DE-EE0008627 Preliminary Design Review
January 17, 2020

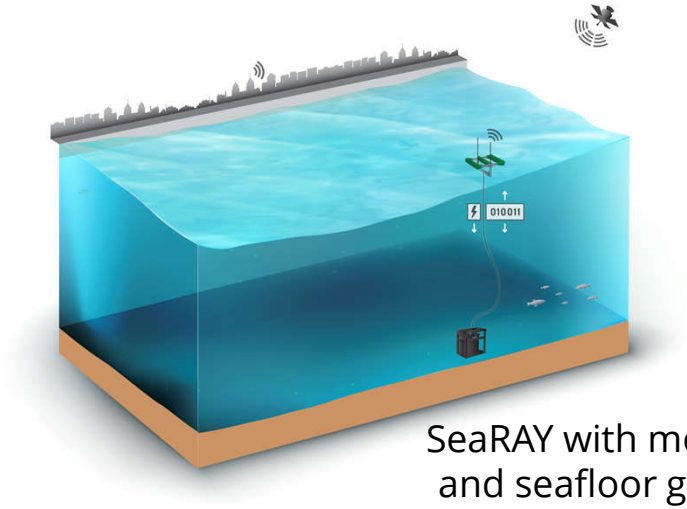
C·POWER
power from the next wave

Agenda

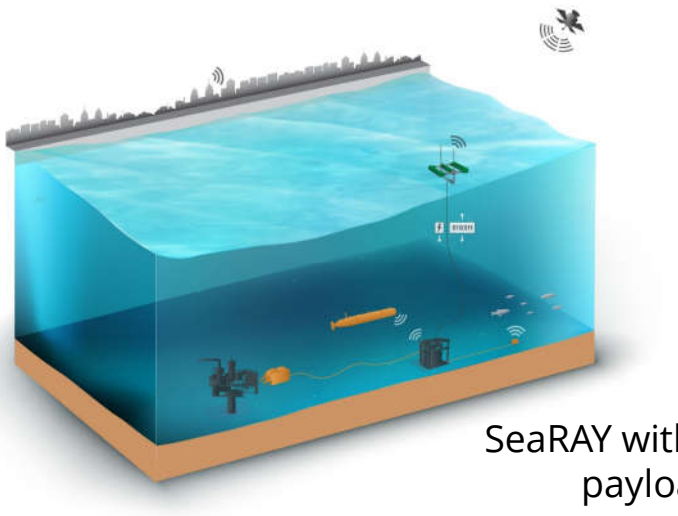
- Project Overview and Objectives
- WETS Site Location
- Technoeconomic Metrics
- Schedule
- State of the Art
- Design Load Cases
- SeaRAY Preliminary Design
- SeaRAY Seafloor Garage Preliminary Design
- SeaRAY CONOPS
- DataRAY Preliminary Design

Project Overview

- Goal is to design, deliver, and test a prototype low-power wave-energy-converter (WEC) that lowers the total cost of ownership and provides robust, new capabilities for customers in the maritime environment.
- This novel WEC system, the SeaRAY, is intended to be a mobile and deployable power, data and communications system for maritime sensors, equipment, and subsea vehicles



SeaRAY with mooring and seafloor garage



SeaRAY with various payloads

Project Objectives

- Gather system requirements
- Evaluate design concepts
- Down-select most promising concept
  - meeting the identified market requirements
  - being technically feasible
  - promising cost competitiveness for the target market
- Design to meet requirements
- Test and validate

Why Change to WETS as Primary Site Location?

- Better demonstrate SeaRAY capabilities
  - Transportability
  - Ease of deployment
  - Operational capabilities in a defense/security environment with US Navy support
  - Start in a lighter wave environment than PacWave
- Advance WEC-charged AUV system towards commercialization
- Potentially avoid being 1st to re-permit PacWave-North
- Gain deployment experience at WETS
- Utilize empty WETS berth

Technoeconomic Metrics

Metric	Unit	Baseline	Targeted	% improvement from baseline	SeaRAY (DOE reference site*)	% improvement from baseline	SeaRAY (WETS)	% improvement from baseline
Levelized cost of energy (LCOE)	$/watt-hour(Wh)	0.324	0.048	85%	0.024	93%	0.026	92%
Annual energy production (AEP)	kWh/year	629	2139	240%	10555	1577%	9671	1437%
Power to weight ratio (PWR)	W/kg	0.061	0.111	82%	0.189	210%	0.173	184%
Peak to average power ratio		40.7	24.0	41%	40.0	2%	43.7	7%

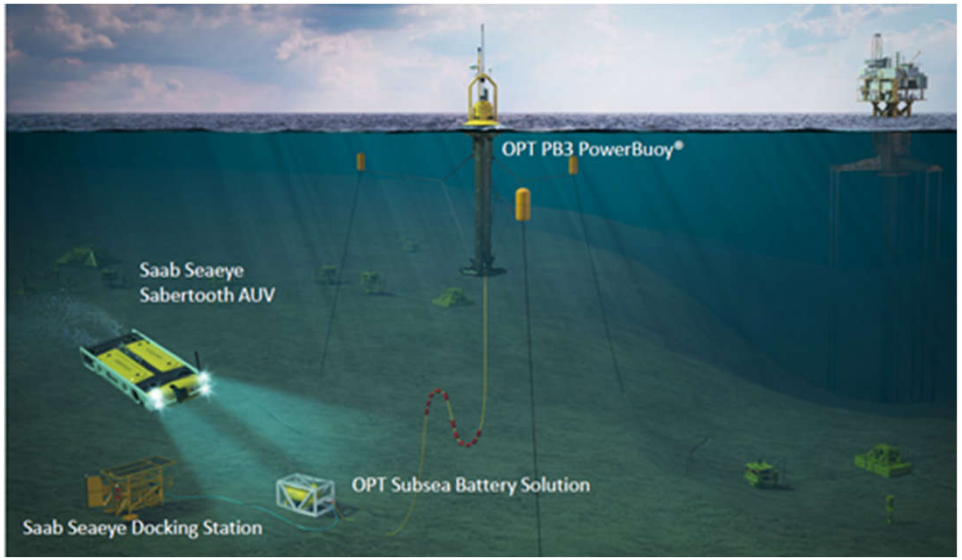
*Depth for reference site 80m instead of 70m

