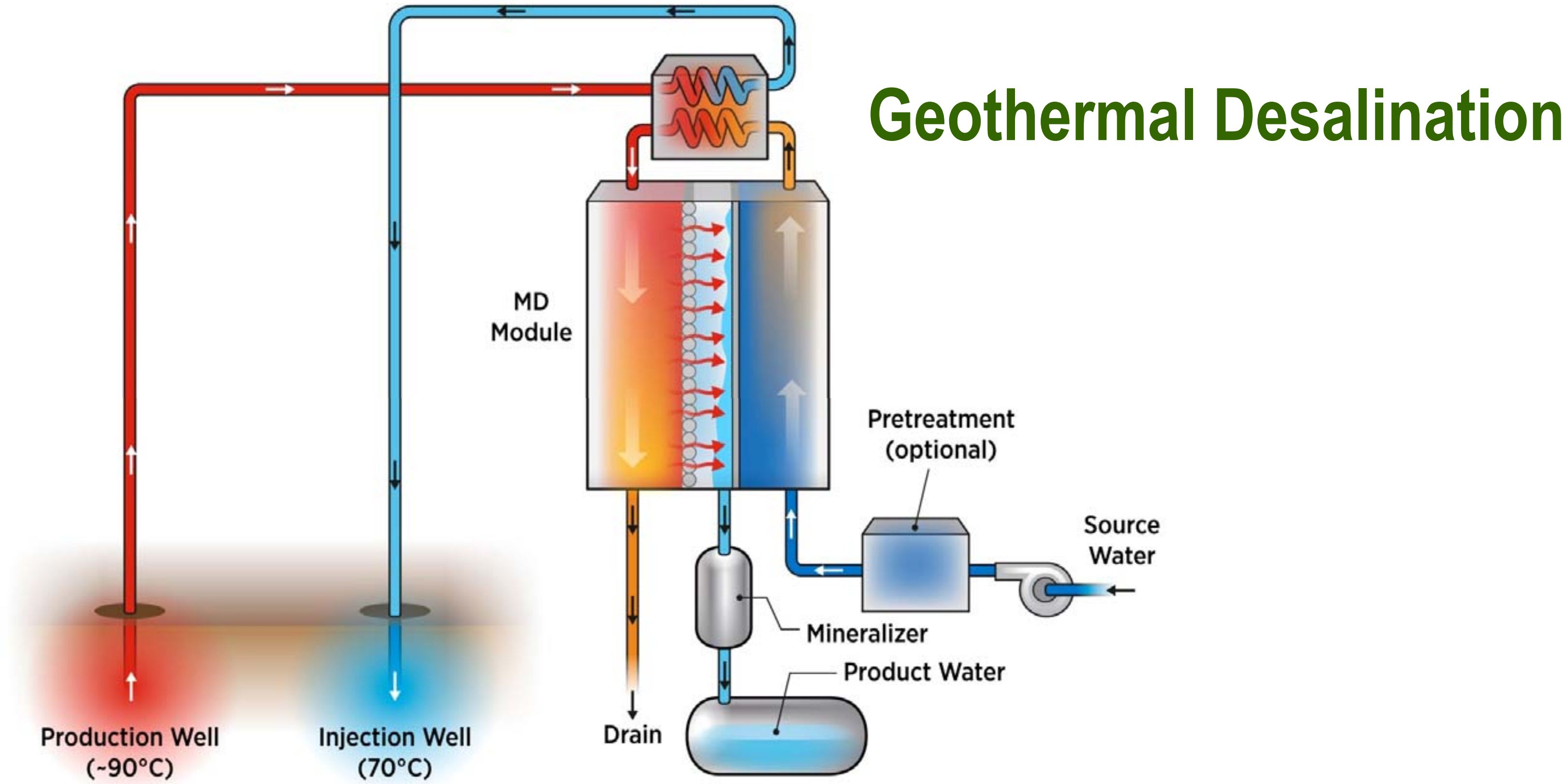


Desalination of Impaired Water Using Geothermal Energy

Project Officer: Holly Thomas

Total Project Funding: $1,893,000

November 14, 2017

Craig Turchi

National Renewable Energy Laboratory

Track Name

Relevance to Industry Needs and GTO Objectives

Goal:

- Expand the use of underused, low-temperature geothermal resources

Objectives:

- Demonstrate the integration of membrane distillation (MD) with geothermal energy,
- Develop a performance model and validate membrane flux estimates with commercial-scale modules under field conditions at different operating conditions,
- Test and evaluate antiscaling and/or antifouling coatings applied to commercial membranes, and
- Define conditions that lead to costs of <$1.5/m^3 or otherwise provide economic viability. Describe and quantify applications beneficial to the geothermal industry.

