DE-EE0007820 Go/No-Go Review Meeting

ADVANCED TIDGEN® POWER SYSTEM

ORPC

May 10, 2018

Meeting Information

ORPC/EE0007820 Go/No Go Review Meeting

Thursday, May 10, 2018

8:30 am | Mountain Daylight Time (Denver, GMT-06:00) | 2 hrs

Meeting number (access code): **903 508 024**

Host key: **451244**

Meeting password: **Y2QmGPHw**

Link to WebEx meeting: start your meeting

Project Contacts

- ORPC
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  - Cian Marnagh, VP Engineering & Program Management
  - Abbey Manders, VP & CFO
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  - Genetta McLean, Grants & Licensing Manager
- DOE
  - Yana Shininger, Technical Project Officer
  - Stephanie Hodge, Senior Management Analyst, III
  - Michael Lawson, Senior Engineer, NREL
  - Steven Dewitt, Technology Manager – MHK
  - William McShane, Technology Manager – MHK

Agenda

1. Overview
2. Design and IO&M
3. Development Tests
4. System Fabrication Plan
5. Risk Management
6. Environmental Monitoring
7. Project Management

Overview

Go/No-Go Criteria

Criteria for approval as defined by the U.S. Department of Energy (DOE):

- Progress toward achieving the goals as stated including the Metric Table (Table 1) in the project's Statement of Project Objectives (SOPO), currently at MOD 0004.
- Completeness in meeting BP1 milestones and deliverables.
- Status of any critical NEPA compliance/holds/permits for BP2 activities.
- Adequate recognition, classification, and mitigation of risk as demonstrated through an updated risk register.
- Reasonableness and justification of ability to meet scope, budget and schedule of future budget periods.

Overview

Project Objectives - SOPO

- **Produce a full-scale design** integrating targeted advanced technologies optimized for subsea operation with improved hydrodynamic performance. Energy generation will be increased by 35% over the baseline.
- **Increase reliability of the structures** and reduce production cost, through composites optimization and accelerated life testing; achieve 20-year service life, 5-year service intervals, 25% reduction of turbine manufacturing cost
- **Implement ORPC's Buoyant Tension Mooring System (BTMS)** for commercial sites to significantly reduce O&M costs by >90% over the TidGen® baseline.
- **Implement ORPC's advanced control strategy** at full scale to achieve sustained maximum power output at all times in a tidal site.
- **Follow a certification protocol** for the Advanced TidGen® Power System. This process will qualify the advanced system at TRL 8 at project end.
- **Verify system design by subsystem tests and a two-month integrated, system deployment** in Cobscook Bay, validating performance gains and verifying functionality in low velocity.
- **Validate the commercial design by a 12-month test in Western Passage**, Maine, verifying system performance and LCOE reduction by >90% over baseline in high velocity.
- **Implement focused environmental monitoring** for the determination of realistic and quantifiable risk thresholds.

Overview

Project Objectives – BP1 Status

- **Completed design of TidGen® 2.0**, with all targeted technology integration. Hydrodynamic efficiency of new turbine is 0.441, a 29% improvement, with a power production increase at rated velocity (2.25 m/s) from a baseline near 85kW to 250kW, a 290% improvement.
- **Composite optimization program**: developed NDI technique capable of fully mapping manufacturing defects throughout the laminate foils, and determined accelerated life testing strategy to compare two resin systems towards achieving a component life greater than 20 years.
- **ORPC has worked with DNV GL to meet all requirements** for achieving a Statement of Feasibility for Technology Qualification, expected received by end of BP1; passed the Design Basis Review.
- **UMaine and ORPC have worked with Adaptive Management Team to identify cost effective monitoring strategies** and a quantitative method to baseline and describe the potential impact on relevant fish and mammal behavior.
- As of the Critical Design Review, **ORPC's LCOE predictions for the Advanced TidGen® Power System are $0.72/kWh,** showing significant progress from the LCOE baseline ($13.58/kWh) and bettering the project target of $0.80/kWh.
- **All milestones and deliverables have been met/are on track for completion** before end of BP1 (*DNV GL letter of support towards Statement of Feasibility)

Overview

Metric Table

Single Device Performance Parameters				
	Baseline System	Targeted System	Improved System	Units
Rated Capacity	0.15	0.3	0.5	MW
Availability	79.0%	92.0%	92.0%	
Transmission Losses	14%	11%	11%	
Theoretical AEP	209	592	633	MWh/year
AEP	142	487	520	MWh/year
Capacity Factor	11%	19%	12%	
Average Electrical Power	0.016	0.056	0.059	MW
Array Performance Parameters				
	Baseline System	Improved System	Improved System	Units
Number of Devices	998	288	269	
Array Efficiency	96%	97%	97%	
Array Rated Capacity	149.7	86.4	134.5	MW
Array AEP	1.36E+05	1.36E+05	1.36E+05	MWh/year
Array Capacity Factor	10%	18%	12%	

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Overview
Metric Table

Cost Parameters (from Cost Breakdown Structure)				
	Baseline System	**Improved System**	**Improved System**	**Unit**
Single Device CAPEX	11,468,676	9,866,432	9,469,850	$
Single Device OPEX	2,896,809	93,917	148,422	$/year
Array CAPEX	4,217,235,234	758,670,777	567,014,916	$
Array OPEX	1,373,953,424	27,047,966	39,959,207	$/year
LCOE Calculations				
	Baseline System	**Improved System**	**Improved System**	**Unit**
Single Device LCOE	29192.46	2381.34	2250.12	$/MWh
Array LCOE	13479.10	801.22	742.37	$/MWh

Overview

Milestones Status

#	Milestone	Milestone Status
1.1	Preliminary hydrodynamic design completed, with CFD models achieving 35% relative increase over baseline turbine performance.	**Completed and meets requirement.**
2.1	Characterization testing of composite material sets completed, with selected composite structure delivering > 20 component life.	**Completed and meets requirement.**
3.1	Mooring system and anchor design completed, with models demonstrating achievement of performance criteria identified during the design process, including stability during installation, operations and retrieval, mitigation strategies covering critical risks such as wave loading, debris, and cable loading and dynamics.	**Completed and meets requirement.**
4.1	Preliminary control system and SCADA design for tidal system operation completed, with control system models supporting capability to maintain maximum power point operation through tidal and turbulence ranges.	***Completed and meets requirement.***
6.1	DNV-GL will have completed a Design Basis Review of the system design per requirements outlined in standards DNVGL-SE-0163 and DNVGL-ST-0164 toward Prototype Certification.	***Partially Completed, On track to meet requirement by end of BP1.***

Overview

Deliverables Status

#	Deliverable	Deliverable Status
D1.1	Preliminary turbine hydrodynamic design, with supporting CFD analysis, structural analysis and design description (Milestone M1.1)	Submitted as D-TID2-1004 Preliminary Turbine Hydrodynamic Design
D1.2	Technical report with final design, supporting CFD analysis, structural analysis, and development plan	Submitted as D-TD20-10144 Technical Report on Final Turbine Design
D2.1	Technical report on composite trade study for chosen material sets	Submitted as D-TD20-10008 Material Set Selection
D2.2	Test report on characterization program, composite testing and selected composite structure (Milestone M2.1)	Submitted as D-TD20-10145 Test Report on Characterization Program
D2.3	Technical report on characterization program, including composite test data, design FMEA for composite structure, material selection, composite design, PFMEA for the composite production process, reliability models, production process control plan and development plan	Submitted as D-TD20-10146 Technical Report on Characterization Program
D3.1	Technical report on deployment and mooring system design requirements and subsystem risk analysis	Submitted as D-TD20-10027 Deployment and Mooring System Preliminary Requirements
D3.2	Technical report on mooring system design, supporting analytical models, and subsystem FMEA (Milestone M3.1)	Submitted as D-TD20-10130 Mooring System Design Technical Report
D3.3	Presentation on all technical work performed, the final subsystem design, supporting analytical models, risk analysis and development plan	Submitted as D-TD20-10187 Deployment and Mooring System Design Presentation
D4.1	Technical report on control system development, supporting simulations and SCADA system requirements (Milestone M4.1)	Submitted as D-TD20-10028 Deployment and Mooring System Preliminary Requirements
D4.2	Final design of control and SCADA system, with supporting simulations and risk mitigation control strategies to address major system technical risks	Submitted as D-TD20-10153 Control and SCADA System Design
D5.1	Submitted applications for required BP2 permits and licenses, NEPA review and acceptance	Submitted with D5.2
D5.2	Technical report on environmental monitoring methods and requirements, with plan for risk reduction throughout service life	Submitted as D-TD20-10186 Budget Period 1: Task 5 Report – Environmental Approach
D5.3	Marine Life Monitoring Plan	Submitted with D5.2
D5.4	Field Test Plans for subsystem and system tests	Submitted as D-TD20-10152 DOE Advanced TidGen® Development Test Plan for BP2
D6.1	DNV-GL documentation supporting completion of Technology Qualification and Design Basis Review towards Prototype Certification (Milestone M6.1)	Fulfilled by submission of this report; a DNV GL letter is included as an appendix of this report supporting completion by end of BP1.
D7.2	Documents for Go/No-Go Decision #1	Submitted as this report.

Advanced TidGen® Project Timeline

Contract Award
(Sep 2016)

ORPC selected for award negotiations

Contract signed Jan 2017, effective Nov 2016. Design work began Jan 2017.