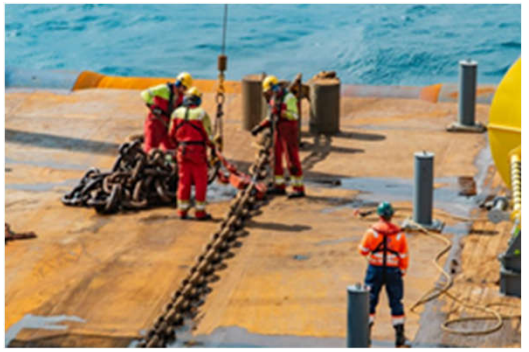
Schedule

Task #	Task Description	Date
M3.4/D3.4	Preliminary design	1/14
T4.0	Final design	1/14 - 4/21
D4.11	System Design and Integration Plan	4/21
M4.12	Final EDR and build drawings	4/21
T5.0	Component and subsystem V&V	1/24 – 6/16
D5.4	V&V report	6/16
T6.0	BP2 Permitting and Test preparations	1/31 – 4/24
D6.4	Permitting Status & permitting plan	4/24
D6.7	Preliminary IO&M Plan	3/27
T7.0	Go/No-Go	3/27-6/29
M7.1	Present Continuing Application	4/24
	BP2 start	6/29
T15	Deploy and Test WEC	9/9 – 3/17