Project Team

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE Geothermal Technologies Office

NREL – National Renewable Energy Laboratory
- Project mgmt
- Economic assessment
- Field support

Colorado School of Mines
- Water analyses, pretreatment design lab and field testing

Ormat
- Site host and support

Sandia National Labs
- MD performance modeling

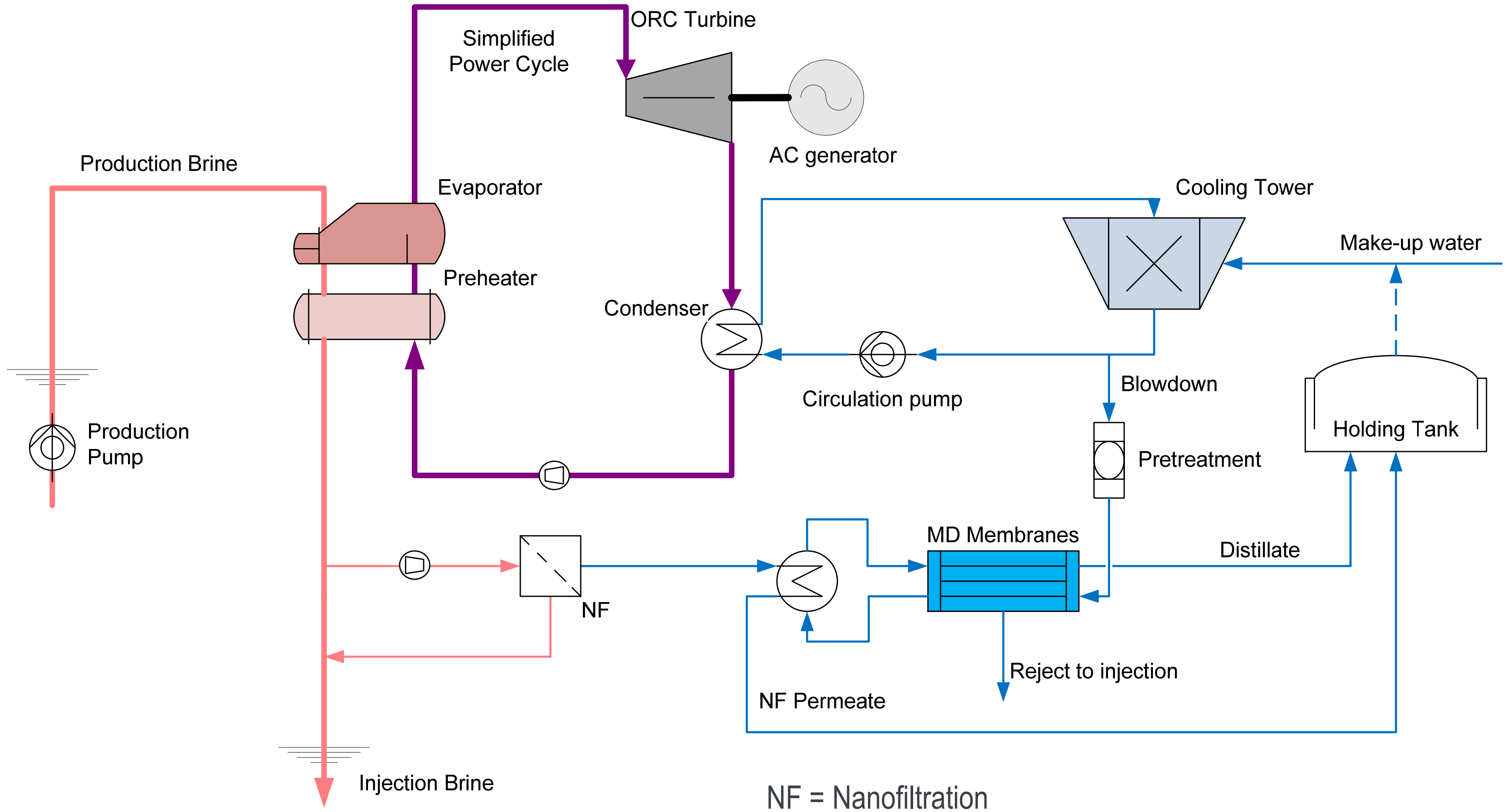
UC Riverside
- Membrane optimization

Challenges:

- Thermal desalination technologies generally do not achieve as low of a product-water cost as reverse osmosis (RO) technologies. Low-cost thermal energy is essential for favorable thermal desalination economics. The use of residual heat in the injection brine is targeted for the MD heat source.
- Membrane life is a primary concern with MD systems. Research on protective coatings is designed to increase overall MD membrane life.
- Small size of desalination facility associated with a geothermal power plant will not allow for economy of scale matching that deployed at large seawater desalination facilities. Accordingly the water cost target was $1.5/m^3, which is about twice the value of state-of-the-art large scale desalination.

Membrane Distillation

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



NF = Nanofiltration

MD = Membrane Distillation

Methods/Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Preliminaries:

- Work with geothermal owner/operator Ormat to identify power plants with water-availability or water-quality issues
- Collect and characterize water at the plant site(s)

Laboratory-Scale:

- Test MD membranes at lab scale to quantify expected flux and select best candidate(s)

Methods/Approach

Optimization:

- Develop and test conductive coatings that allow one to manipulate the water chemistry at the membrane surface and thereby minimize or remove chemical scale. Test in representative impaired water
- Develop MD performance models to predict system performance; use lab and field data for validation

Methods/Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Field Demonstration:

- Perform field test to determine system perform and provide data for model validation (Cancelled)

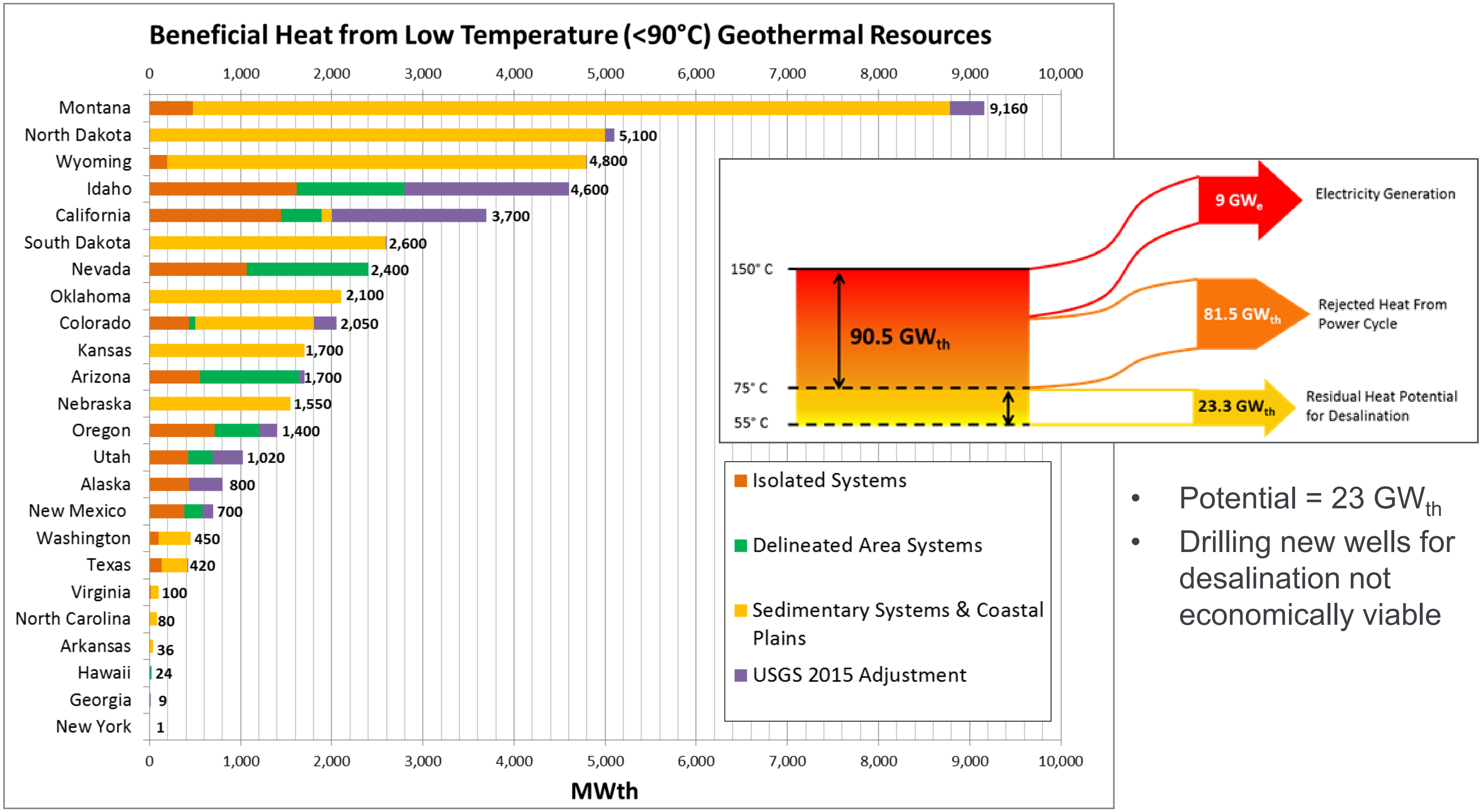
Economics:

- Explore the potential of geothermal-driven desalination across the United States
- Assess the techno-economic potential of MD usage at the field site and identify barriers to commercialization

Technical Accomplishments and Progress

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Select Field Site	M2-1. Visited two plant sites and selected Ormat's Tuscarora plant in northern Nevada	March 2016
Complete characterization of source water	M3-1. Documented water quality at visited plant sites. Used data to create surrogate water for tests	June 2016
Document potential of Geo-Desal opportunity	M4-2. Presented Geo-Desal potential at GRC Meeting in 2016	Oct. 2016

Geothermal-Desal Potential



- Potential = 23 GW$_{th}$
- Drilling new wells for desalination not economically viable

Akar & Turchi, “Low Temperature Geothermal Resource Assessment for Membrane Distillation Desalination in the United States,” GRC 2016.

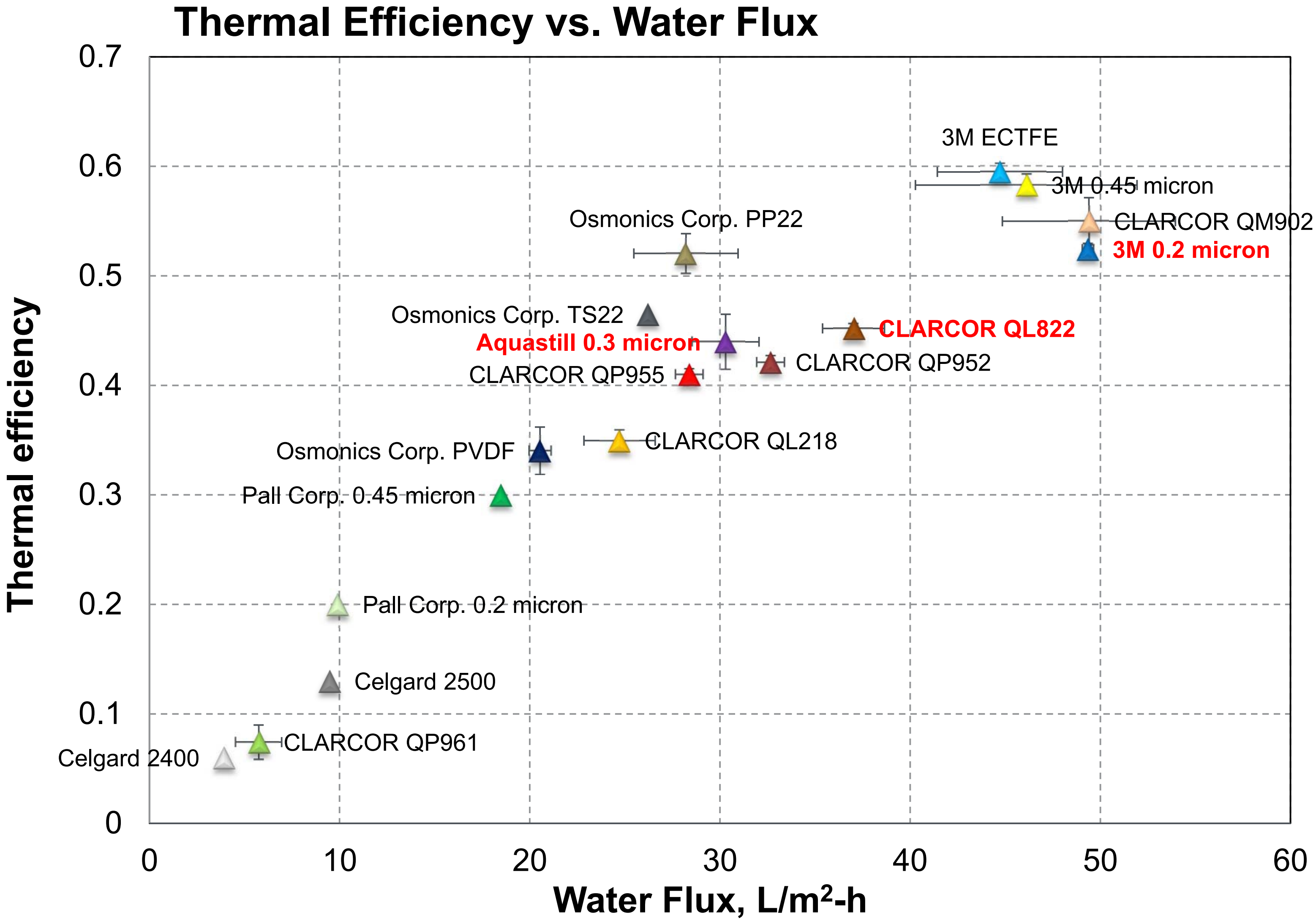
Technical Accomplishments and Progress

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Original Planned Milestone/Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Document pretreatment requirements and membrane selection	M5-2. Document the selection of membrane(s) based on commercial availability, cost, and flux performance in laboratory testing on surrogate site water.	Jan. 2017
Go/No-Go Decision based on preliminary techno-economic analysis	M6-1. MD-based systems estimated at a cost of $1.4/m^3$ to $1.6/m^3$, which bracketed the target of $1.5/m^3$. However, this design was not cost competitive with nanofiltration for the Tuscarora site.	May 2017
Submit field test plan	Cancelled	June 2017
Membrane-coating effectiveness report	Journal article submitted to ACS Applied Materials & Interfaces documents ability to regenerate membranes from silica scale	Oct. 2017