Budget Period 1
(Effective Nov 2016
Began Jan 2017)

BP1: Design

Full system detail design and test planning:

- CDR in Dec 2017
- DOE continuation application in Mar 2018
- DOE approval in Jun 2018

Budget Period 2
(Jul 2018)

BP2: Build & Verify

Field testing:

- Turbine tow testing, Q4 2018, Cobscook Bay
- Anchors, Q2 2019, Western Passage
- Deployment subsystem, Q3 2019
- 2-month system installation, Q2 2020, Cobscook Bay

Budget Period 3
(Sep 2020
Propose Oct 2020)

BP3: Field Validation

12-month installation and operations in Western Passage, Q3 2020 to Q3 2021

Decommissioning
(Oct 2021)

Project complete Q1 2022

Design

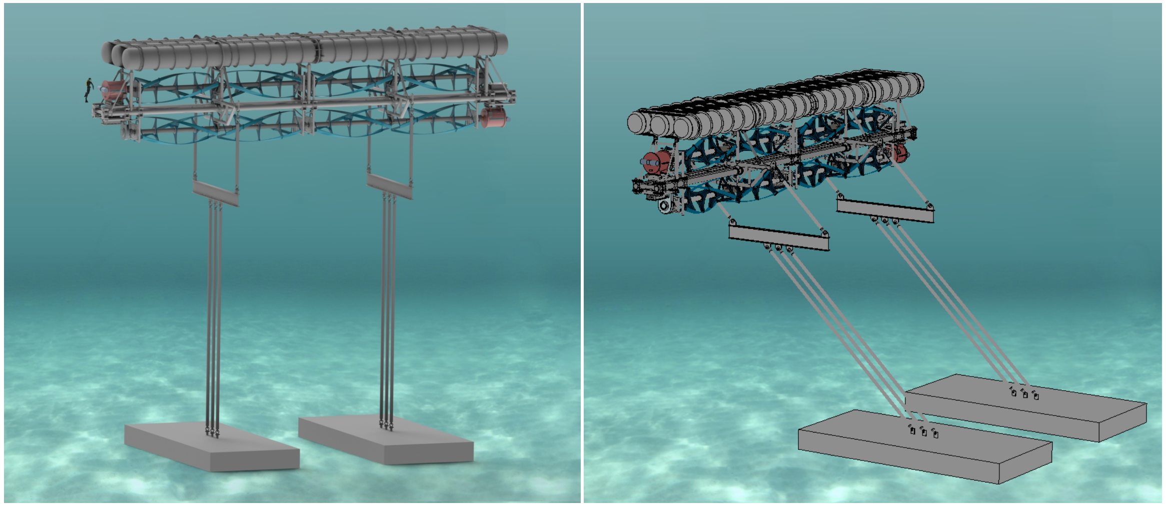
System Overview

Design

Contents

1. System Overview (Task 7)
2. Turbine Design (Tasks 1 & 2)
3. Driveline (Task 3)
4. Chassis and Buoyancy Assembly (Task 3)
5. Mooring System (Task 3)
6. Electrical and Control System (Task 4)
7. IO&M: Deployment and Retrieval System (Task 3)

TidGen® 2.0 Power System
Baseline - Critical Design Review (CDR)

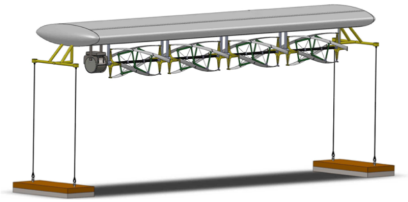


TidGen® 2.0 Device Specifications & Technologies

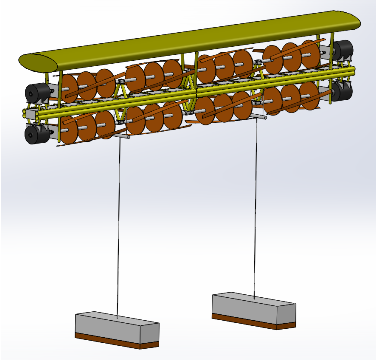
- Dimensions (approx.): 8.8m X 34.6m X 8.2m
- Rated Output at generator terminals: 260kW at 2.25m/s, 500kW at 3.0m/s
- High performing design with C_P 0.441
- System dry weight: 160,000kg (No anchors)
- Buoyant anchor weight:
  - 172,000kg per anchor (X2) Western Passage
  - ○ *Primary drivers are turbine drag loads and low coefficient of friction*
  - ○ *BP2 subsystem testing to begin with turbine barge testing for accurate load assessment, followed by design refinement and anchor evaluation to reduce overdesign, and deployment system to reduce operational risks*