State of the Art

- Ocean Power Technologies

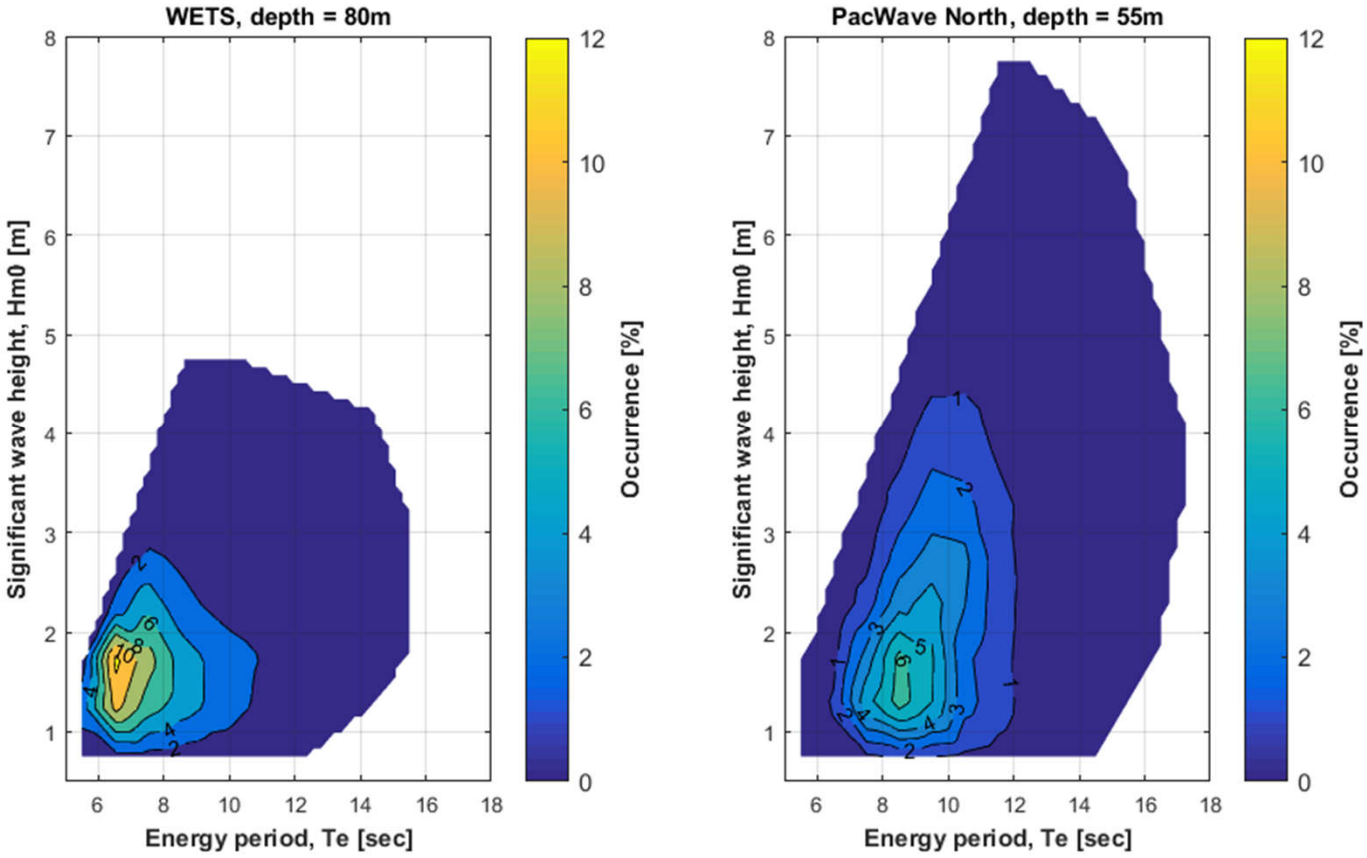




Design Objectives

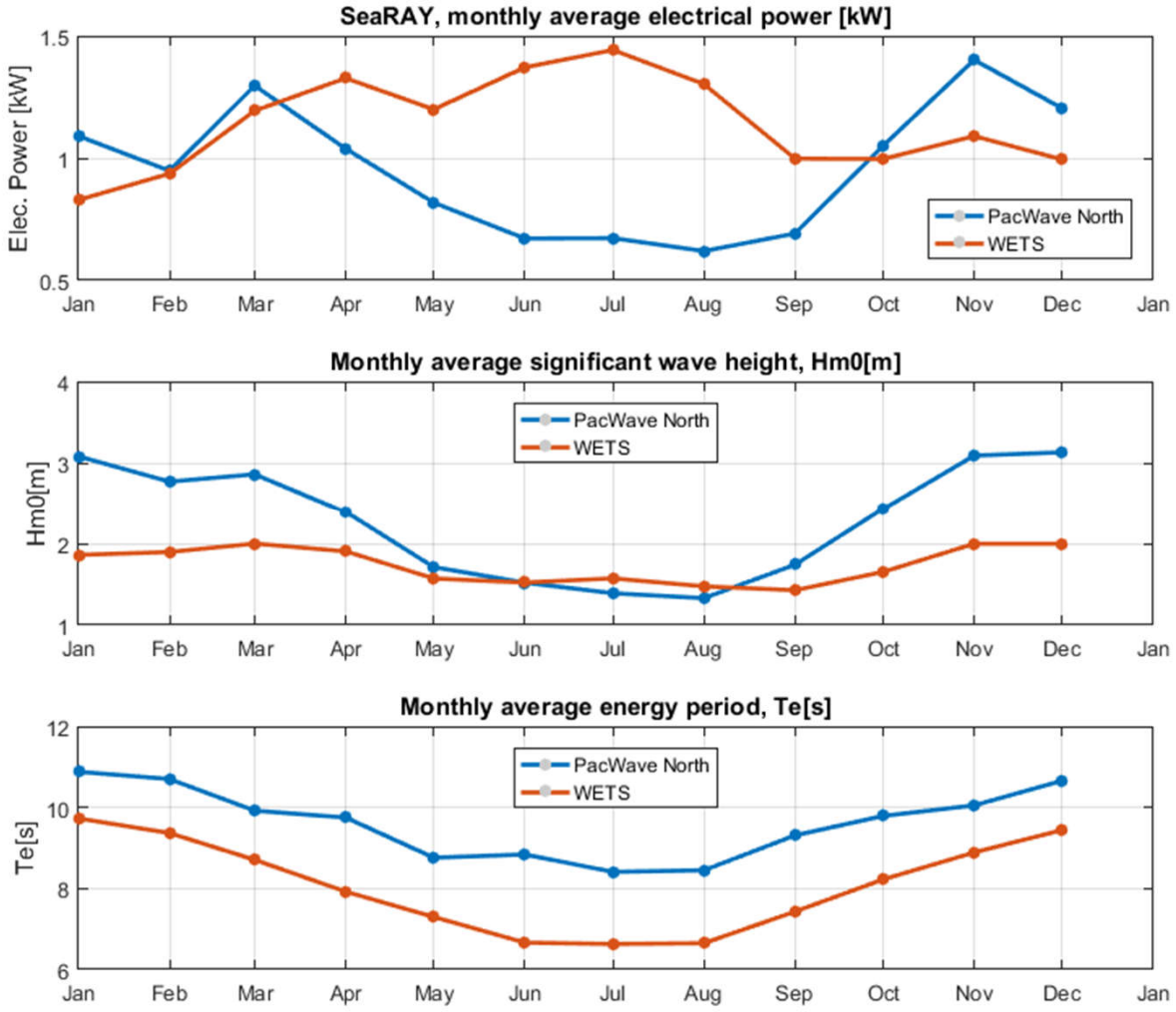
- Average energy generation above 1 kW
- Low-mass
- Rapidly deployable
  - System fits within 20’ standard ocean container(s)
  - Minimal assembly work dockside
  - Able to use smaller, lightly manned vessels
- Mooring, data, and comms combined in one line
- Fully-integrated energy storage
- Capable of delivering continuous power as required
- Designed for PacWave North and WETS

Design Load Cases

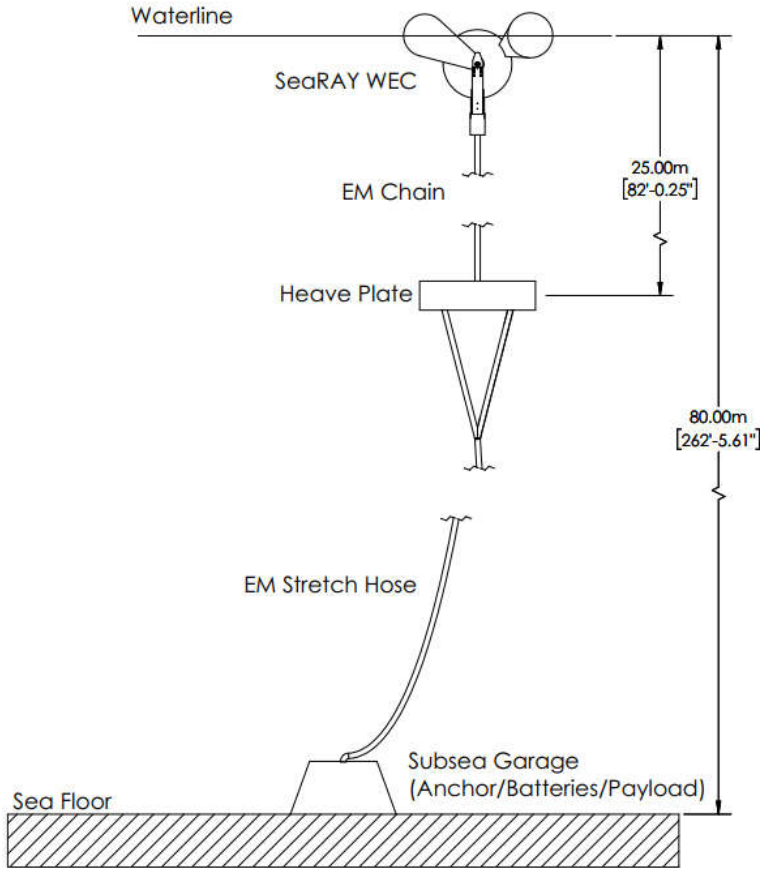


- 100-year return extreme sea condition
  - WETS: Hm0 = 7.24m, Te = 12.98s
  - PacWave North: Hm0 = 17.31m, Te = 16.57s

