The Design, Fabrication, and Test Program for NREL's Wave-Powered Desalination System

January 24, 2024

Pan-American Marine Energy Conference 2024

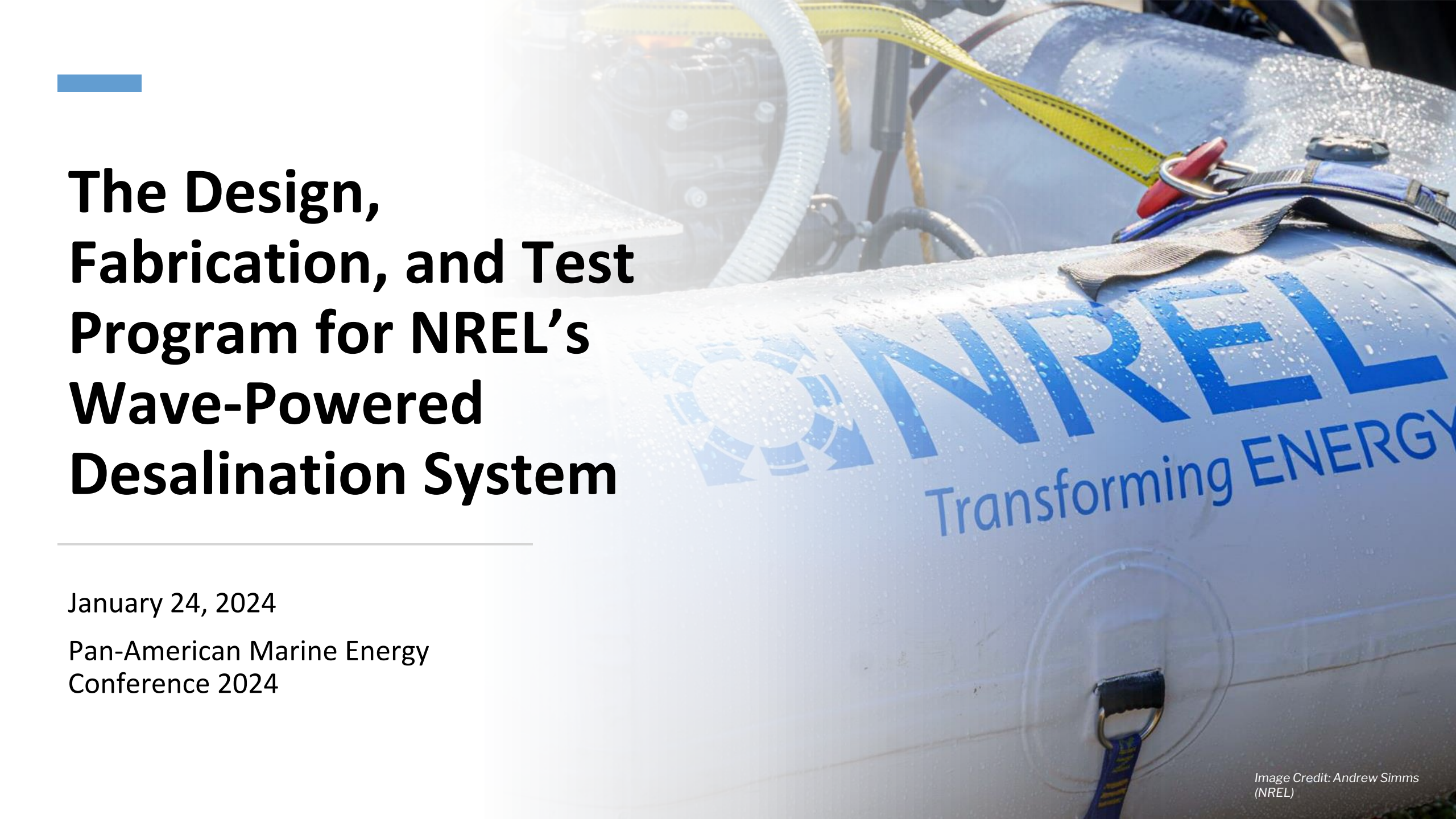
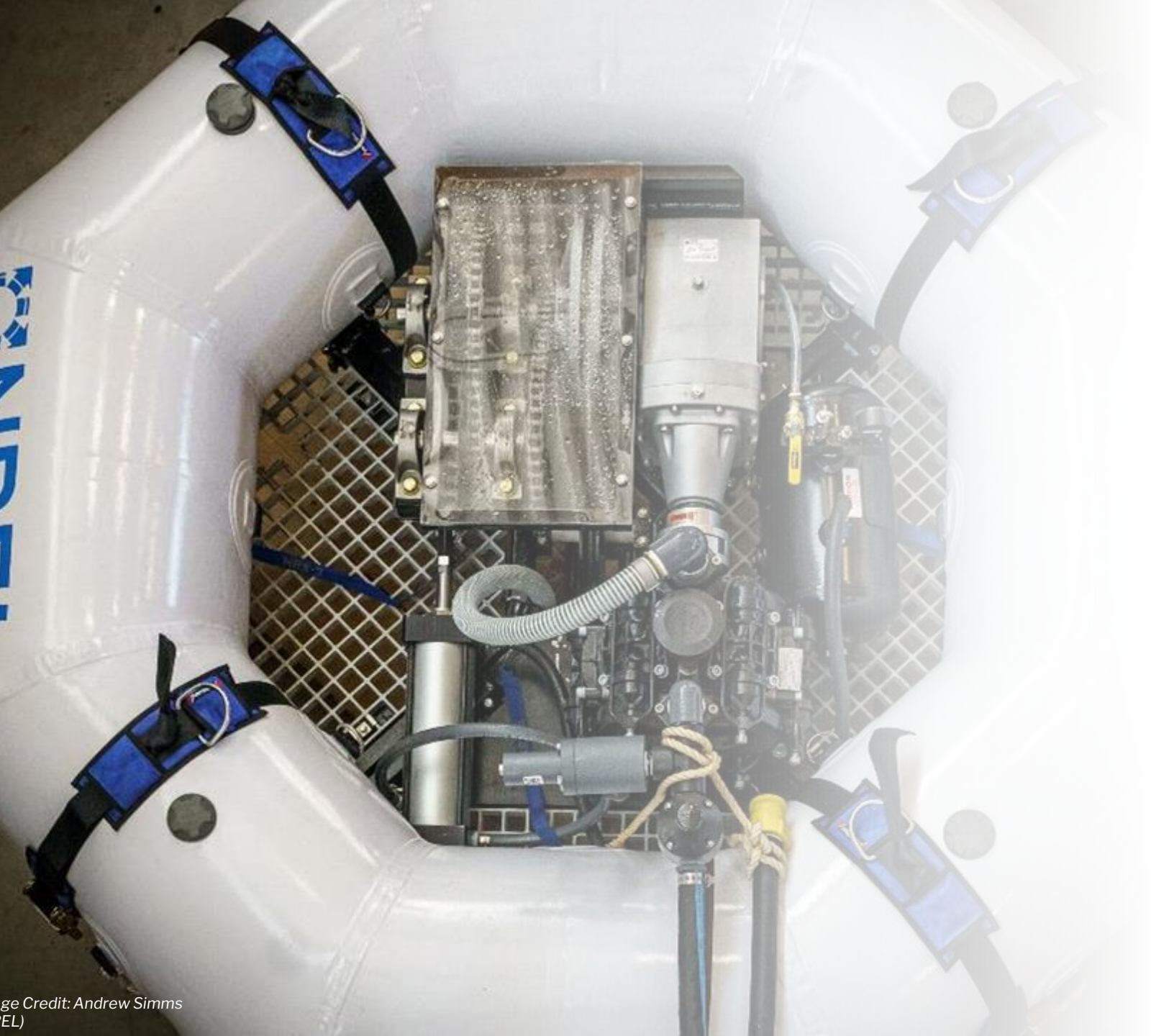