Advanced TidGen® Device

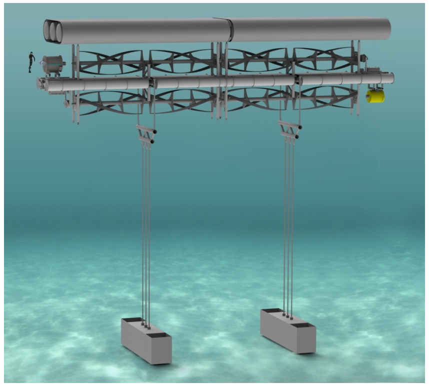
Jan. 2017



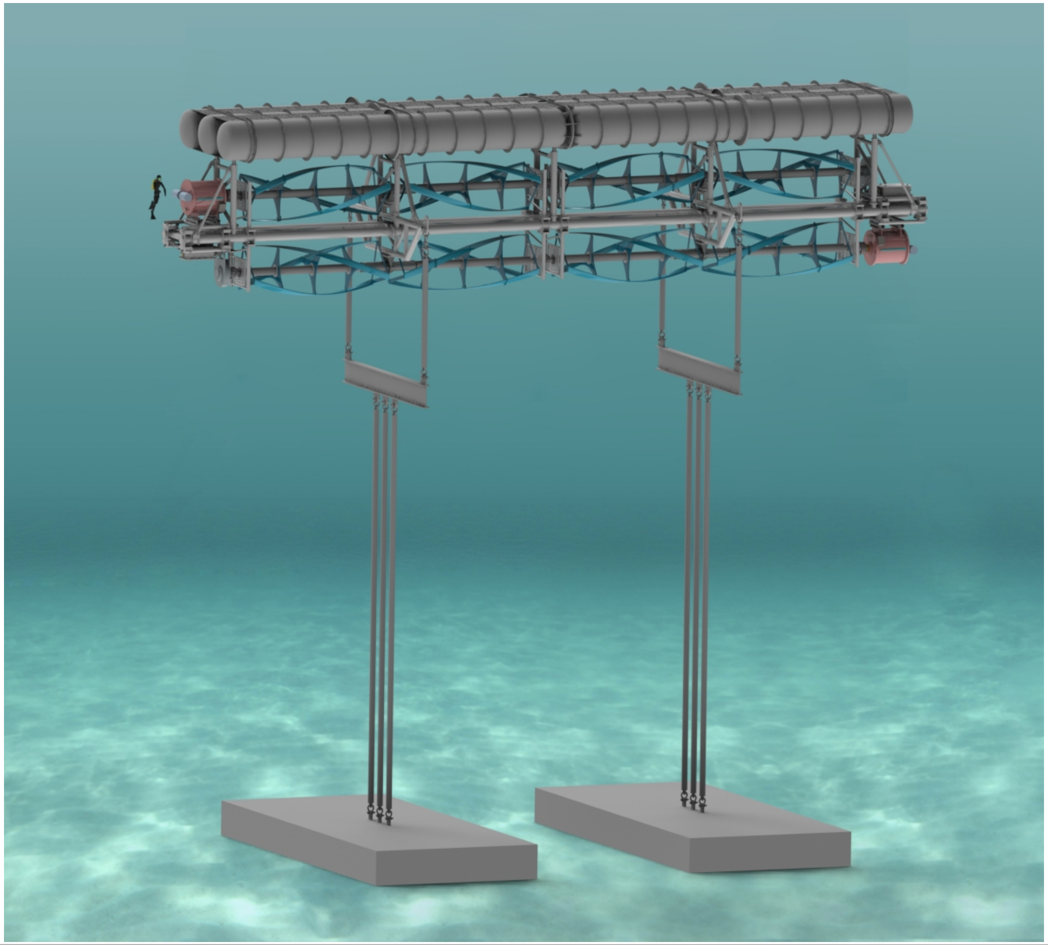
Jun. 2017

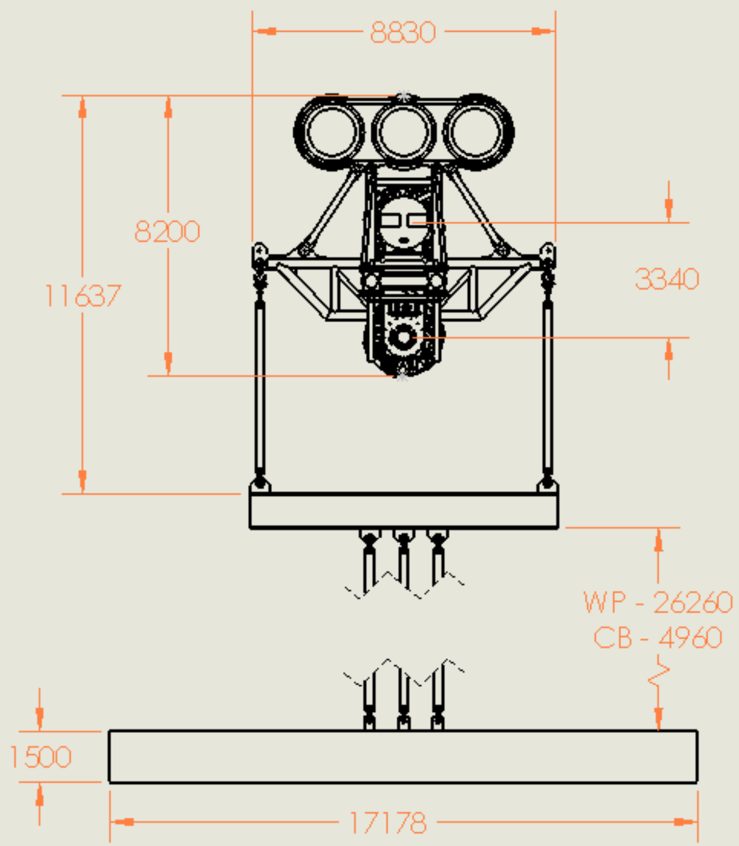


Sep. 2017



TidGen® 2.0 for Western Passage, December 2017 Design





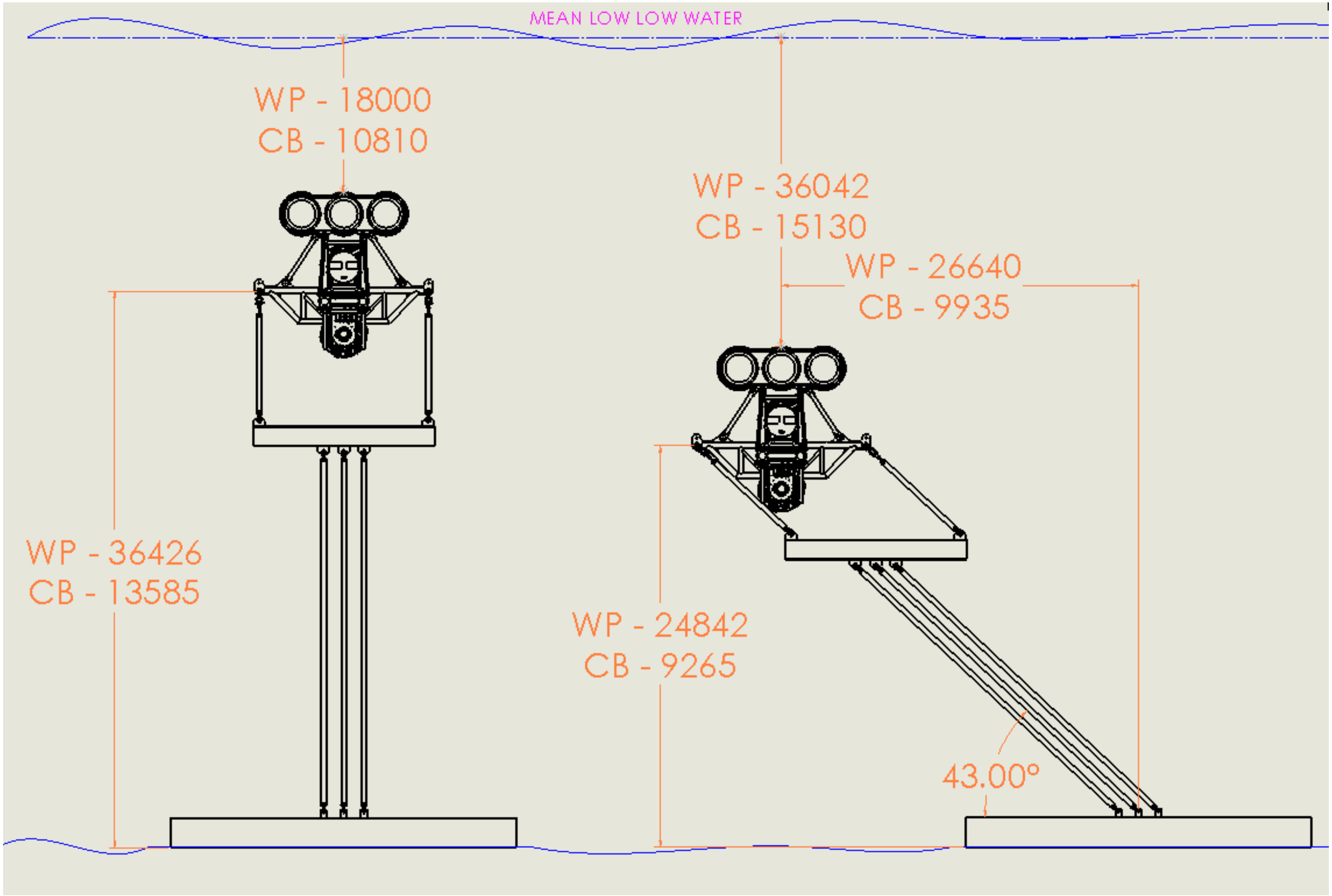
Turbine Diameter - 2.2m
Number of Foils - 3
Solidity - 0.13

TSR, max power - 2
TSR, freewheeling - 3.5

At 2.25 m/s:
RPM, peak power - 39 RPM
RPM, freewheel - 61 RPM

System weight - 160,000kg
System dimensions - 34.6x8.2x8.8m

Anchor weight - 172,000kg
Anchor dimension - 17.2x7.5x1.5m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CB - 9265
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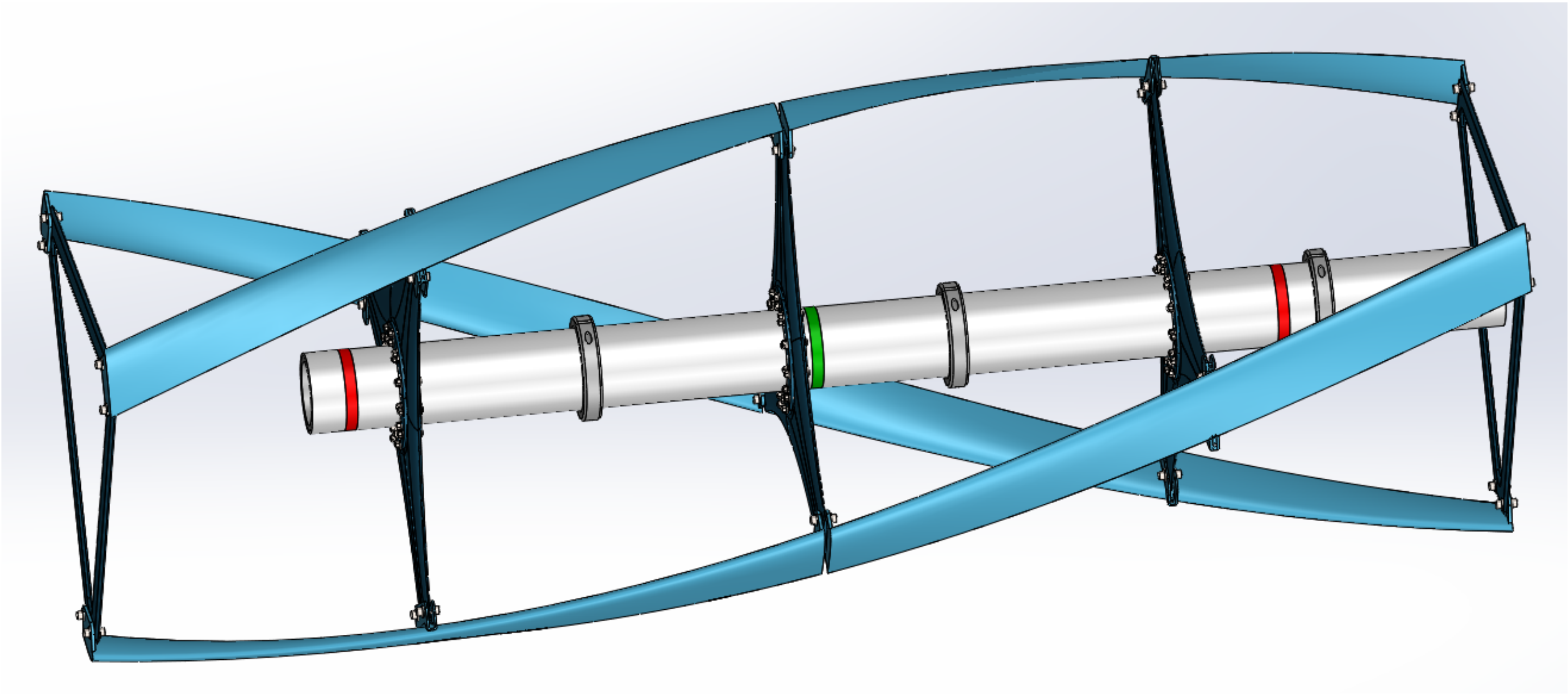
Design

Turbine – Tasks 1 and 2

Design
Turbine



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Design
Turbine - Analyses Performed

- CFD for performance and load estimation (tangential, radial and axial)
  - Qblade, 2D CFD with OpenFOAM, LexCOSS for extrapolating 3D performance; 3D CFD with OpenFOAM
- Structural analyses (FEA) with SolidWorks, Ansys (BlueSource), and CalculiX (open source)

