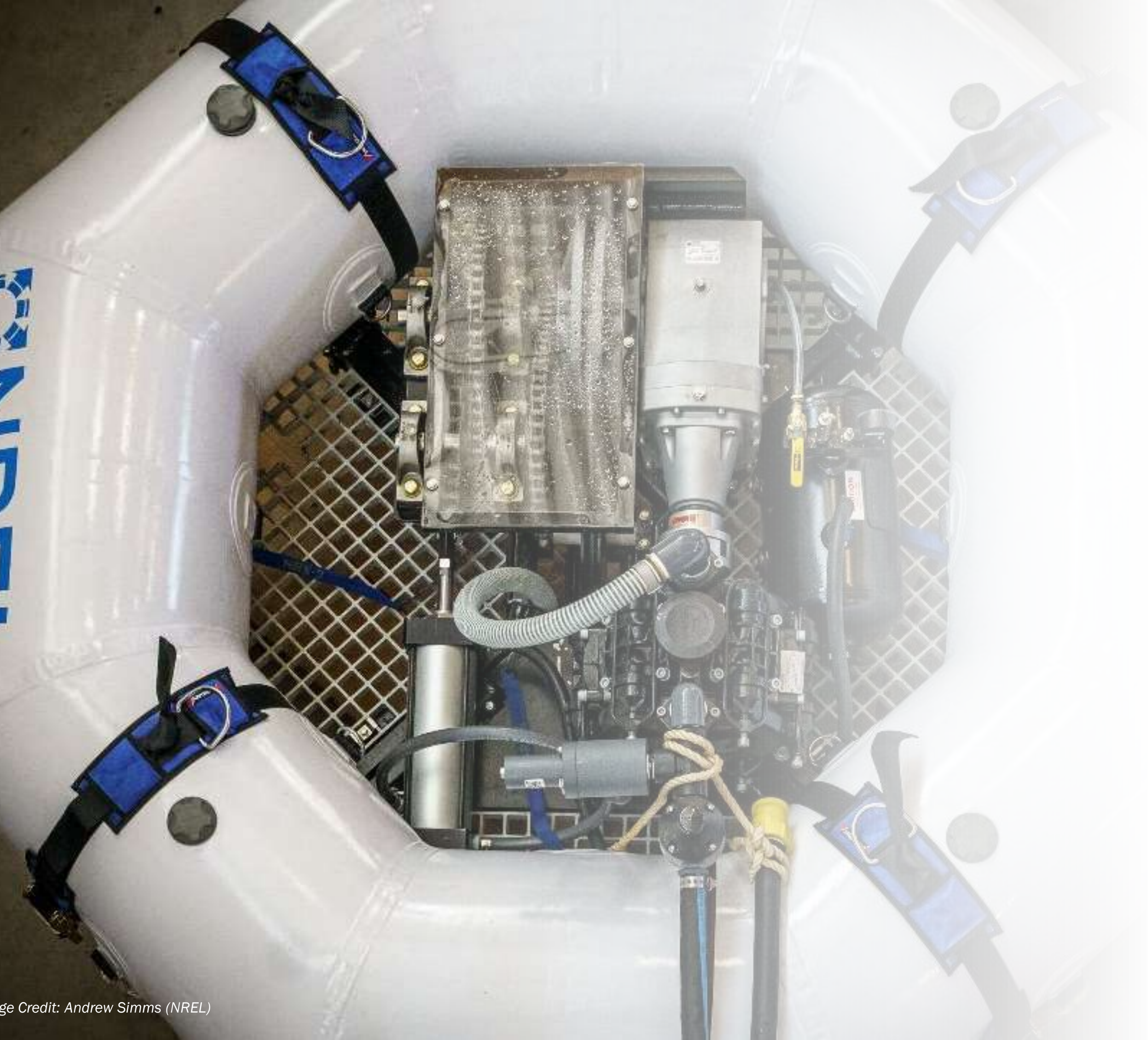
NREL Marine Energy Desalination R&D Portfolio

January 23, 2024

Pan-American Marine Energy Conference 2024

Image Credit: Andrew Simms (NREL)



ge Credit: Andrew Simms (NREL)

Contents

NREL at a Glance

3,343 workforce, including:

- 2,482 regular/limited term
- 485 contingent workers
- 183 postdoctoral researchers
- 125 graduate students
- 68 undergraduate students

—as of 12/31/2022

World-class research expertise in:

- Renewable power
- Energy efficiency
- Sustainable transportation
- Energy systems integration

Partnerships with

- Industry
- Academia
- Government

3 campuses operate as living laboratories

More Than 1,000 Active Partnerships in FY 2022

Agreements by Business Type

Funding by Business Type

Image and graphics credit: NREL

Marine Energy Team

Marine energy researchers are advancing wave energy and tidal, ocean, and river current energy technologies, which could deliver renewable electricity to the grid and power offshore needs.

Collaborating closely with the U.S. Department of Energy's Water Power Technologies Office and the marine energy community, NREL researchers leverage their extensive expertise in numerical modeling, laboratory testing, and open-water validation. Marine energy stakeholders benefit from NREL's decades of renewable energy experience, working together to provide solutions that can support and accelerate the development of the evolving blue economy.

- Design, Simulation, and Control
- Powering the Blue Economy
- Technology Innovation and Assessment
- Testing and Validation
- Grid Research
- Economic Analysis
- Resource Characterization
- Data Access and Analysis Tools
- Market Acceleration and Workforce

Image: NREL researchers (from left), Rebecca Fao, Mark Murphy, Casey Nichols, Andrew Simms, and Ismael Mendoza. *Photo by Werner Slocum, NREL*

- ✓ Developed a resource assessment for Alaska's Cook Inlet, which involved submerging three data-gathering moorings in the inlet for two months. The data will help validate and refine tidal energy models, indicate how much energy could be generated in the inlet, and help developers build tidal turbines that perform reliably in the inlet's environment.
- ✓ Installation of NREL's first-ever wave tank to support the development and demonstration of technologies designed at different scales and for different blue economy applications.
- ✓ Published a "cheat sheet" for IEC TC 114 standards, designed to help the industry understand how to use and apply marine energy standards.
- ✓ Deployed HERO WEC (hydraulic and electric reverse osmosis wave energy converter) in support of the Waves to Water Prize. As NREL's first marine-powered desalination device to weather real ocean waters, the HERO WEC deployment signals advancements for marine renewable energy and desalination technologies but also helped ensure a fair contest in the Waves to Water Prize DRINK Finale.

NREL’s Role in Marine Energy

Learn

- Understand challenges
- Identify knowledge gaps
- Quantify accuracy, limitations, etc.

Seed

- Provide needed tools
- Reduce the learning curve
- Enable competitive edge (Tech Transfer)

Support

- Support existing small businesses
- Provide access to facilities and capabilities
- Develop workforce: students, visiting professors, academic programs

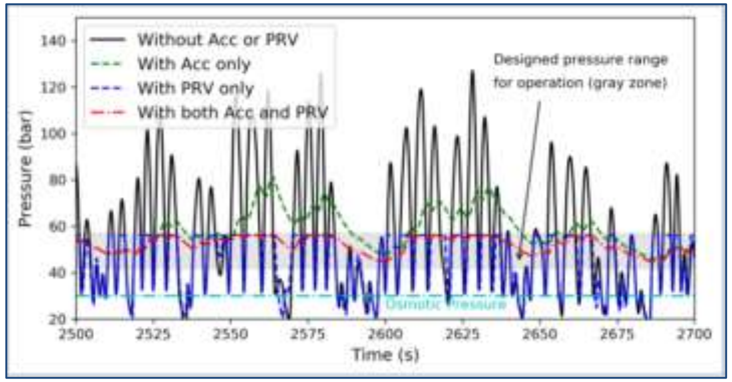
Disseminate

Work across large network to ensure knowledge is not lost.