Design Load Cases



SeaRAY Description



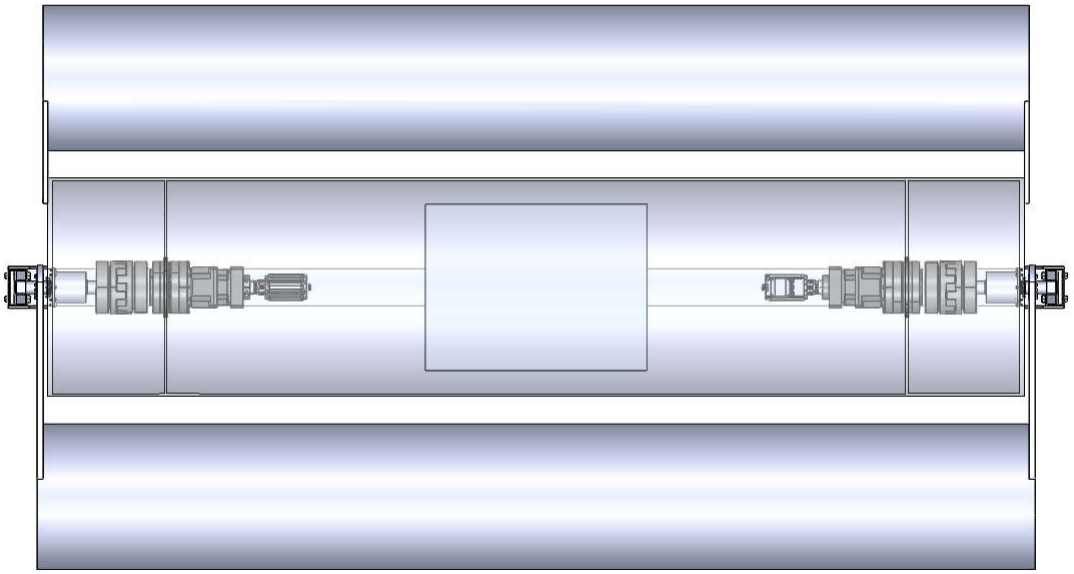
- WEC
  - Nacelle – PTO housing
    - 1.3m OD x 5.18m (17') length
    - 3347 kg
  - Forward float – wave actuated
    - 0.85m OD x 5.33m (17'6") length
    - 1150 kg
  - Aft float – wave actuated, fixed to nacelle
    - 0.85m OD x 5.33m (17'6") length
    - 1150 kg
- Heave Plate
  - Large surface area to stabilize nacelle in water column
  - 3300 kg
- Garage
  - Gravity anchor
  - Batteries
  - Payload
  - 6800 kg

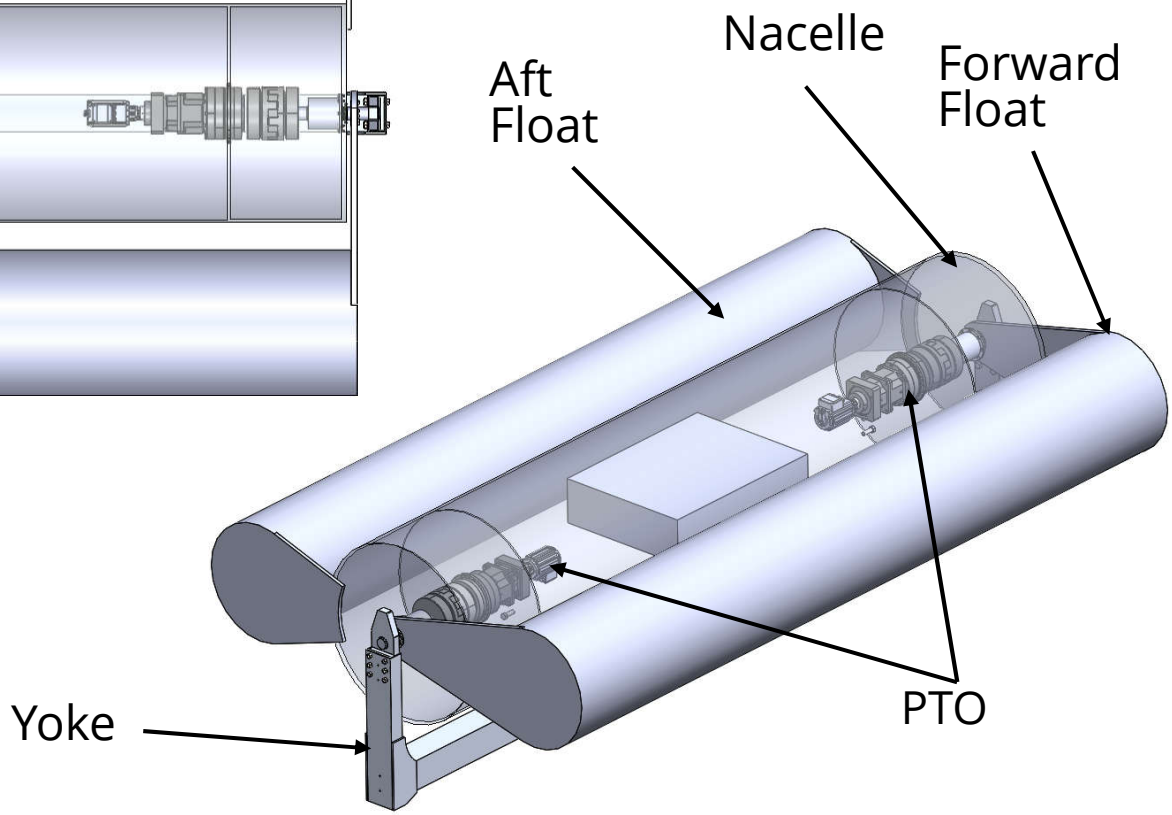
SeaRAY Systems

System #	System Name	System Owner	EDR* Complete	Major Vendor
100	Hull	KO	Yes	Malin Marine
200	PTO	KO/LR	Yes	
300	Electric Plant	LR	Yes	AMS
400	SCADA	LR	Yes	AMS/APL
500	Auxiliary Sys.	AM/LR	Yes	APL
600	Outfit & Furnish	AM/KO	Yes	
700	Mooring/Umbilical	AM	Yes	EOM
750	Seafloor Garage	AM	Yes	EC-OG