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Hydrodynamic Turbine Loads

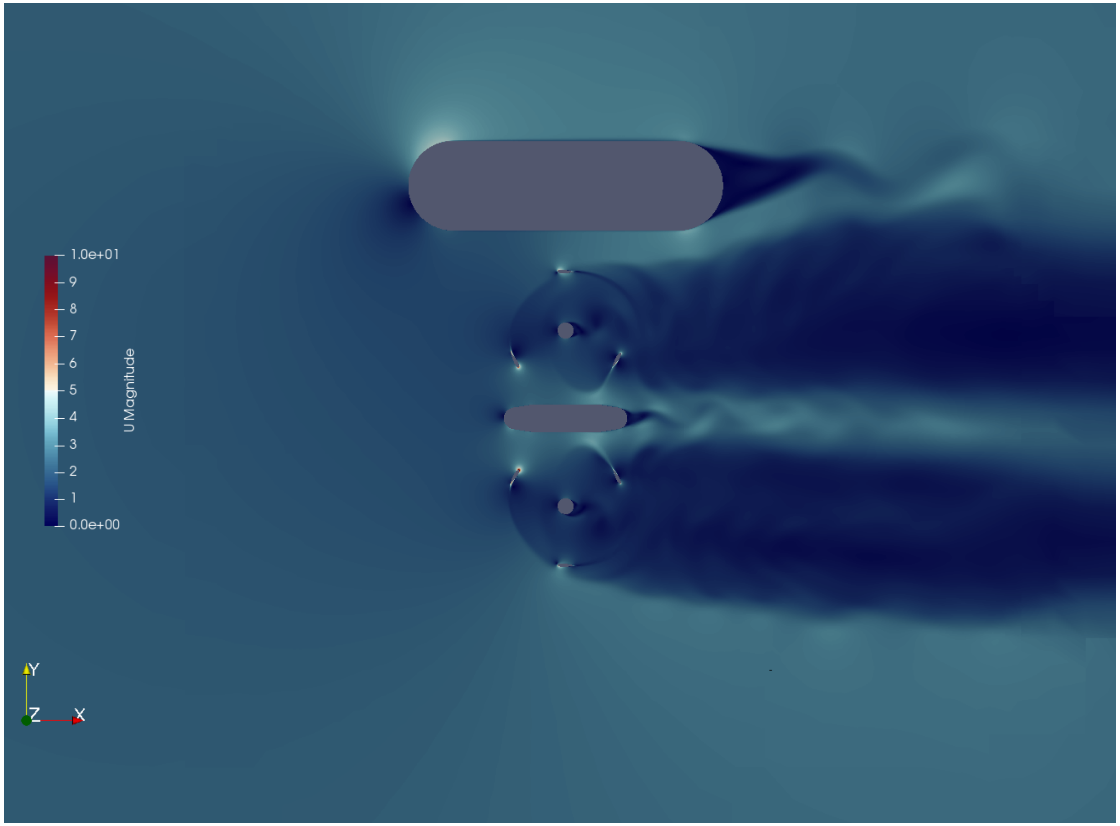
Cp estimates:

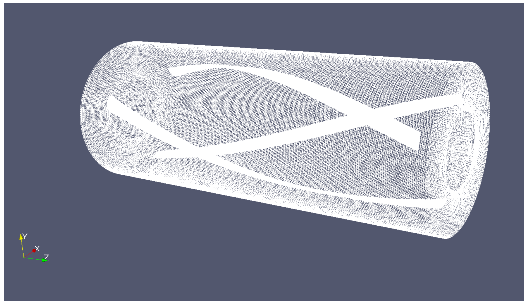
2D estimate – 40.0%

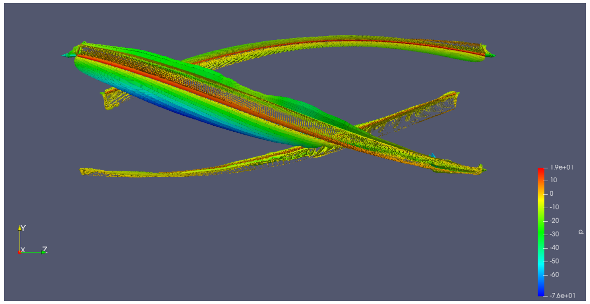
2D LExCoSS post processed

3D estimate – 48.1%

Single 3D turbine with counter rotating est. improvement of 33.7%

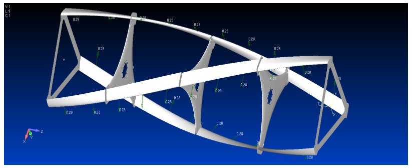




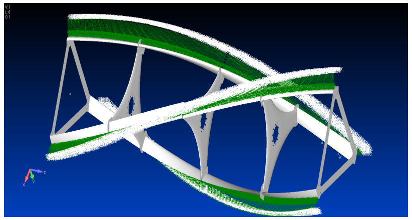


Design

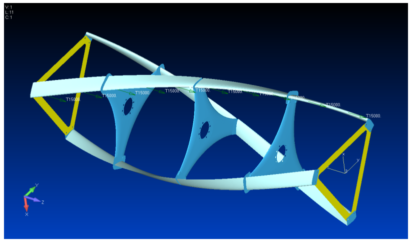
Turbine - Load Analyses



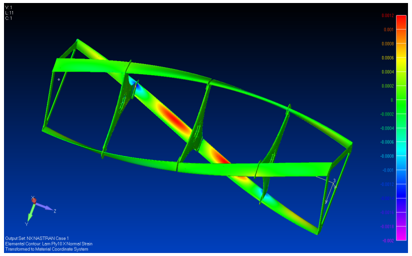
Tangential pressure as line load applied to the leading edge.



Radial Pressure load over 3 chordwise elements (0.0225m chordwise each) approximately at the 1/4 cord. Applied pressure PR=PR(z) * 0.3/(3*0.0225) = PR(z)*(4.44) as the multiplier. Negative pressure is radially inward, applied to the outer surface PR(z)*(-4.44) to get inward force.



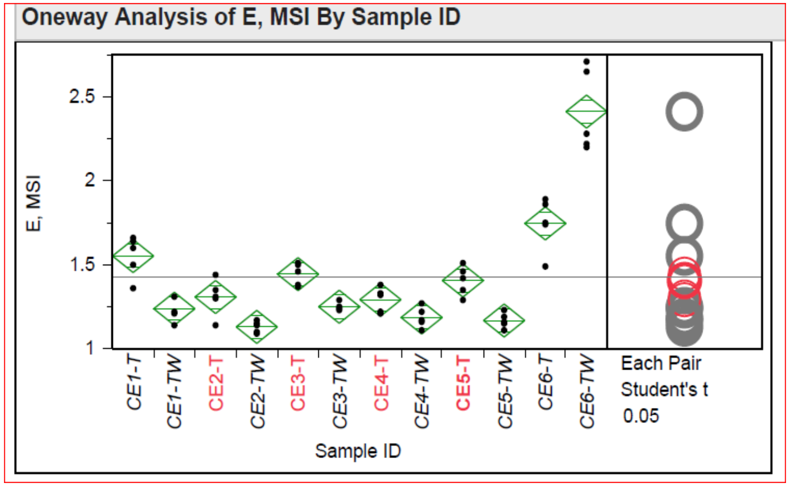
Maximum foil axial load is taken as 10% of the maximum single foil normal load of 150,000N, yielding 15,000N, applied as a line load on the foil leading edge.