Image Credit: Andrew Simms (NREL)



ge Credit: Andrew Simms
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What Was the Waves to Water Prize?

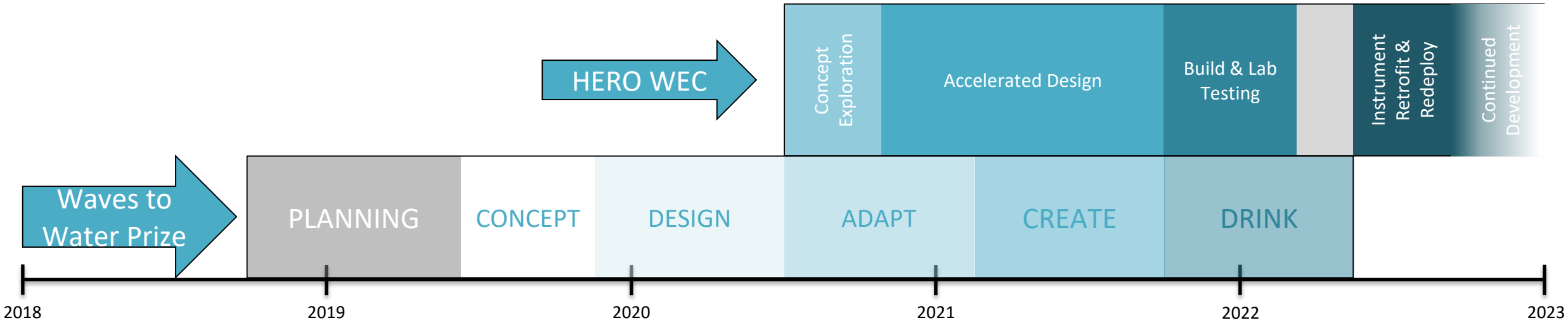
As an Event

The Waves to Water Prize was a five-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** – 90+ NREL staff involved
- **Rules development** – 5 stages
- **Final event** – public awareness, investor pitches, in-water testing
- **Down-selects** – from 65 down 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** – hydraulic and electric reverse osmosis wave energy converter – aka **HERO WEC**

HERO WEC Timeline



- **Concept Exploration:** Converged on a winch-driven point absorber
- **Detailed Design:** Focused on a robust and reliable WEC
- **Build & Lab Testing:** Lab testing was focused on ensuring WEC wouldn't exceed design loads
- **Instrument Retrofit & Redeploy:** Quick turnaround to learn from DRINK Finale