Image credit: John McCord – Coastal Studies Institute

Marine Energy Desalination R&D

Techno-Economics and Simulation Work



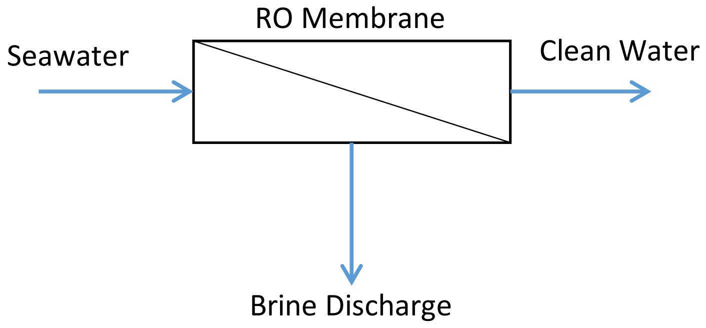
NREL-Developed HERO WEC

Image Credit: John McCord (CSI)

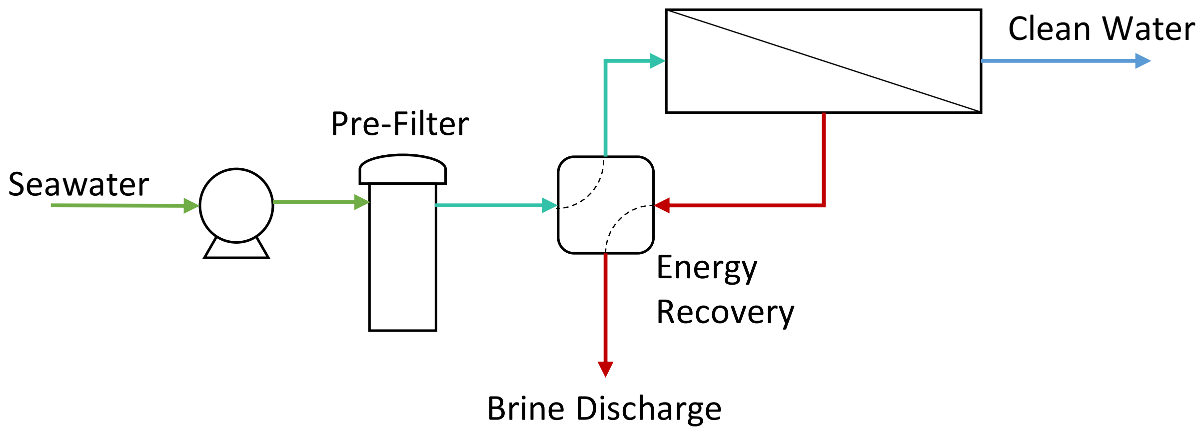
Bench-Scale Laboratory R&D

Image Credit: Scott Jenne (NREL)