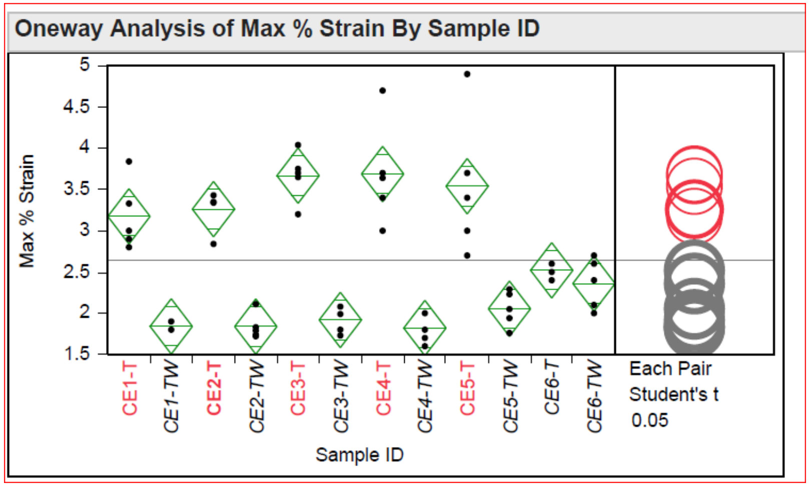


X-Direction strain – underside view

Design

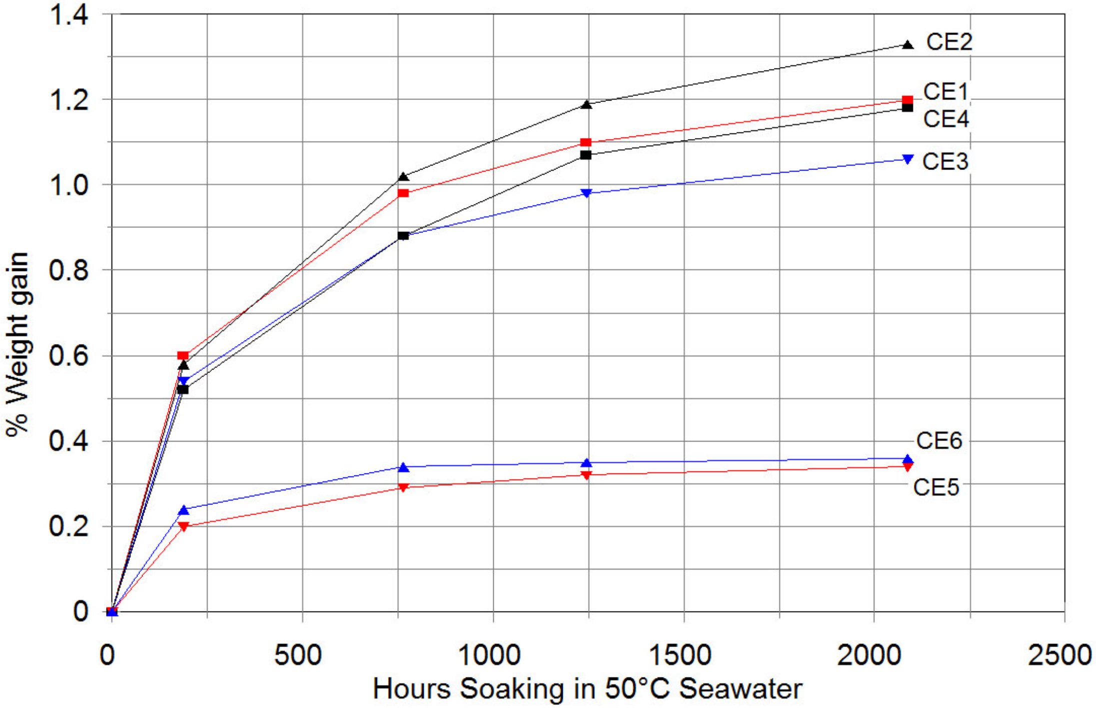
Turbine - Composites

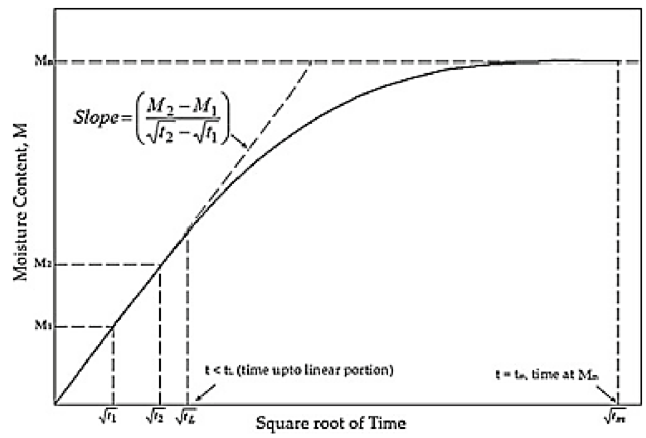




Design

Turbine – Composites, Material Set Saturation





Design

Turbine - Composites, Testing

1. Fundamentally the moisture soak in this accelerated testing induced change to the mechanical behavior of the laminate.
2. Results suggest that either the Carbon fiber and its associated coupling agents are more susceptible to moisture ingress and disbanding, or that the fiber itself absorbs moisture and therefore weakens the structural properties of the laminate in the salt water emersion environment.
4. Belief that the diffusion rate of moisture is higher when the composite laminate is under stress, then these static emersion tests do not fully identify the detrimental effects of moisture absorption. Further testing will explore:

a) Resin Chemistry
b) Reinforcement behavior and absorption characteristics
c) coupling agent robustness, stability, and compatibility
d) Laminate Coating (in mold and secondary application) to control moisture ingress, biological growth and mechanical wear and degradation
e) Mechanical stress induced degradation under sea water

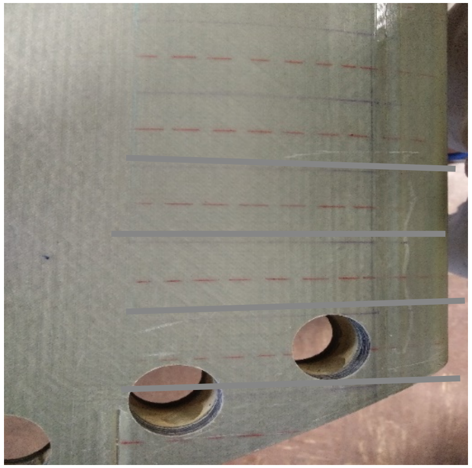
Design

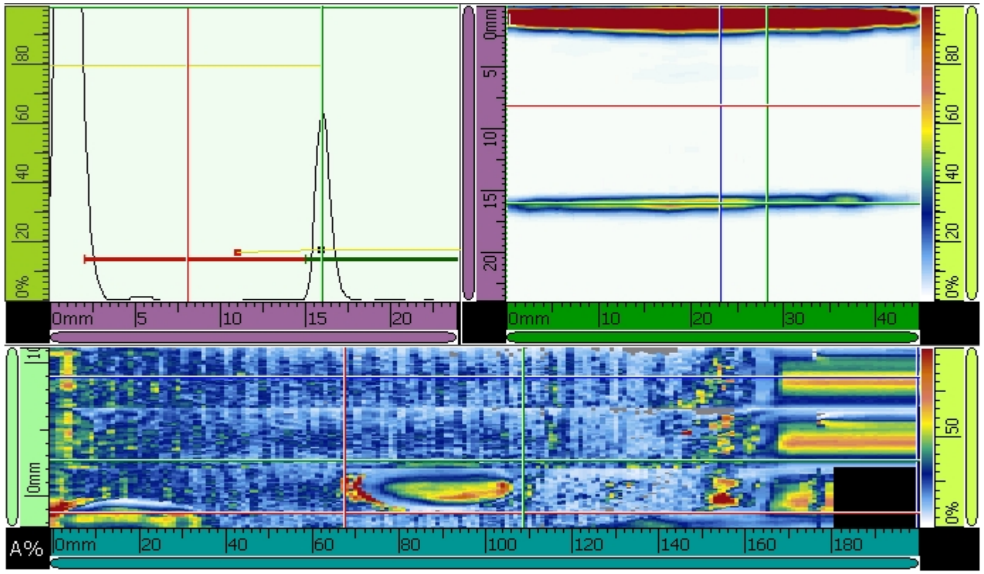
Turbine - Composites

- Project targets creating S-N curves to calculate cycles to failure and percent damage to estimate the total damage over the project life of 20 years.
- Currently composite coupon fatigue data from DOE MHK Composites program is not adequate to produce an S-N curve due to gaps in the data.
- As the characterization program continues these gaps will be closed and a high-quality S-N will be produced for the chosen material set.

Design

Turbine – Composites NDI



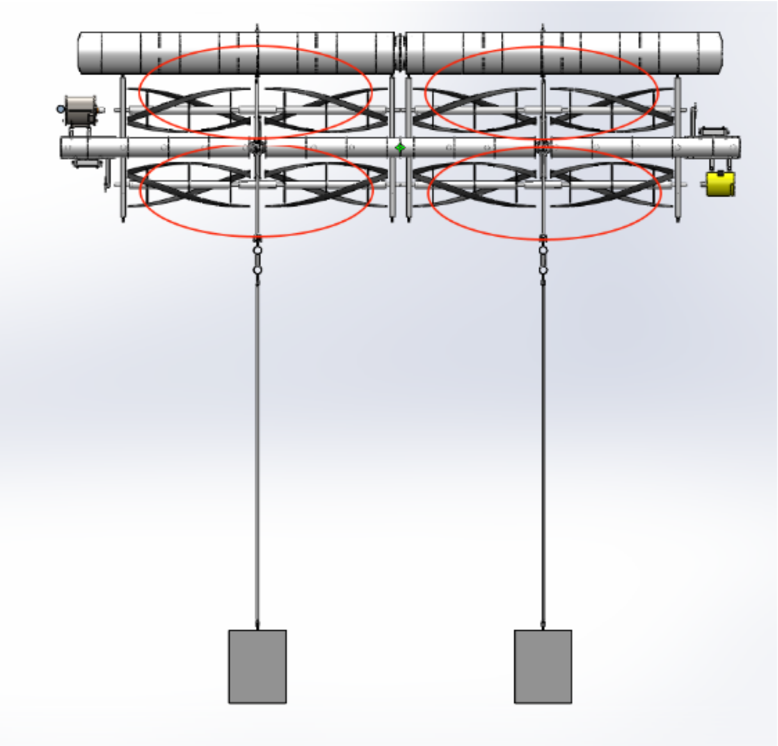


Design

Driveline – Task 3

Driveline Overview

Functional Description & Performance

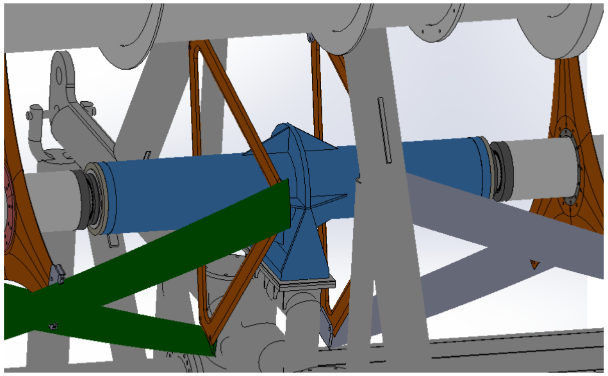


Overall Design

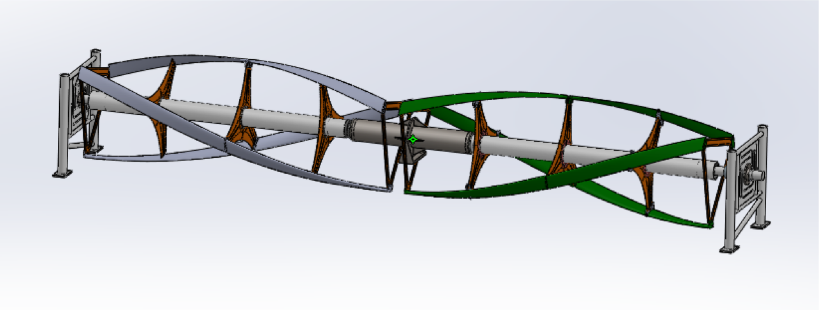
- Performance: >5 year life with <5% power loss.
- Driveline sections consist of two turbine pairs – 4 total.
- Overall system design concept mirrors the "PTO Driveline Test System":
  - Mid-bearing assembly constrains turbines radially and axially
  - End-bearing constrains radially and allows for axial movement and does not over-constrain.
- Turbines rows are interconnected by flexible couplings to allow for axial and radial misalignment.
- Complex loading, system flexure, combined with high-cycle count; make driveline design difficult – conservative design necessary for 20 yr life.