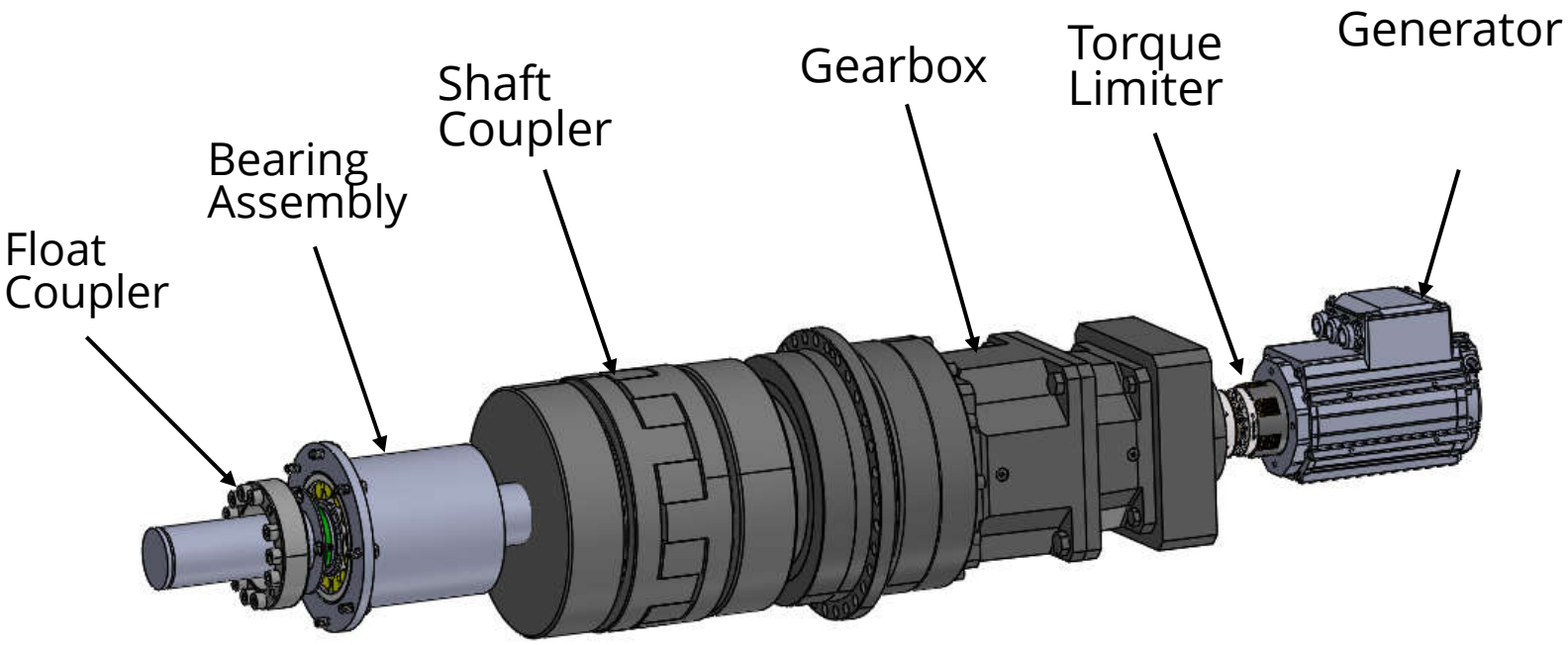
*Engineering Design Requirements

0100 Hull

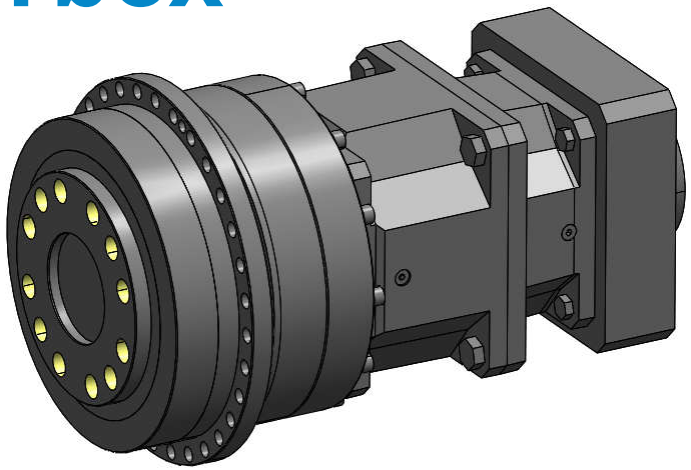




0200 PTO


Float Coupler
Bearing Assembly
Shaft Coupler
Gearbox
Torque Limiter
Generator

0200 PTO - Gearbox

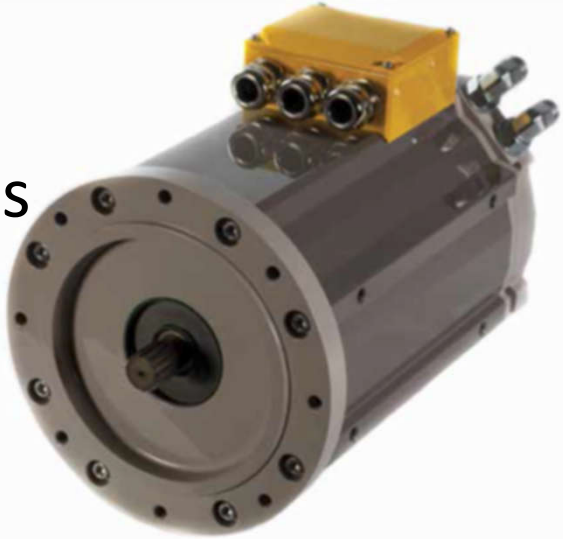


Gearbox

- PHQ1033
- Ratios: … 91, 96, 120, …
- Nominal Torque: 6,500 Nm
- Accel Torque: 10,000 Nm
- Peak Torque: 20,000 Nm

0200 PTO - Generator

- Permanent Magnet Traction Motor
- Used in high efficiency hybrid electric powertrains
- Three phase
- Low torque ripple
- SAE J455
- Heavy duty environmental standards