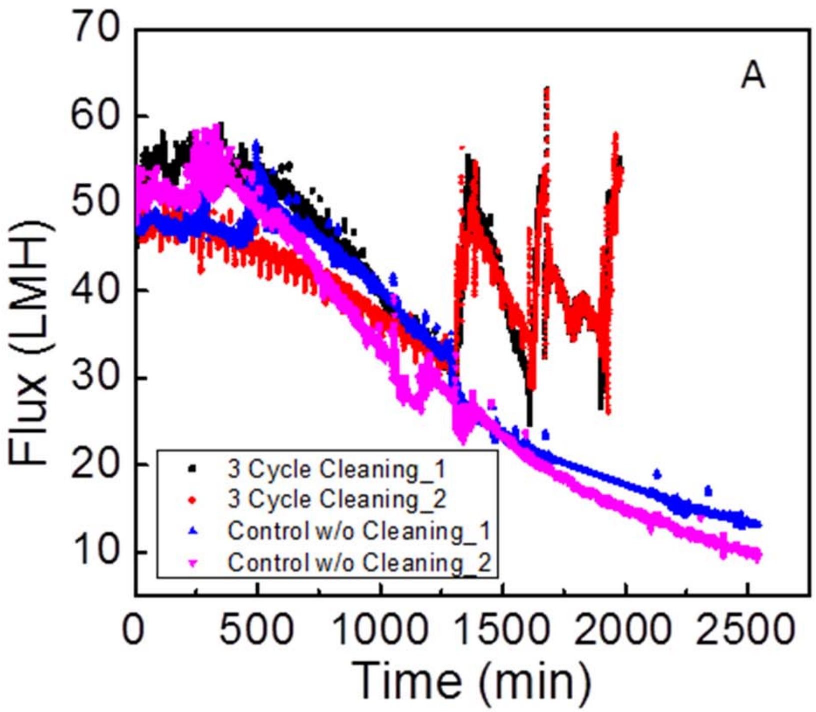
MD Membrane Selection

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

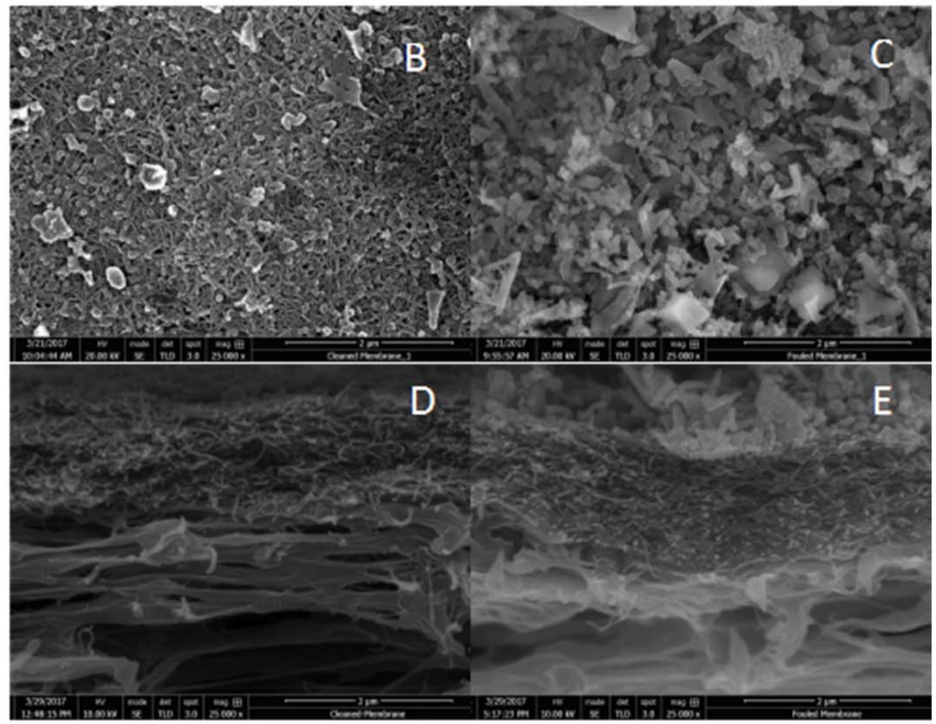


Vanneste, J., J.A. Bush, K.L. Hickenbottom, C. A. Marks, D. Jassby, C. Turchi, T.Y. Cath, "Novel thermal efficiency-based model for determination of thermal conductivity of membrane distillation membranes," *J. Membr. Sci.*, submitted 2017.

Membrane Coatings



Cleaned (B and D) Uncleaned (C and E)