Simplified Single-Pass RO membrane



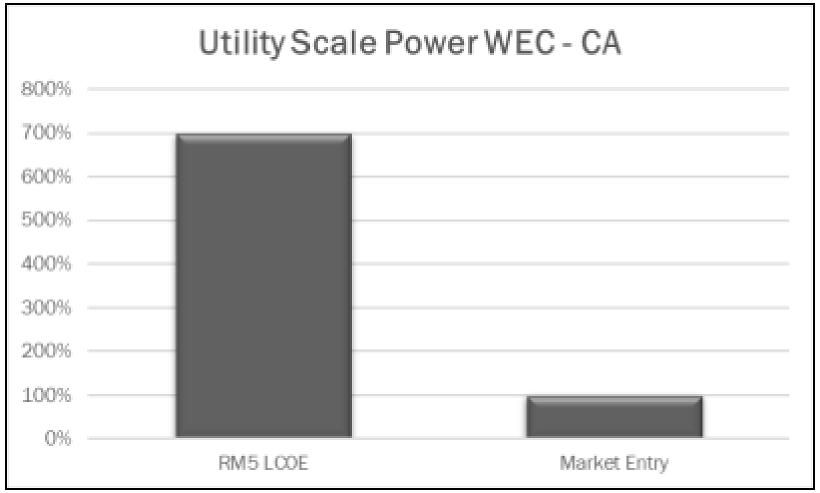
RO System With Energy Recovery

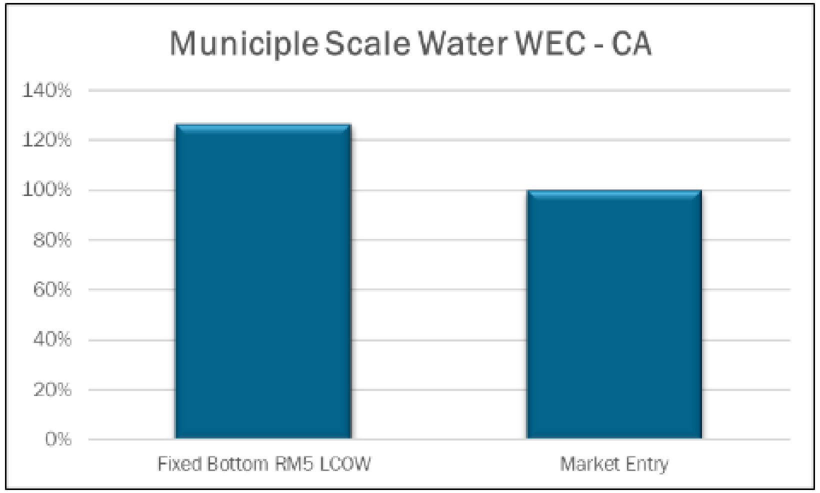


Reverse Osmosis (RO) Basics

- High-pressure process that pushes water through a semi-permeable membrane
- Most energy efficient of commercial technologies
  - 2.5–4 kWh/m^3 produced water
- Roughly half of the cost of water is energy input (prior to distribution)
- Designed for steady-state inputs
  - Intermittent energy sources are a significant integration challenge.

Image credit: Scott Jenne (NREL)





Initial Techno-Economic Study (2016)

Economic Considerations

- Electricity-producing WEC is approximately 5–10 times more expensive than market entry rates – utility scale in the United States.
- Using the same WEC technology and off-the-shelf RO technology, we are only 25%–50% above market entry rates.

Energy Considerations

- U.S. utilities are targeting power plants 50 MW and above.
- Carlsbad Desalination Facility is equivalent to about 35 MW.

Techno-Economic and Simulation Work

Early simulations performed to understand pressure and flow fluctuations

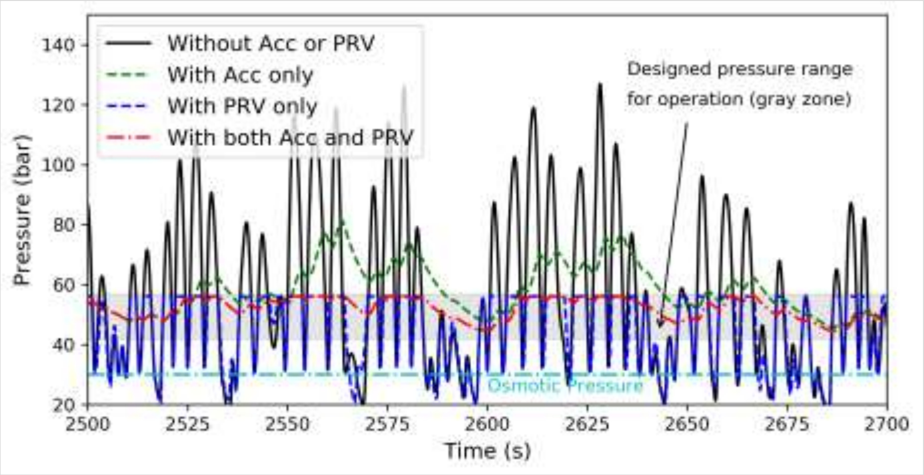
- Without significant smoothing, most of the energy would need to be dissipated.
- Evaluated impact of different smoothing techniques
  - Hydraulic accumulators
  - Pressure relief valves
  - "Digital switching" control
  - Novel pressure intensification.