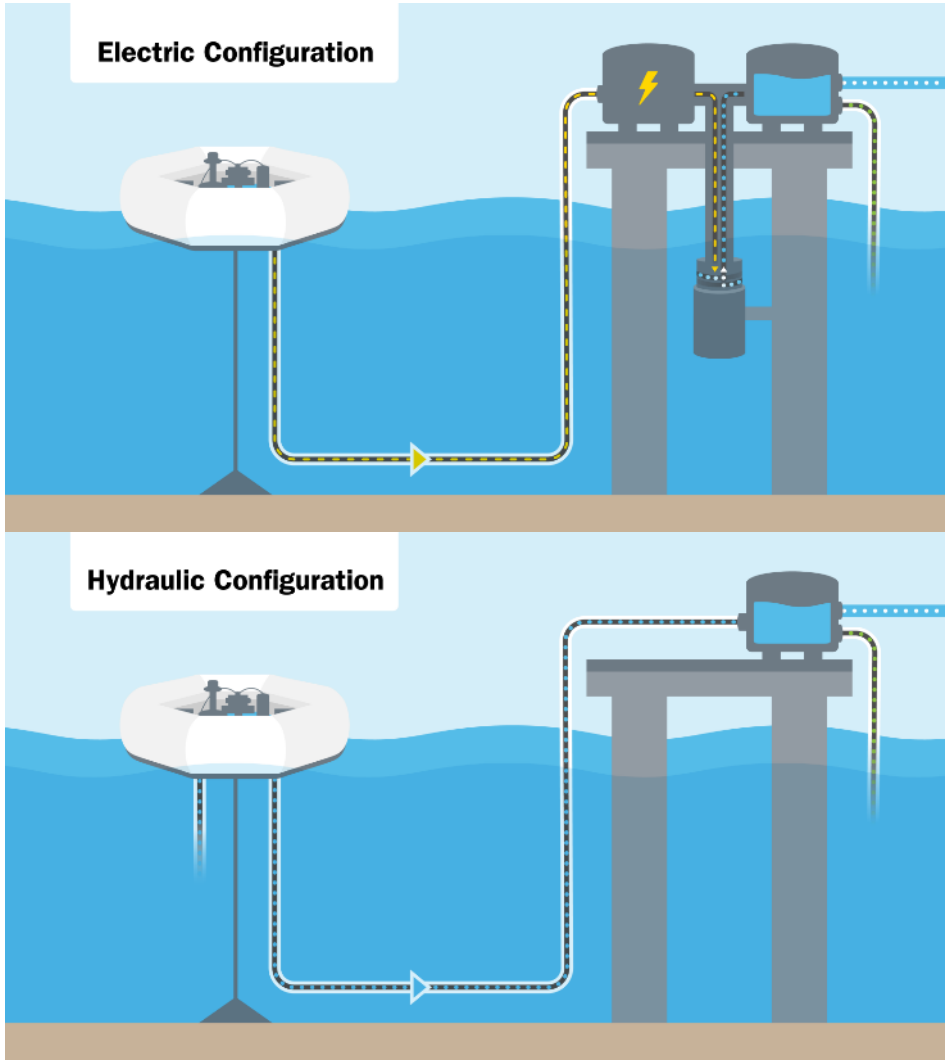
HERO WEC Design Objectives

Primary objectives

- Provide CSI team a practice installation
  - Water connections
  - Electrical connections
  - Anchor connection
  - Lift and tow process
- Evaluate prize requirements
  - Water quality
  - Produced volume
  - Shipping weight
  - 48-hour setup time
  - Battery storage
- Open-source design

Translating to a WEC design

- Modular power take-off (PTO)
  - Evaluate both an electric and hydraulic configuration
- Compliant with standard anchor
- Maintain station with a single point mooring
- Operate in 2–3 m water depth
- Simple and robust design



Prototype Design

Frame and Connections

- Steel box tubing designed and fabricated at NREL
- 4 bolted quadrants to maintain box constraints

Prime Mover – Clutched Winch Assembly

- NREL designed and fabricated winch
- Clutch enables unidirectional power and necessary winch recoil

Spring Return

- Tunable pneumatic spring system that can be isolated during install/recovery

Rotary Drive

- Helical bevel gearbox as speed increaser
- Drives either our custom Innotec generator or our commercial off-the-shelf (COTS) diaphragm pump

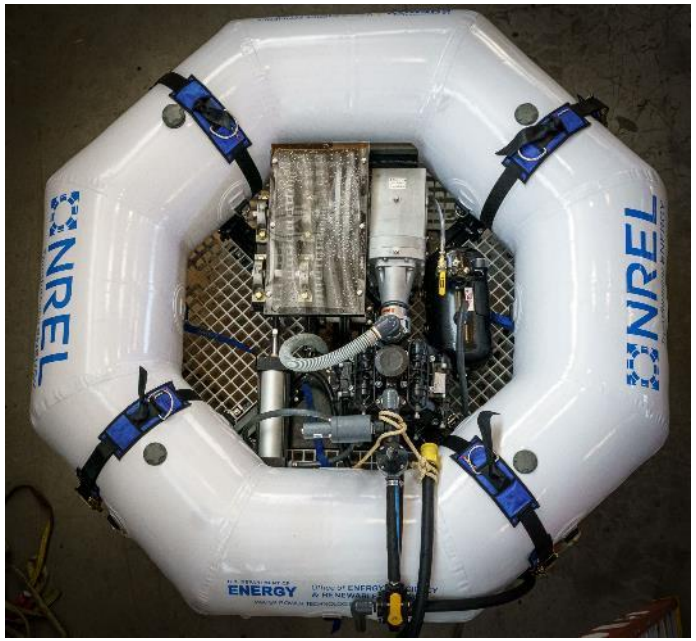
Electrical Enclosure

- Converts “wild AC” into DC for battery storage, ~~and back to 110-V AC to run a submersible pump~~
- In 2023 we removed the DC to AC conversion for increased efficiency

Original design (modified in 2023)

Reverse Osmosis (RO) System

- ~~Coupled two Spectra LB400s units together~~
- In 2023 we removed one of the Spectra units to maintain higher feed pressure, resulting in higher water quality



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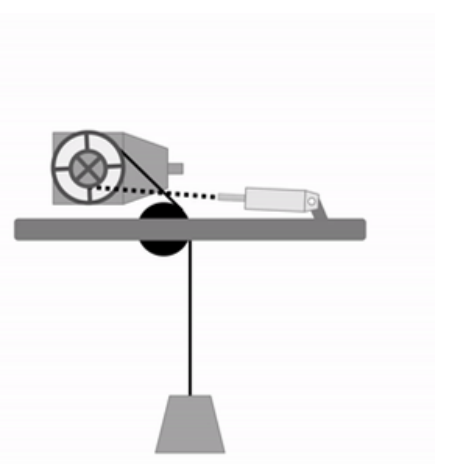

