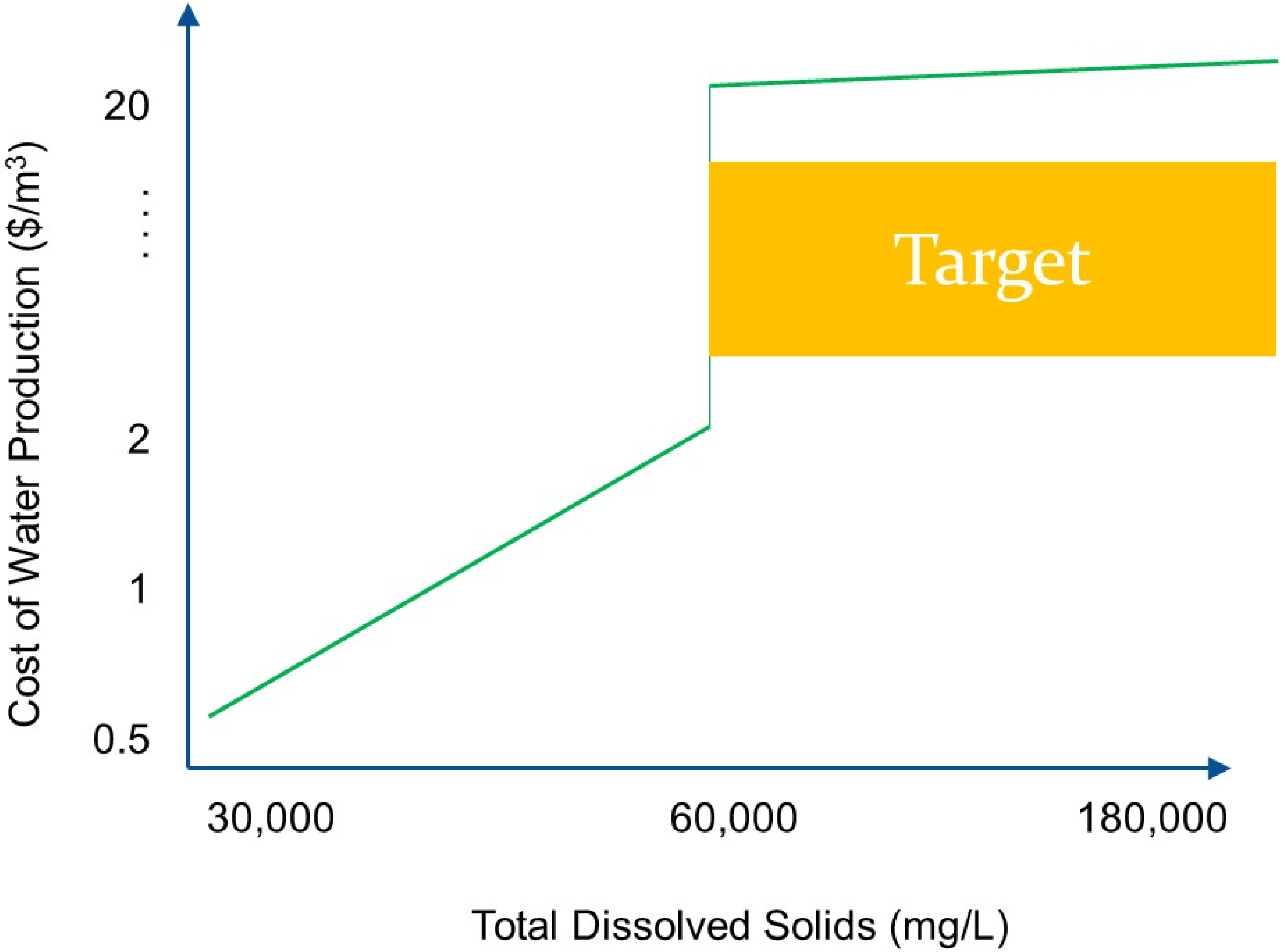
Transition and Deployment-Updated Roadmap