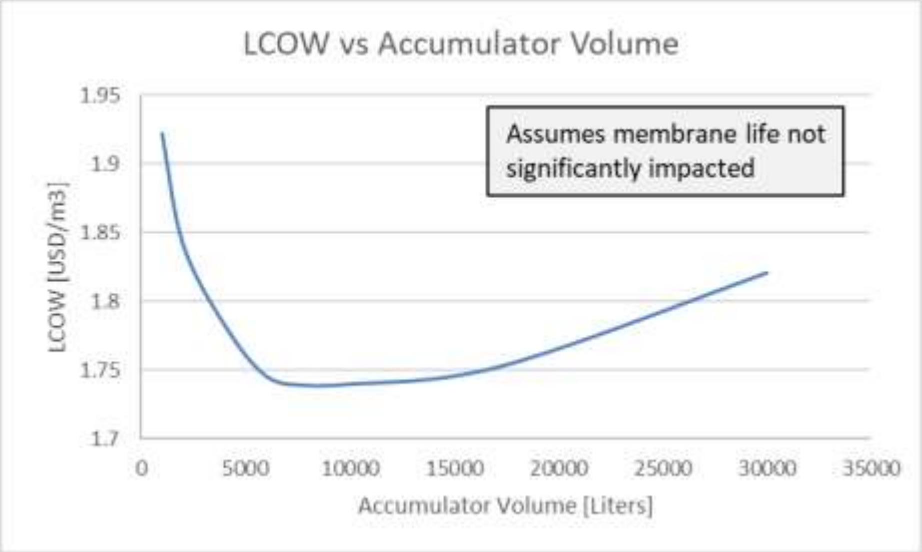
Smoothing flow is possible but has practical limits

- The amount of accumulator volume required to get to a true steady state is unrealistic (both space constraints and economics).
- Impacts the ability to integrate active WEC control.

Assumptions that need to be tested

- Is permeability, or membrane "performance," impacted during transient operation?
- How does variable pressure and flow impact membrane life?





Waves to Water Prize

As an Event

The Waves to Water Prize was a 5-Stage, $3.3M contest to accelerate the development of small, modular, wave-powered desalination systems capable of providing potable drinking water in disaster relief scenarios and remote coastal locations.

As an NREL Project

4-year-long portfolio (2019–2022) – 90 NREL staff involved

- **Rules development** – 5 stages
- **Final event** – public awareness, investor pitches, in-water testing
- **Down-selects** – From 65 to 5
- **Partner subcontracts** – Coastal Studies Institute, Engineering for Change, U.S. Army Corps of Engineers
- **Private sponsorships** – International Desalination Association, Janicki Industries, WoodNext
- **Waves to Water themed comic book** – Chromosphere Studio
- **Waves to Water test article** – HERO WEC

HERO WEC

De-risk Waves to Water Prize

- Provide the install team an opportunity to install and recover a WEC before the event
- Evaluate prize constraints and metrics.

Evaluate technology barriers

- Evaluate numerical modeling techniques
- Develop testing best practices.

Develop publicly accessible data sets

- CAD models
- Bill of materials
- Numerical models
- Laboratory and ocean test data.

Image Credit: John McCord (CSI)

Image Credit: Josh Bauer (NREL)

Image Credit: Andrew Simms (NREL)

Membrane Characterization

Initiated experimental work with Colorado School of Mines

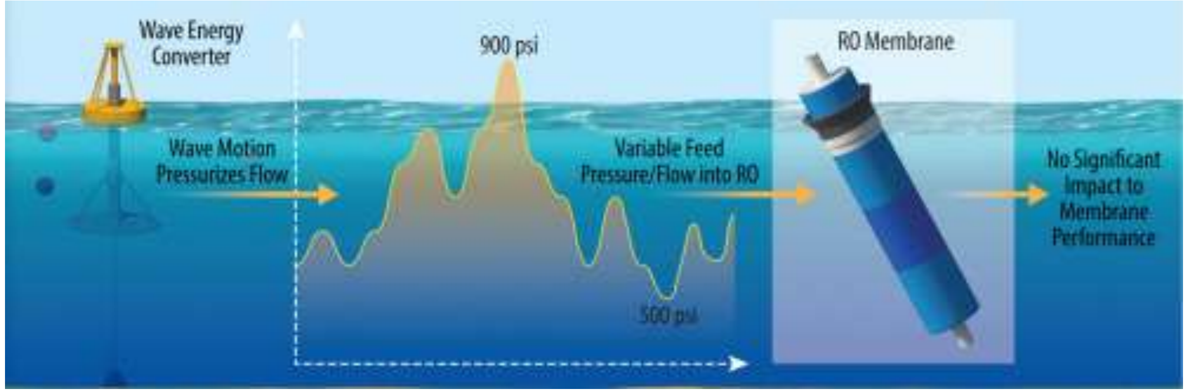
- Developed a membrane test stand to evaluate pressure fluctuations within acceptable membrane operating parameters.

Evaluated both sine waves and “irregular” WEC output

- Sine waves were intended to capture a set of pressure ranges and frequencies.
- Irregular WEC output was used to validate numerical models.