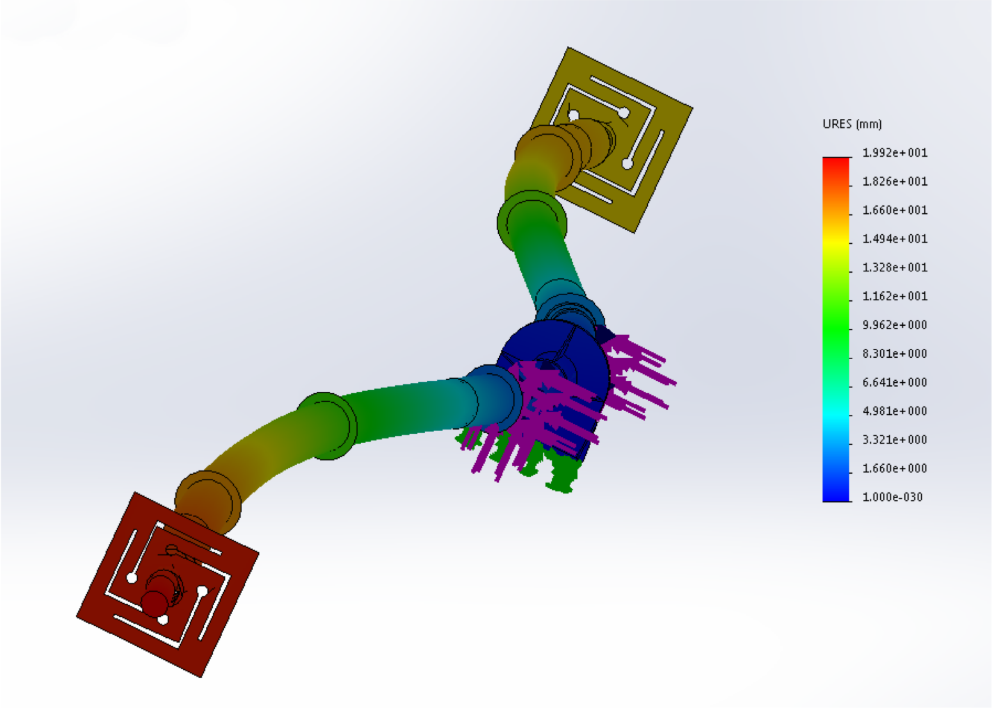
Driveline Overview

Present Design



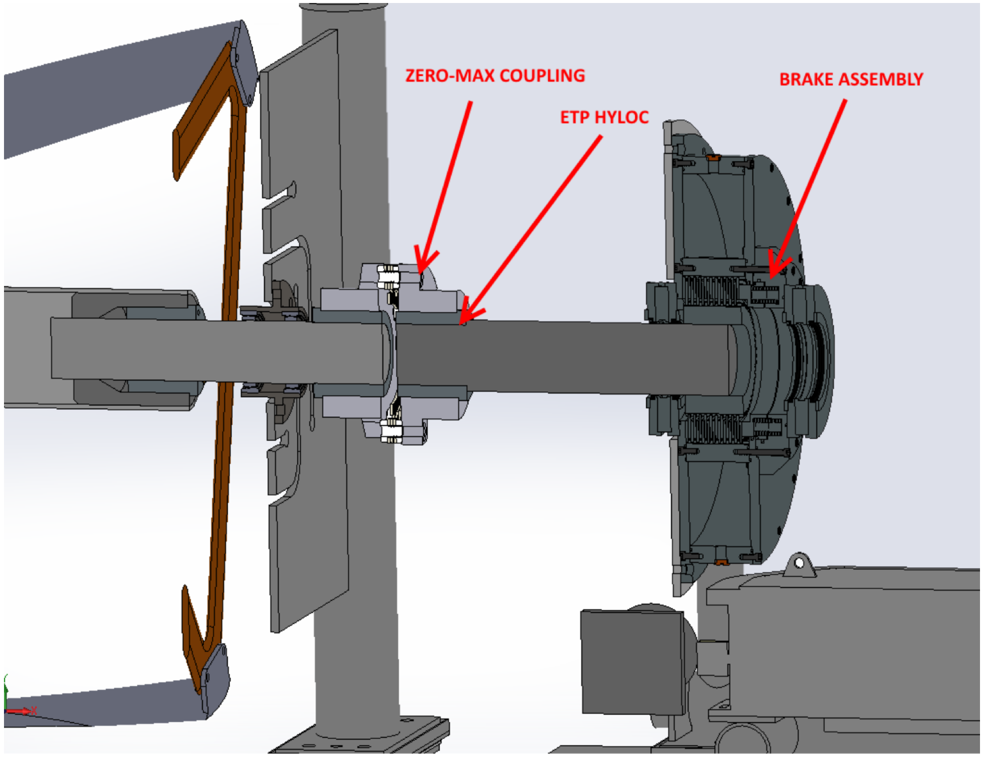
- Mid-Bearing Stanchion extended to reduce bending loads on center stanchion and driveline tube.
- Turbines cantilevered over bearing housing.
- Can handle asymmetric loadings





Brake Interface Details

Specifications



Turbine to Brake Connection

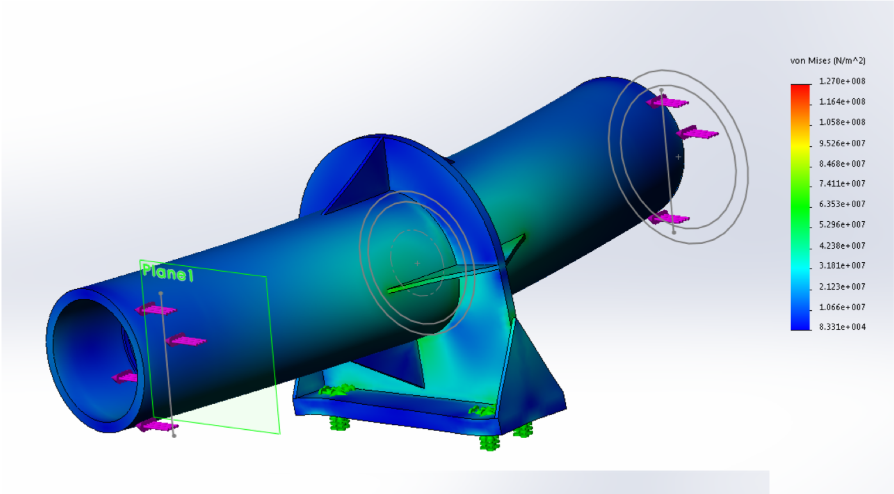
Standard ETP and Zero Max coupling used with custom interface.

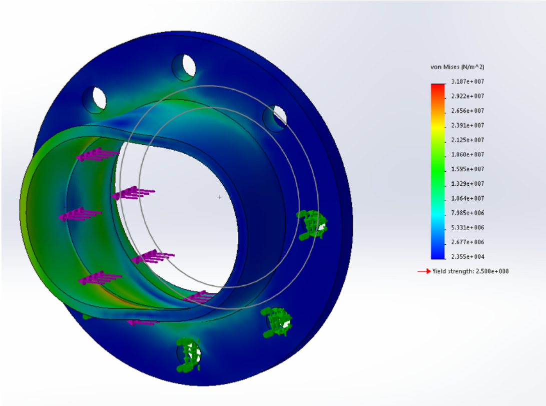
Brake design is ongoing.

•45 kNm torque rating
•180mm Turbine Shaft
•180mm Brake Shaft
•Angular deflection and misalignment within limits.

Analysis Overview

Driveline Component Analysis





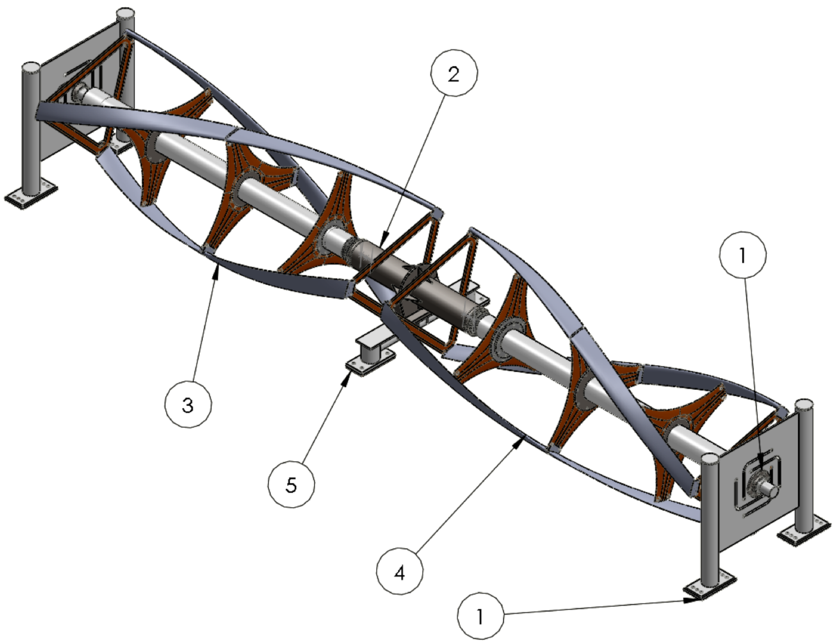
FEA Analysis

Bearing housings have been reviewed, pass initial screens for strength under freewheel operation.

Corrosion Protection

Corrosion protection strategy - PCD Bearings

Remainder of system will utilize traditional epoxy coating system and supplemental cathodic protection.