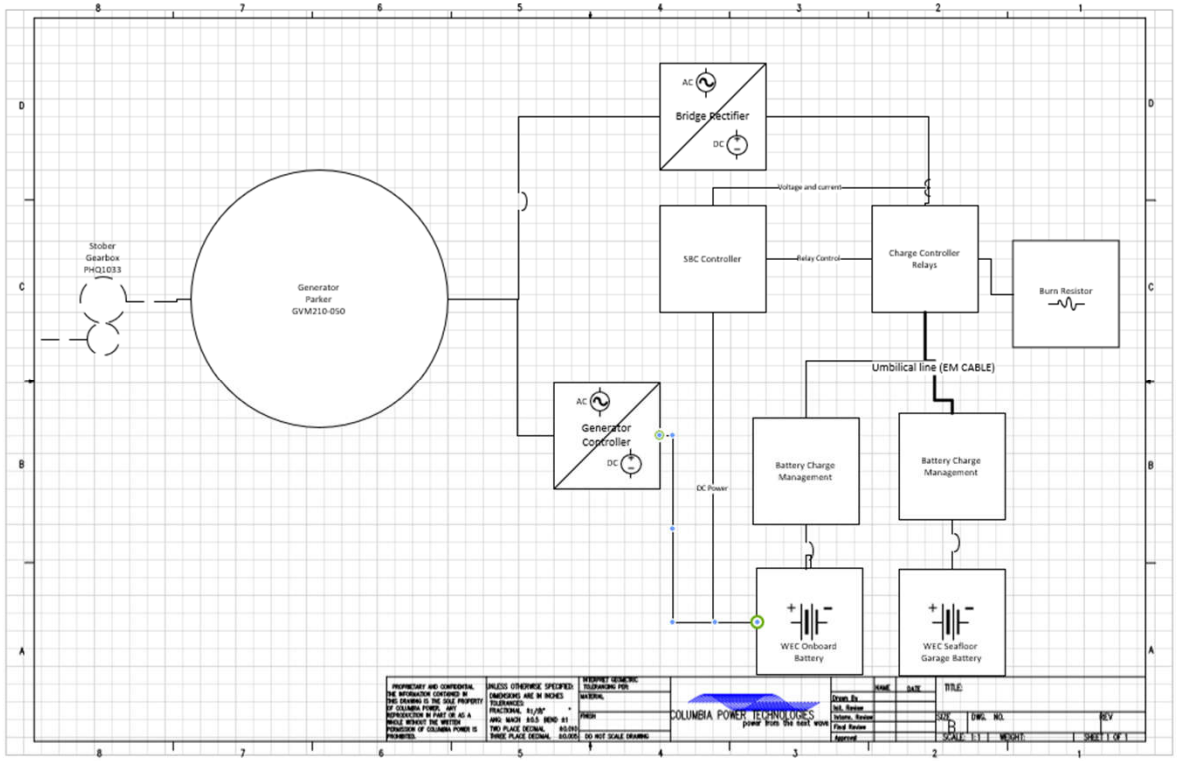
0200 PTO - Coupler

Float Coupler
- PL100X145 AS-SS
- Stainless Steel
- Shaft OD: 3.9”
- Hub ID: 5.7”
- Torque: 8400 Nm

Shaft Coupler
- EK6-9500
- Rated Torque: 10,000 Nm
- Max Torque: 20,000 Nm

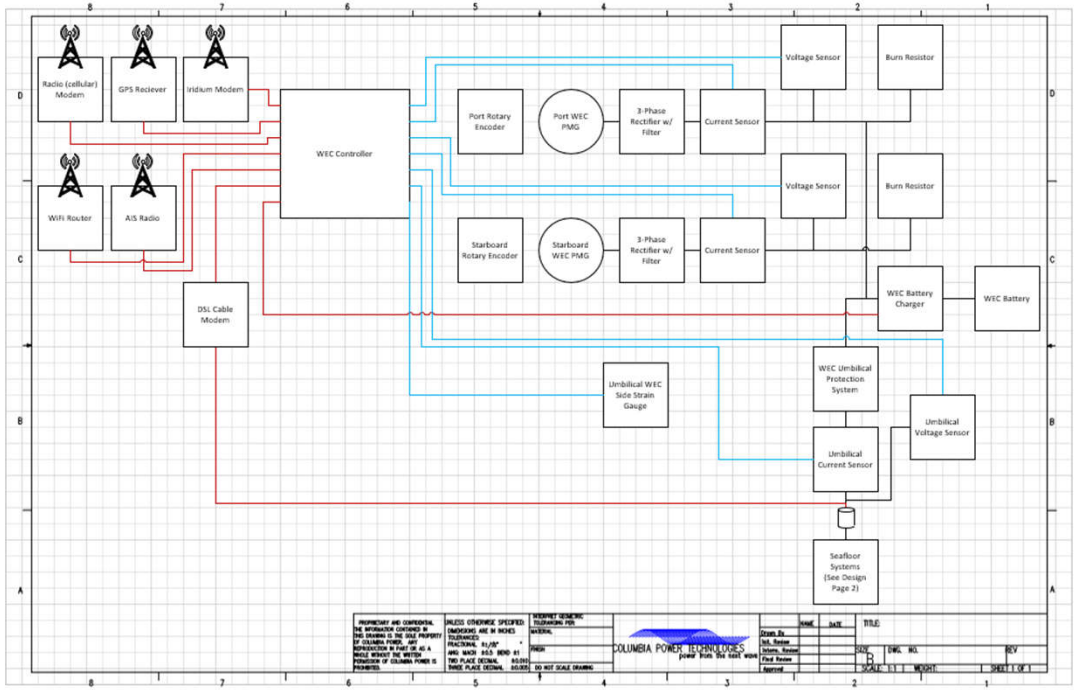
0300 Electric Plant

- 3 Phase AC Generator
- AC to DC Conversion
- Operational Battery System in WEC
- Power Storage Battery on Seafloor
- Transmission WEC to Seafloor ~400V