2023 System Upgrades

Mechanical Upgrades
- Blasted and re-coated frame
- Relocated spring return
- Modified gearbox mount
- Decreased transfer hose ID

Electric System Upgrades
- Modularized enclosure for easier maintenance
- Eliminated DC to AC conversion
- Smaller DC permanent magnet pumps for RO unit
- Increased battery capacity and switched to a $LiFePO_4$ chemistry

RO System Upgrades
- Eliminated one Spectra unit
- Increased pre-filtration area (~20x increase)
- Increased accumulator volume

Image Credit: Scott Jenne (NREL)

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Image Credit: Andrew Simms (NREL)

Laboratory Testing

2022 Bench Testing

- Approximately 30 test cases
- Limited to monochromatic (sinusoidal) wave profiles
- Did not do a full RO system test (tunable orifice valve
- Primarily intended to check system safety checks

Image Credit: Scott Jenne (NREL)

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2023 Motion Platform Testing

- 30 multi-chromatic (irregular) wave profiles
- 30 monochromatic (sinusoidal) wave profiles
- 9 heave-only profiles
- Evaluated drivetrain-only and both configurations with and without RO system on

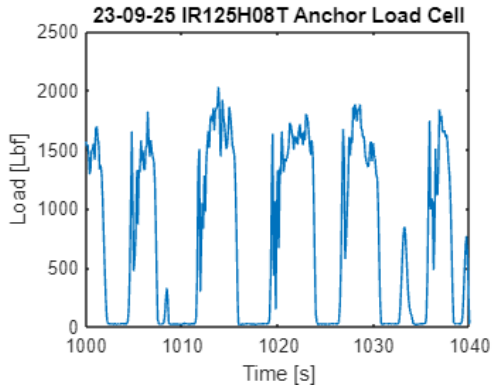
Video Credit: Taylor Mankle (NREL)

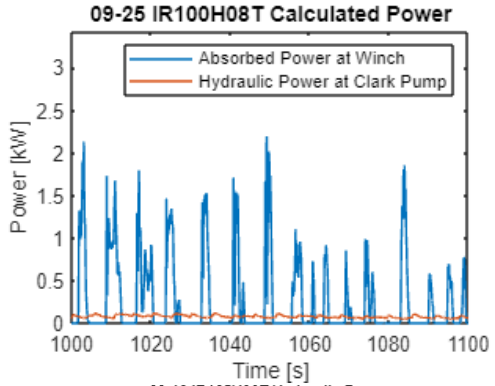
2023 Test Data – Publicly Available

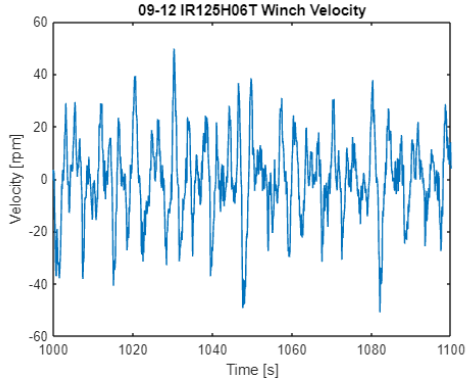
86 Processed data structures
- 47 hydraulic system runs
- 37 electric system runs
- 2 drivetrain runs (each contains 3 wave profiles)

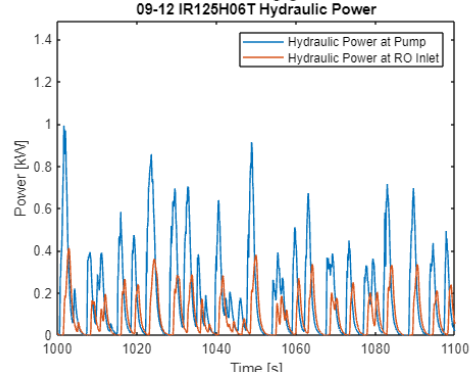
All 86 data structures include some variation of the following:

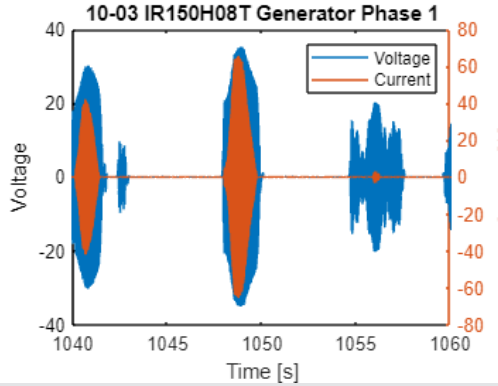
Data Summary not including time arrays		
Quantity	Description	Subsystem
Measured Values		
1	Anchor force measurement	All
1	Encoder measurement for winch position	All
2	Conductivity Measurements (RO system inlet and clean water outlet)	RO System
4	Pressure measurements (1 pump output and 3 points within the RO system)	Hydraulic and RO
5	Flow measurements (1 pump outlet and 4 points within the RO system)	Hydraulic and RO
8	Current measurements through power electronics enclosure (including DC pump current)	Electric and RO
10	Voltage measurements through power electronics (including DC pump voltage)	Electric and RO
Calculated Values		
25	Calculated or simulated arrays (e.g., power, efficiency, rotational speed)	All
33	Additional scalar value calculations (e.g., average values, cumulative values, minimum and maximum values)	All

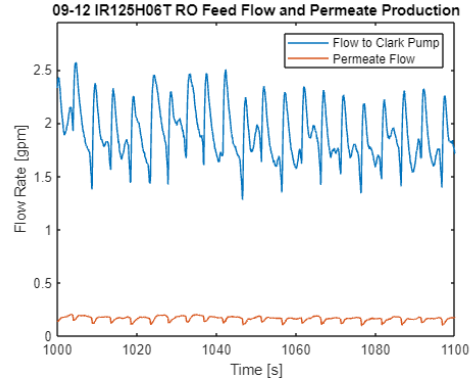












WEC Installation – Aug. 15, 2022

Electric configuration went first

- Had not been in the water before
- Anchor loading is less aggressive than hydraulic
  - “Damping” can be tuned on the pier
- Eliminated the risk of ruining the electric cable prior to installation
- Initial plans to install both cable and hose on first day

Installation process went as planned

- First deployment from the boat
- Anchor installed week prior to installation
- Divers connected WEC to anchor
- WEC was boarded to set air-spring, attach cable, and ensure all components were working as designed

Image Credit: John McCord (Coastal Studies Institute)

First Waves – Aug. 16–17, 2022

Waves started to pick up on Aug. 16

- But not enough voltage to push through the charge controller
- 32-V threshold, spent most of the time between ~0 and 30 V
- Combination of tuning, gearbox compromises, lack of onboard storage, etc.

Aug. 17 was more aggressive

- Controller needed additional tuning for Jennette's Pier
  - Lab experiments focused on higher end of voltage range
  - Did not run irregular conditions in the lab
- Regularly saw 30–70-V inputs with no current draw
  - Tuned controller on pier and started making water

Image Credits: John McCord (Coastal Studies Institute)

Drivetrain Swap – Aug. 21, 2022

Our first in-water PTO swap

- Disconnect WEC from anchor, de-energize spring, disconnect power cable
- Towed over to the Duffy and put back on the deck
- Data from both DAQs downloaded, batteries replaced, and a field repair was necessary on load cell cable
    - Sheathing on cable put too much strain on the cable and ripped out conductors
    - Total swap took about 2 hours
        - Swapping generator with pump took about 30 min
        - Damaged cable took significantly longer without proper equipment

Aug. 22 installed hose and hooked up RO unit

- Not enough wave action to pump water through the RO system

Image Credit: John McCord (Coastal Studies In

Deployment Data

Electrical enclosure and RO system

- Power monitoring
  - Voltages (both AC and DC)
  - Current (both AC and DC)
  - RO feed flow
  - RO pressure

Topside WEC black box (retrofit)