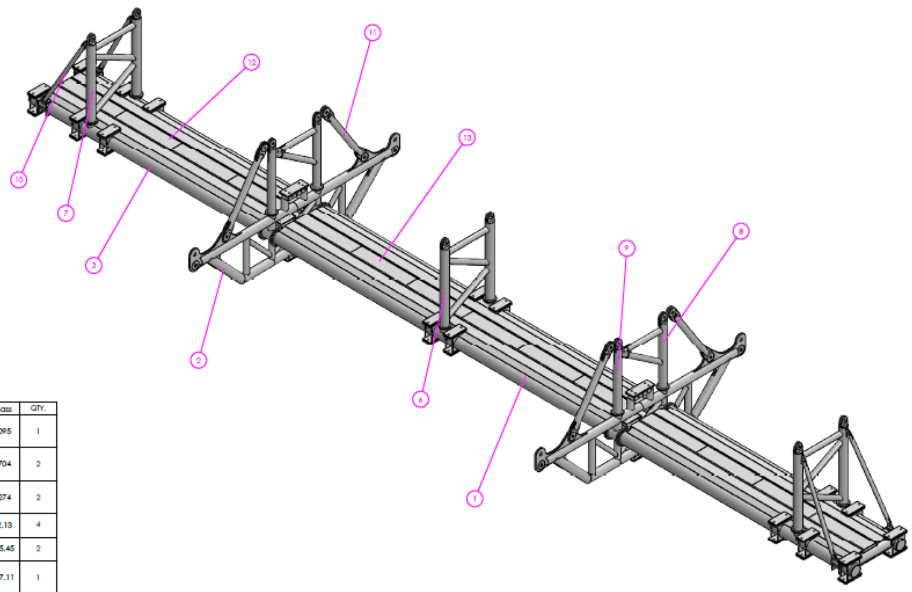


Design

Chassis, Buoyancy and Structural Assembly – Task 3

Subsystem Overview

Subsystem Components



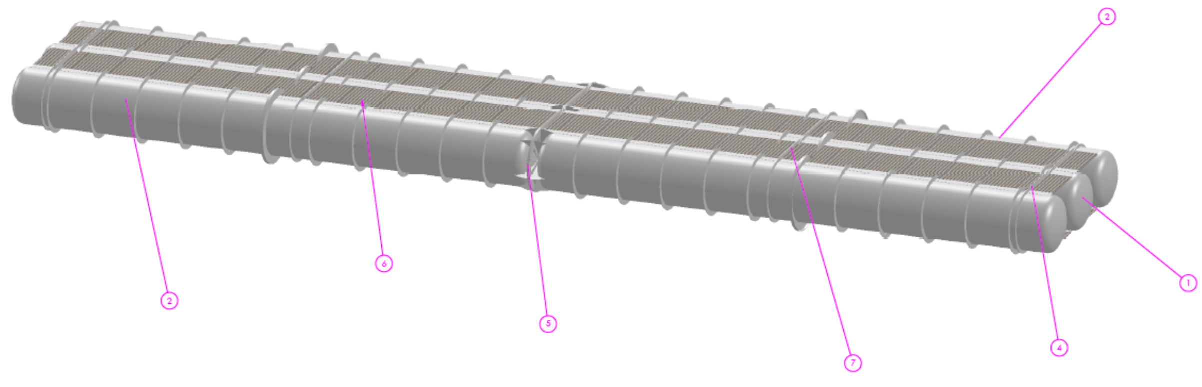
ITEM NO.	PART NUMBER	DESCRIPTION	Material	Mass	QTY.
1	A-TD20-10086 - Core Chassis Frame - MIDDLE	CORE CHASSIS FRAME - MIDDLE	ASTM A500 (TUBE) GRADE B	8095	1
2	A-TD20-10078 - Chassis Mooring Mount	CHASSIS MOORING MOUNT	ASTM A500 (TUBE) GRADE B	3704	2
3	A-TD20-10085 - Core Chassis Frame - END	CORE CHASSIS FRAME - END	ASTM A500 (TUBE) GRADE B	5274	2
4	P-TD20-10087 - Chassis Fairing Bottom Panel 01	CHASSIS FAIRING BOTTOM PANEL 01	HDPE	72.13	4
5	P-TD20-10090 - Chassis Fairing Bottom Panel 02	CHASSIS FAIRING BOTTOM PANEL 02	HDPE	105.45	2
6	A-TD20-10080 - Chassis BP Connection Frame 01	CHASSIS BP CONNECTION FRAME 02	ASTM A500 (TUBE) GRADE B	747.11	1
7	A-TD20-10080 - Chassis BP Connection Frame 01	CHASSIS BP CONNECTION FRAME 01	ASTM A500 (TUBE) GRADE B	753.23	2
8	A-TD20-10082 - Chassis BP Connection Frame 03	CHASSIS BP CONNECTION FRAME 03	ASTM A500 (TUBE) GRADE B	479.83	2
9	A-TD20-10083 - Chassis BP Connection Frame 04	CHASSIS BP CONNECTION FRAME 04	ASTM A500 (TUBE) GRADE B	357.70	2
10	P-TD20-10084 - Generator Support Spar	GENERATOR SUPPORT SPAR	ASTM A500 (TUBE) GRADE B	92	4
11	P-TD20-10079 - Mooring Support Spar	MOORING SUPPORT SPAR	ASTM A500 (TUBE) GRADE B	224	4
12	P-TD20-10088 - Chassis Fairing Top Panel 01	CHASSIS FAIRING TOP PANEL 02	ASTM A709 GRADE 36T2	46.39	16
13	P-TD20-10088 - Chassis Fairing Top Panel 01	CHASSIS FAIRING TOP PANEL 01	ASTM A709 GRADE 36T2	46.03	12

Critical Changes Since PDR:

- Increased reliance on BP for “assisted” rigidity
- Separation of driveline stanchions and BP connection frames
- Removal of “strap-on” buoyancy
- Reduced “height”
- Increased width for stiffness
- Raised mooring connection frame to center of drag
- Increased mooring connection frame span to mitigate chain interference

Subsystem Overview

Subsystem Components



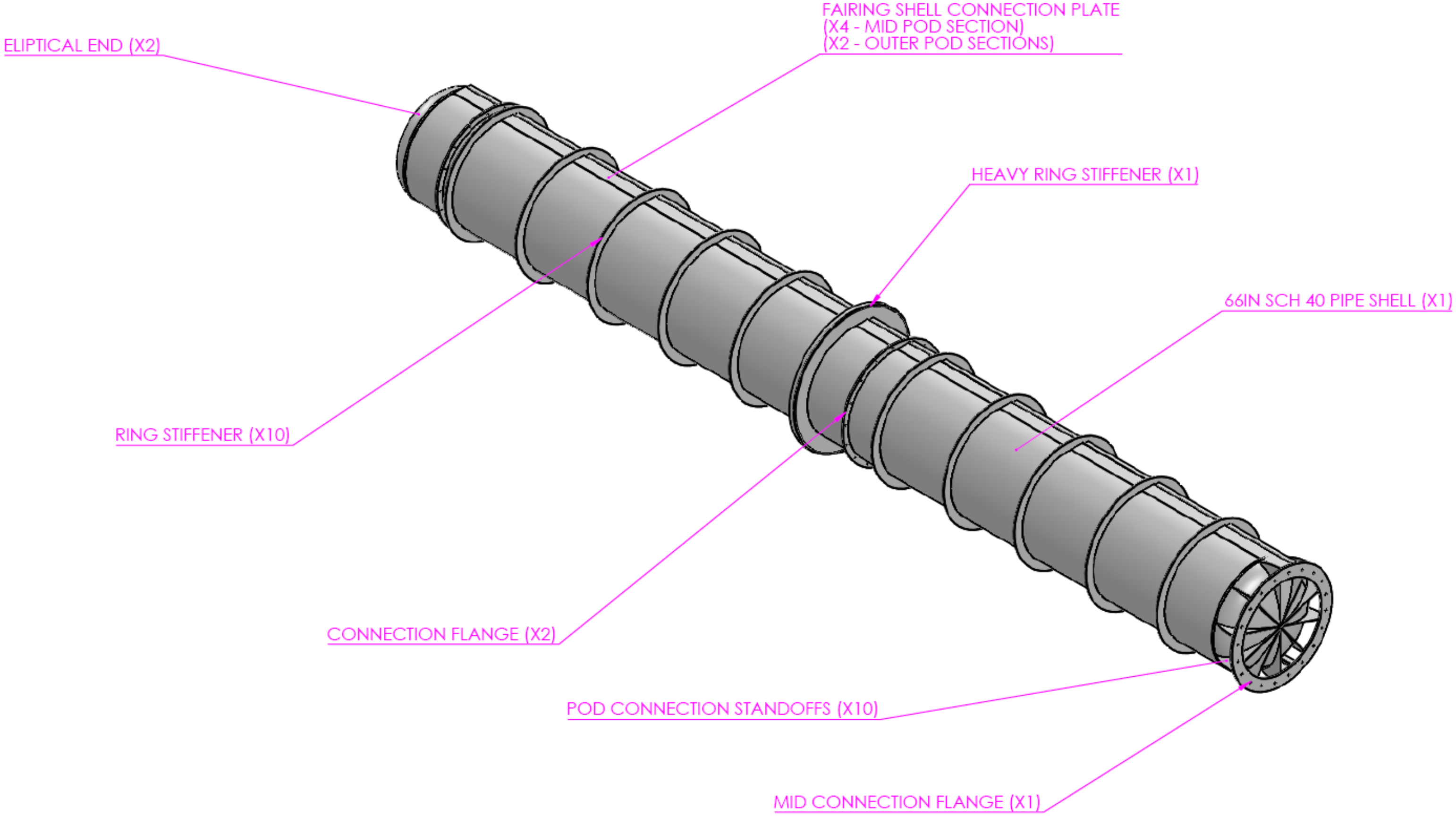
ITEM NO.	PART NUMBER	DESCRIPTION	Material	Mass	QTY.
1	A-TD20-10071 - Buoyancy Pod Pipe Assembly - Middle	BUOYACY POD PIPE ASSEMBLY - MIDDLE	ASTM A106 GRADE B	8979.74	2
2	A-TD20-10071 - Buoyancy Pod Pipe Assembly - Middle	BUOYACY POD PIPE ASSEMBLY - OUTER1	ASTM A106 GRADE B	8757.03	2
3	A-TD20-10071 - Buoyancy Pod Pipe Assembly - Middle	BUOYACY POD PIPE ASSEMBLY - MIDDLE	ASTM A106 GRADE B	8757.03	2
4	P-TD20-10074 - BP Connection Plate 01	BP Connection Plate 01	ASTM A709 GRADE 36T2	259.15	4
5	P-TD20-10076 - BP Connection Plate 03	BP CONNECTION PLATE 03	ASTM A709 GRADE 36T2	571.14	1
6	P-TD20-10077 - BP Fairing Plate 01	BP FAIRING PLATE 01	ASTM A36 Steel	16.38	108
7	P-TD20-10075 - BP Connection Plate 02	BP CONNECTION PLATE 03	ASTM A709 GRADE 36T2	292.04	4