Initial experiments were promising

- Negligible impact on membrane performance.
- No obvious signs of membrane degradation.



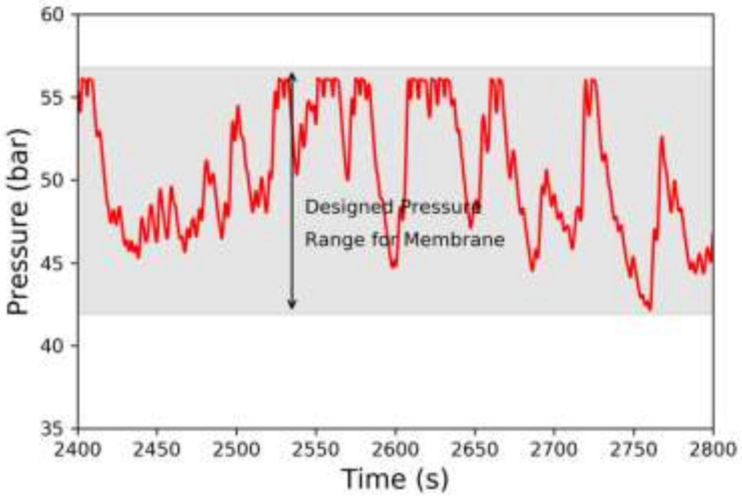


Image Credit: Scott Jenne (NREL)

Membrane Characterization

Built new test platform

- Larger 4-in. membranes
- Higher sampling frequency.

Developed a more focused experimental plan

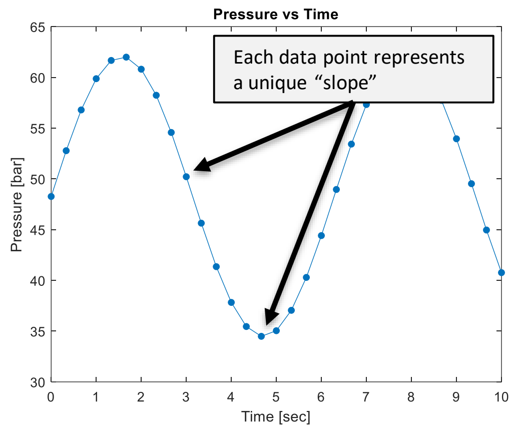
- Trapezoidal waves instead of sine waves
  - Isolating slope and pressure magnitude
  - Number of data points are easily controlled
  - Easier to run convergence studies to determine appropriate length of experiments.

> **Hypothesis 1:**
> Permeability $= f(\frac{dP}{dt}, \mathrm{P})$

Quantifying membrane fatigue

- How does varying pressure and flow impact membrane life?
- Initial experiments suggest negligible impact.

> **Hypothesis 2:**
> Varying flow may **REDUCE** operating costs by reducing membrane cleaning cycles.



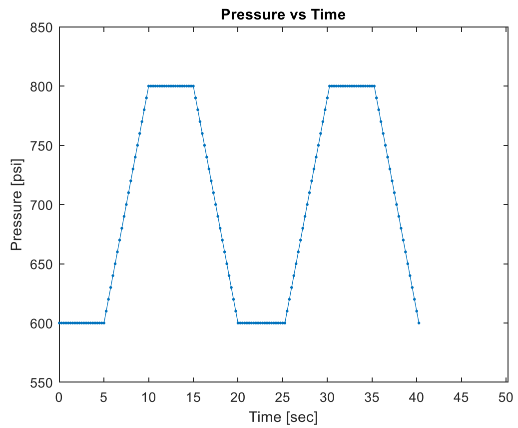


Image Credit: Scott Jenne (NREL)

Future Work

Continue HERO WEC development

- Emphasis on system reliability
- Increase laboratory testing on motion platform.

Long duration membrane testing

- Evaluate impact that oscillatory flow has on membrane life and maintenance.

Leverage our lessons learned in both ocean and lab tests

- Develop best practices for small wave-powered desalination systems.

Continue the refinement of techno-economic models

- Closes the R&D feedback loop.

Image Credit: Josh Bauer (NREL)

Questions?

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Image Credit: John McCord (Coastal Studies Institute)

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