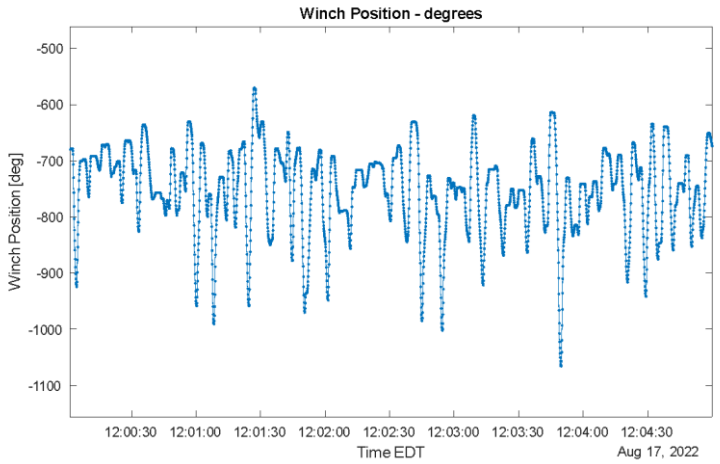
- WEC motion
  - Winch encoder
  - GPS
  - Accelerometer IMU

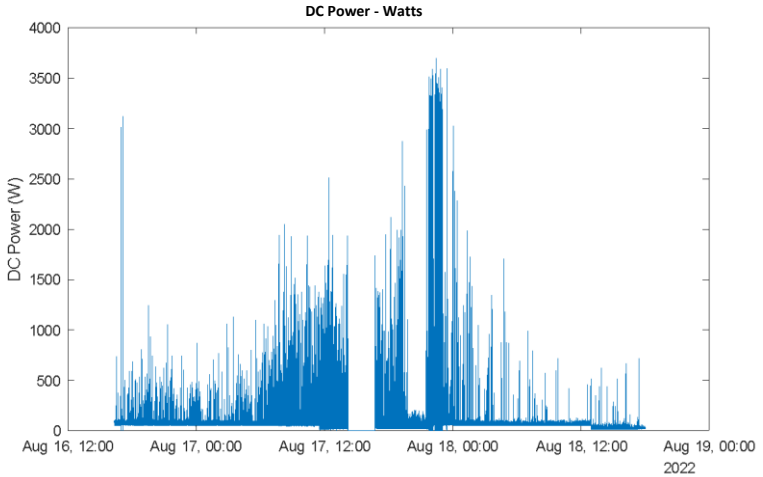
Submerged black box (retrofit)

- Mooring loads
  - Load cell (mooring tension)
  - Lost data after failed connector

Data publicly available on MHKDR: https://mhkdr.openei.org/submissions/487

Or search "HERO" on MHKDR





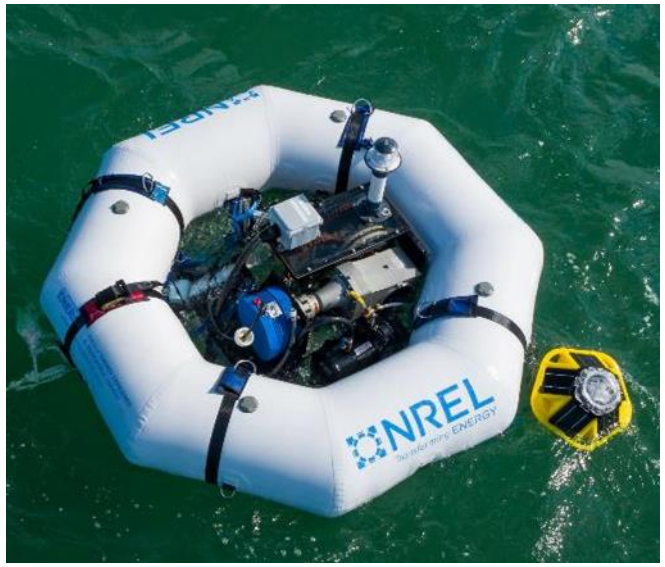


Image Credit: John McCord (CSI)

Load cell disconnected underwater

Next Steps

4-6 week deployment starting early February

- Need more data before we determine what direction we're going with V2

HERO V2 re-design

- Emphasis will be on more robust drivetrain design
- Longer design life (currently only designed for approximately 2-4 week continuous operation)

Controller re-design

- Will be focusing efforts on a new controller that can efficiently manage both the fluctuations in voltage as well as the rate of change (dV/dt)

Additional motion platform characterization/testing

- Currently evaluating Hardware in the Loop (HIL) capabilities

Image Credit: John McCord (CSI)

Questions?

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