	Previous Work	Current Project: RTI / DOE-AMO (Partners: Veolia, Duke University)		Future Development/Sustainment	
Yr	→**2011**	2012-14	2015-2016	2016-2019	2019+
TRL	2-3	3-5	5-6	7-8	9
	Proof-of-Concept / Feasibility	Laboratory Validation ✓ Membrane screening & evaluation ✓ Process development, modeling, & integration ✓ Bench integrated system (25-gpd) testing with real wastewaters	Relevant Environment Testing • Fabrication of field, pilot-scale testing skid (500-gpd) • Installation & commissioning of pilot-scale testing skid • Continuous, extended pilot-scale testing with real wastewater • Final techno-economic assessment	• Membrane & module engineering improvements / optimization to increase process economic competitiveness & market relevance • Membrane / Module manufacturing • Advanced process heat (energy) integration design • Field process operational data (≥ 6 mos.) • Pre-commercial demonstration	Deployment

Potential End Users: Membrane manufacturers, System integrators, Engineering firms, Utilities

Commercial Partners will expedite the acceptance of the new technology in the market

Measure of Success



Project Management & Budget

- **Project Duration***: 52 mos. (4.33 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

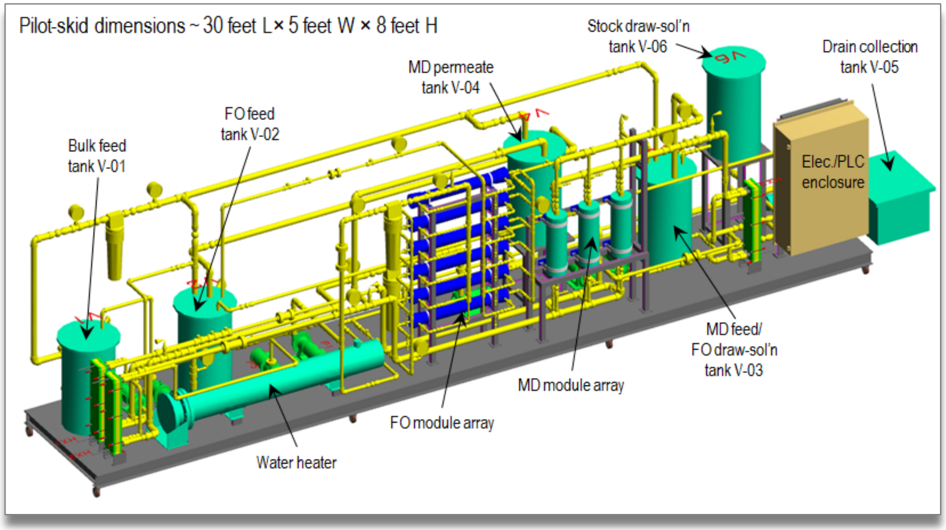
* 6-mo. no-cost time extension through Dec. 2016 being processed by DOE

	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 (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 (18 mos.)*		Q12 – Field prototype, integrated system (500-gpd) installation/ commissioning
		Q14 – Hybrid FO/MD process modeling tool fully validated with field data
		Q15 – Field-testing of prototype, integrated system
		Q16 – Final techno-economic and environmental analysis

Results and Accomplishments

Project Status / Accomplishments Since May 2015 Peer Review

- Currently in Month 46 of project (Budget Period 3)
- Field-test site changed from industrial facility to site on RTI campus (Real industrial wastewater to be shipped from O&G production facility to RTI as feed)
- Build of pilot-scale, integrated FO/MD prototype (500-gpd) in trailer nearly completed (mid-June)



Skid front-angle view - 1


Skid front-angle view - 2


Skid back-angle view

Planned Future Work

- Field-testing of pilot-scale, integrated prototype completed
- Final techno-economic and environmental analyses