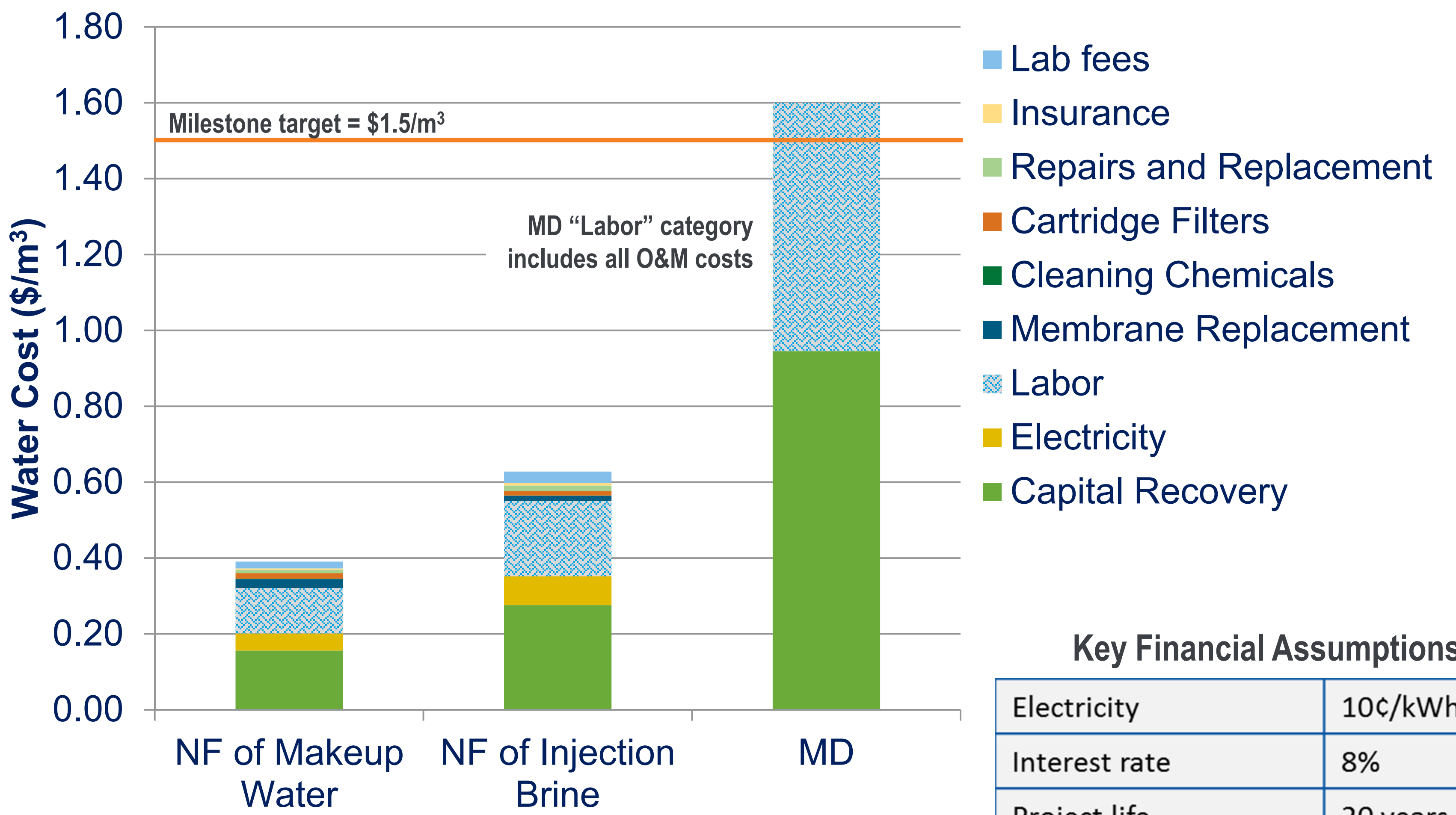


Electrochemical cleaning of silicate-fouled MD membranes: (A) The application of an electrical potential (20 mA, membrane as cathode) rapidly recovered membrane flux (black and red lines), while in the absence of potential the membrane continuously fouled (blue and purple lines). SEM images of the surface (B, C) and side-view (D, E) of electrochemically cleaned membranes and fouled (not cleaned) membranes.

Li Tang, A. Iddya, X. Zhu, A.V. Dudchenko, W. Duan, C. Turchi, J. Vanneste, T. Cath, and D. Jassby, “Enhanced Flux and Electrochemical Cleaning of Silicate Scaling on Carbon Nanotube-Coated Membrane Distillation Membranes Treating Geothermal Brines,” *ACS Applied Materials & Interfaces*, submitted 2017.

Economics (at Tuscarora site)

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Key Financial Assumptions

Electricity	10¢/kWh
Interest rate	8%
Project life	20 years
Fixed charge rate	0.1019
Labor	1 FTE ($89k)

Research Collaboration and Technology Transfer

- Ormat has assessed the results and concluded that water treatment is not a good option for Tuscarora
  - Other Ormat plants sites with water needs are being discussed
- Collaborating with MD developer Aquastill to test membranes in a cartridge configuration
- Two journal publications submitted and under review
- Presentations given at GRC 2016 and 2017

Future Directions

- Field test cancelled due to estimated technology cost and expectation of no funding in FY18
- Remaining work focused on membrane development and testing
- Tasks extended into FY18 as possible to support university researchers

FY18 Milestones	Status & Expected Completion Date
Validated MD component model in IPSEpro software	Dec. 2017
Demonstrate hot-NF potential: 25% increase in flux with less than 10% decrease in salt rejection	Dec. 2017
Final report: • Document laboratory testing with modified MD membranes • Assess MD for hybrid cooling at geothermal plants (higher value water use)	March 2018

Mandatory Summary Slide

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Conclusion	Implication
1. Even with "free" heat, preliminary costs for MD are not competitive for cooling tower makeup water	• Higher-value market needed for desalinated water. Distilled water for hybrid cooling being explored.
2. "Hot nanofiltration" can produce high-quality water from geothermal brines at higher efficiency than ambient temperature operation	• Direct production from geothermal brine could provide fresh water for remote plants. • Heating NF/RO feedwater may lead to higher fluxes and lower costs if low-cost heat is available.
3. Membrane coatings shown to provide silica scale removal under electrical potential	• In situ cleaning holds promise. Testing also underway on sulfate and carbonate scales. • Technique may be applicable to NF, RO, and MD membranes