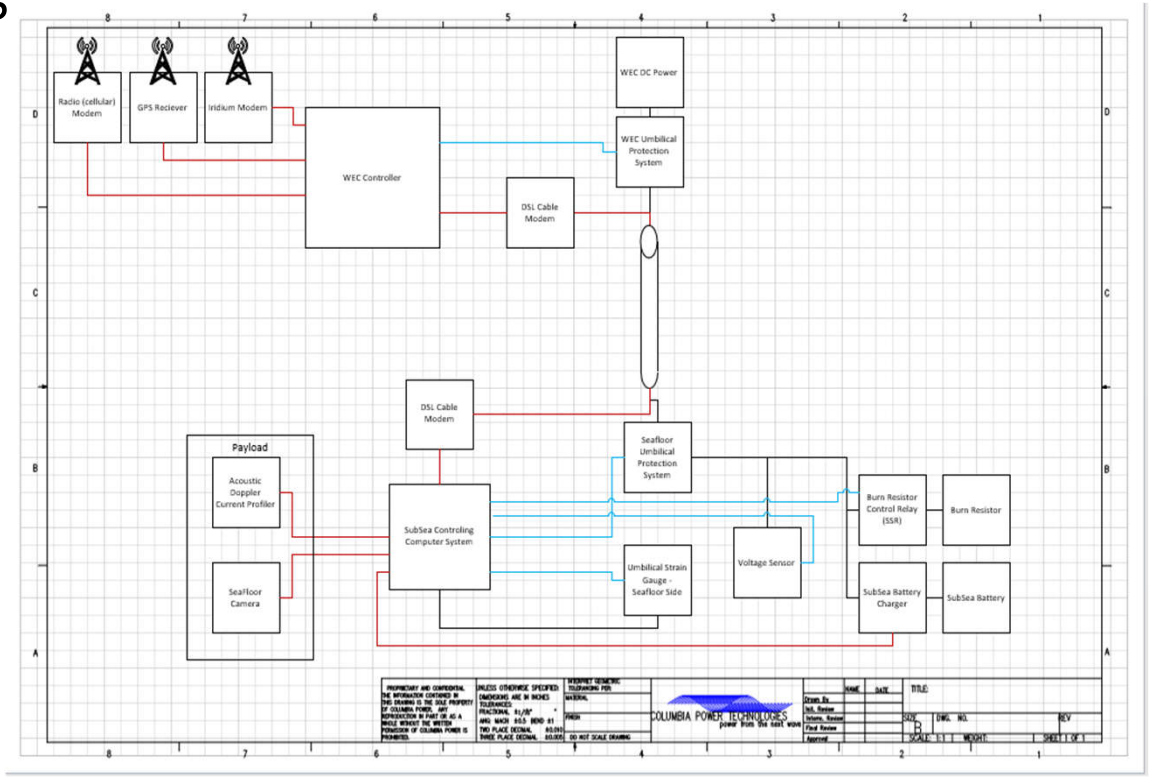
0400 SCADA

- WEC's surface SCADA Network
  - Electric Plant Condition, Monitoring & Control
  - Battery Condition Monitoring
  - Communication Systems
  - WEC Auxillary System Monitoring and Control
  - Position Monitoring
  - Data Modems
  - Mooring Monitoring



0400 SCADA

- Seafloor SCADA and Communications
  - Seafloor Battery Condition Monitoring
  - Mooring Monitoring System
  - Seafloor Sensor Payloads
  - Additional Package Support as defined
  - Data Modem



0500 Auxiliary Systems

- 0520 Emergency Systems
  - Fire Protection
  - Flooding Alarms
  - Access Alarm
  - Emergency-Stop (E-Stop)
  - Safety Controller
  - Safety Communications

- 0570 Bilge
  - DC Bilge pumps
  - Pumps controlled by 0520's flooding alarm sensor
  - Thermal Control provided by TEGs or heaters
- 0580 Surveillance
  - GPS Antenna System
  - IMU (inertial measurement device)
  - Onboard Camera system
  - AIS System

0600

- 0610 – Designation & Markings
- 0620 – Hull Fittings
- 0630 – Hull Penetrations
- 0640 – Paint (internal and external)
- 0645 – Anodes (passive corrosion mitigation)
- 0665 – Lightning Protection

0700 Mooring/Umbilical - EOM

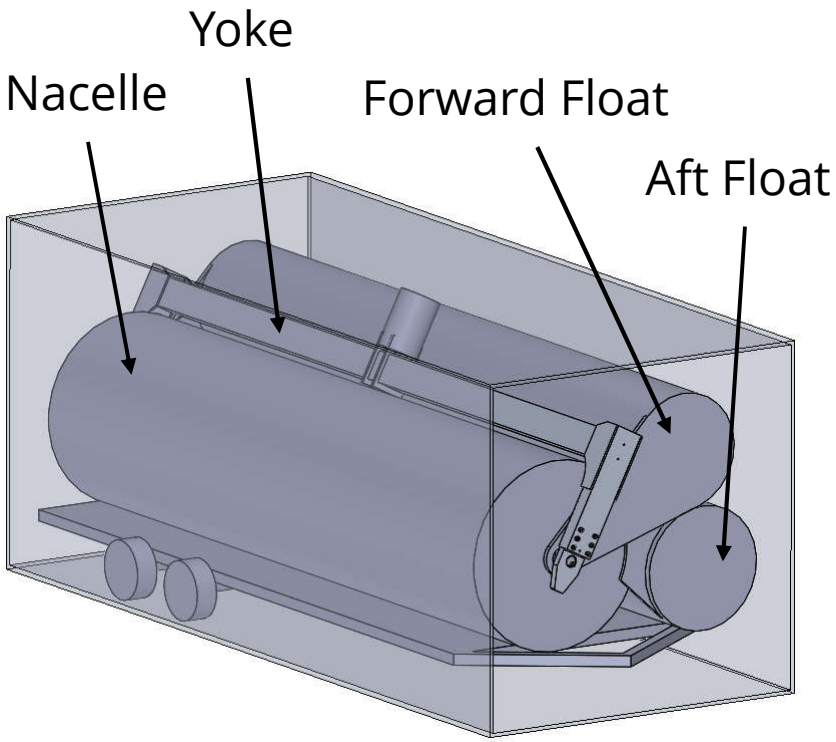
- Combined mooring and umbilical cable
  - Top section: EOM's Chain
  - Bottom section: EOM's Stretch Hose
- Design loads at WETS: 39 T peak tension
  - Compared to 48 T peak at PacWave-North
- All hardware needs to fit in 20' shipping container

0750 Seafloor Garage

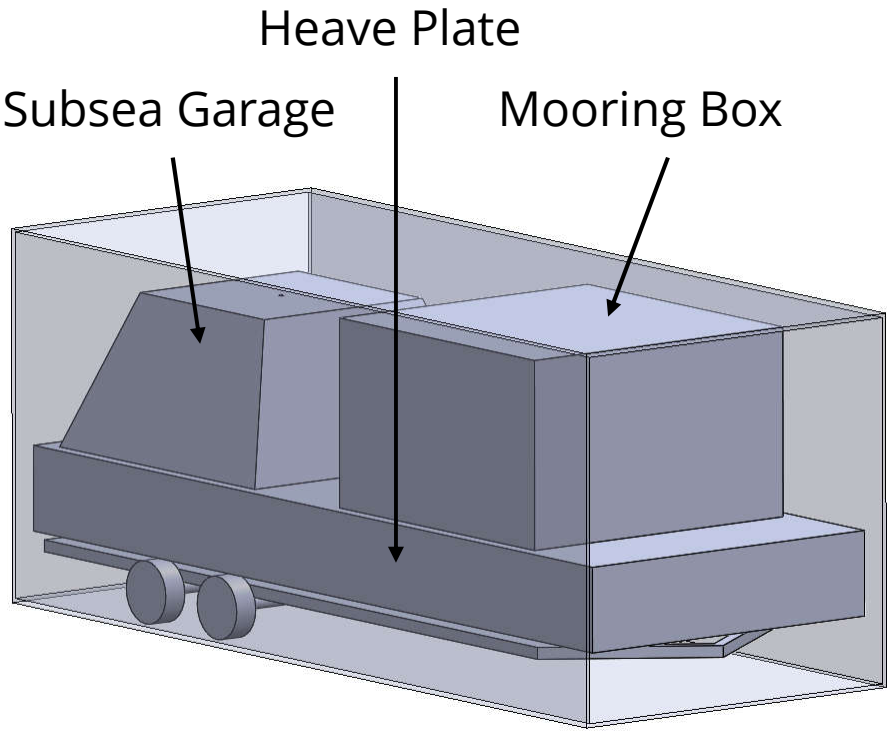
- Three main components:
  - Mooring gravity anchor
  - Battery bank
  - Sensor array payload
- Total wet weight < 5.64 Tn
  - Total dry weight > 6.5 Tn assuming steel anchor
  - Total dry weight > 9.3 Tn assuming concrete anchor
- Example: EC-OG's HALO

CONOPS

Container #1

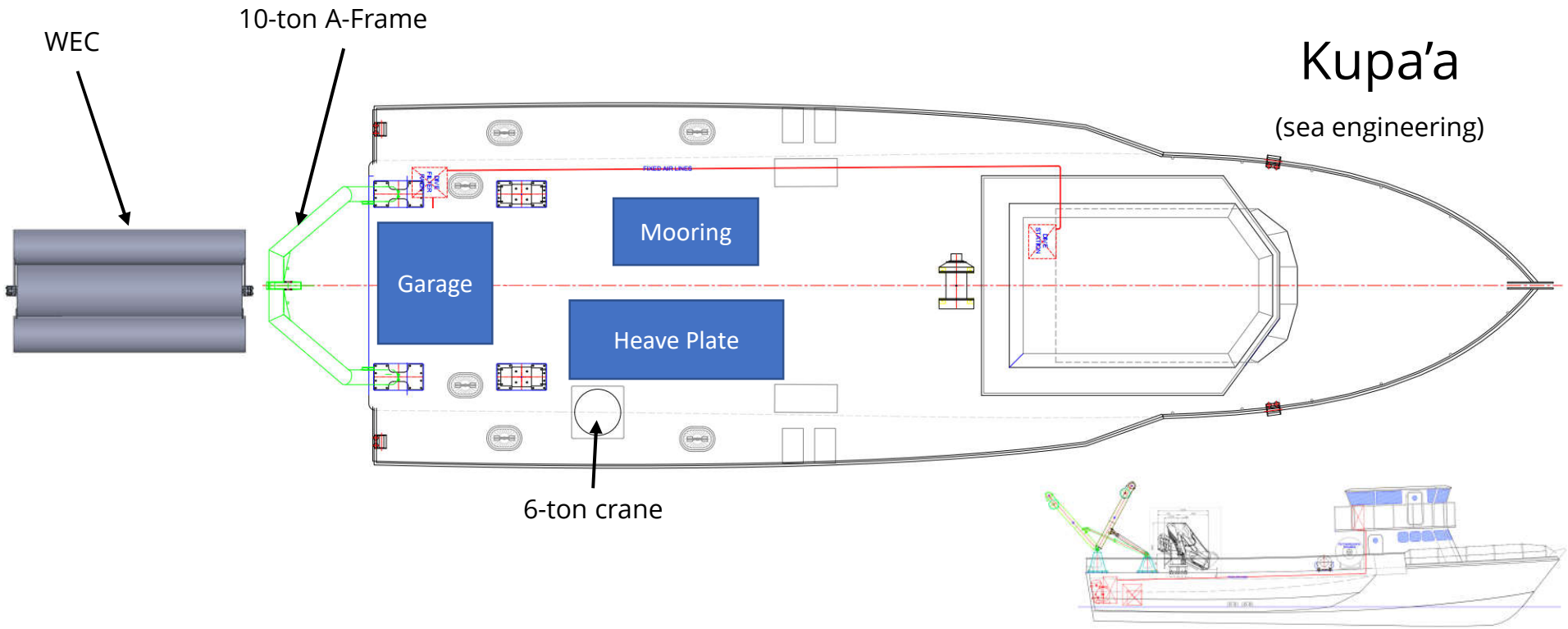


Container #2



CONOPS

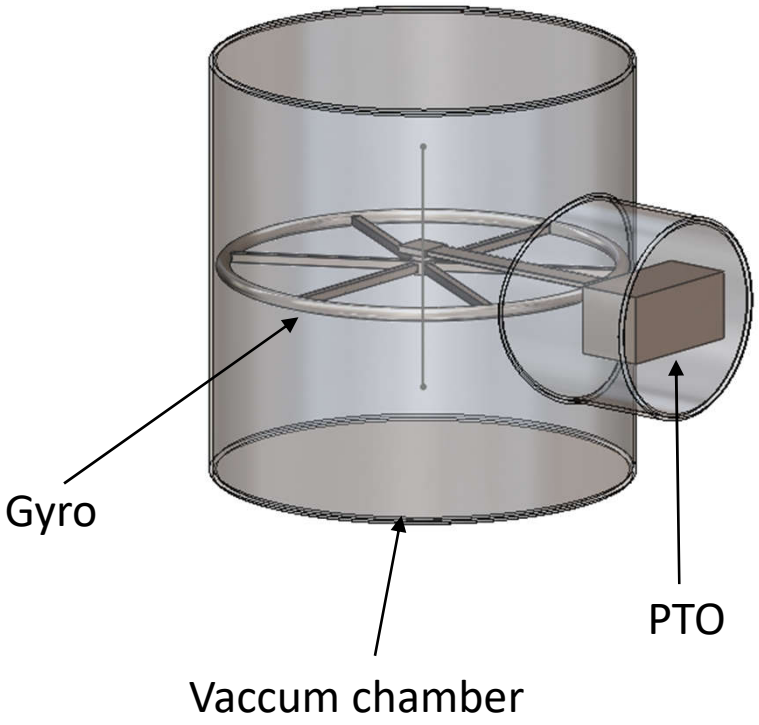
Deployment Configuration



DataRAY Design Considerations

- Auxiliary Power Unit
  - Target 10W Average Power Output
- Hosting WEC
- Self Contained
- Design Life - 2 Years

DataRAY Overview



- Gyro
  - High Speed
    - 3000-5000 RPM
- PTO
  - Low Speed
  - Generator with Gearbox
- Vacuum Enclosure
  - 1e-3 to 1e-5 ATM

DataRAY Bench Test

- NREL to perform bench test
- Objectives
  - Bearing test – effects of non torque loads
    - Break-in
    - Axial load
    - Radial load
    - Moment load
  - Gyro test
    - Windage measurement (torque)
    - Various vacuum levels