Critical Changes Since PDR:

- Extended length to support generator weight
- Connected pods to provide stiffness for chasses
- Elliptical ends to reduce local stresses
- Reduced pod-pod connections
- Flanged plate connections to chassis & between pods

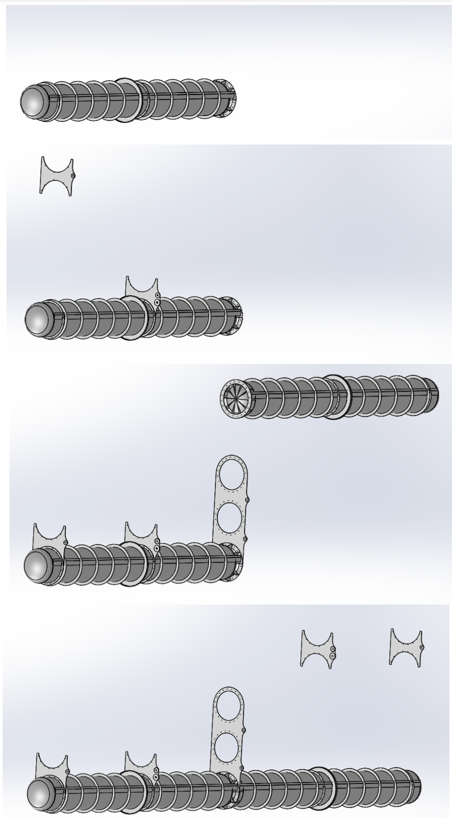
Subsystem Overview

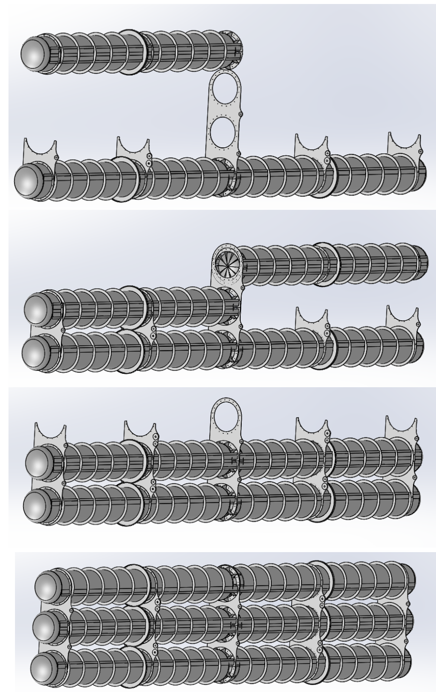
Dimensions – A-TD20-10071 & A-TD20-10072 (MAIN PIPE SECTIONS)



Assembly, Installation, & Maintenance

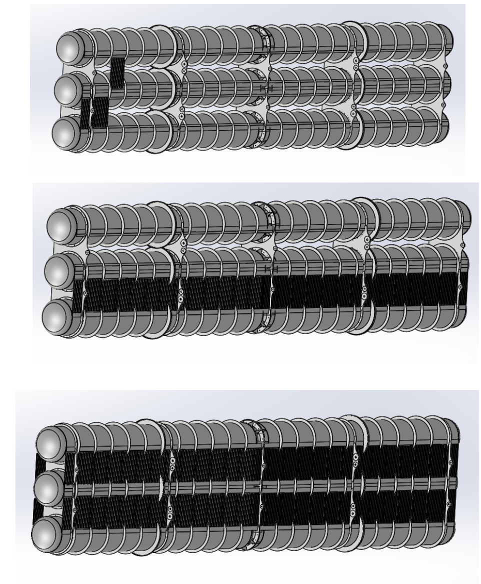
Subsystem Assembly Strategy





ASSEMBLY MAIN STRUCTURE

1. Each pipe section can be lifted with local equipment.
2. Sections are bolted together
3. Assembled pods CAN NOT be lifted
4. Assemble in required orientation for System Integration



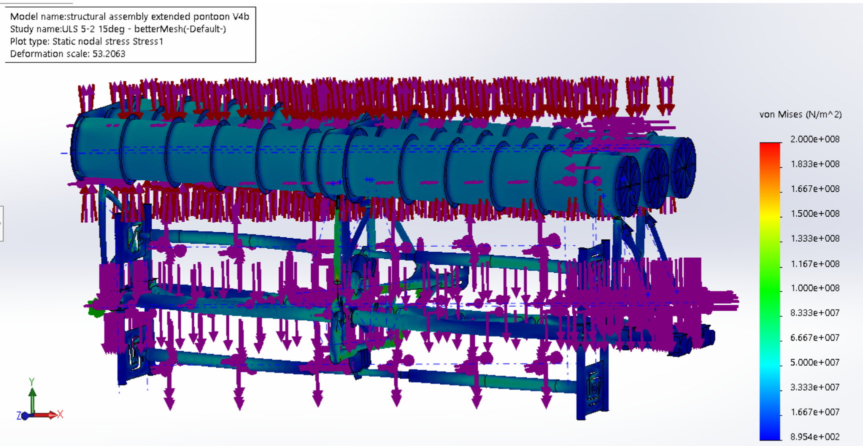
ADD FAIRING PANELS

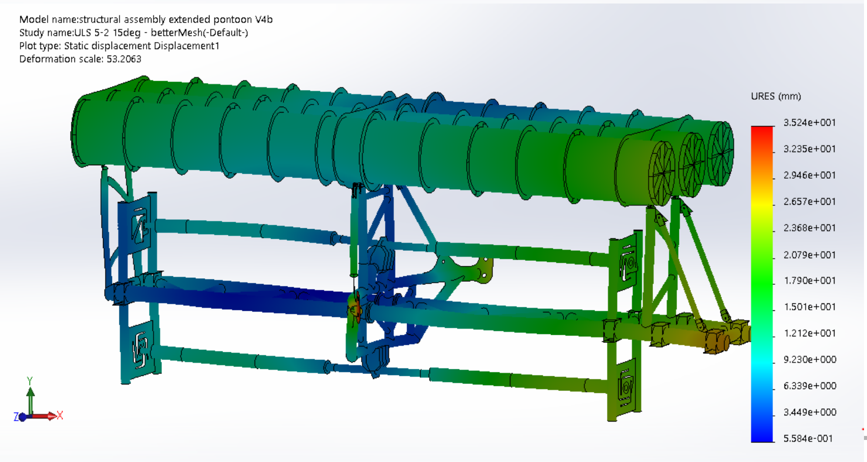
1. Panels can be handled by hand or with local equipment
2. Panels are screwed? Into place (**~2600 screws!!!!**)

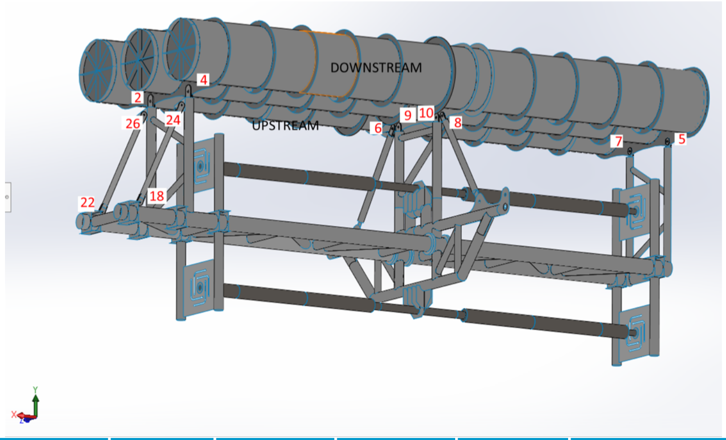
Analysis Overview

Critical Results: Structural Assembly

EXAMPLE: ULS 5.2-15deg







radial [kN]	force angle	Type	Resultant	X-Component	Y-Component	Z-Component	Connector
208	14.82681	Shear Force (N)	2.08E+05	0	-2.01E+05	-53178	Pin Connector-2
61	-6.90057	Shear Force (N)	60825	0	-60385	7308	Pin Connector-4
14	-3.34841	Shear Force (N)	13529	0	13506	-790.2	Pin Connector-5
45	14.97138	Shear Force (N)	44791	0	43270	11571	Pin Connector-7
5	-82.8909	Shear Force (N)	4821.1	0	-596.65	4784	Pin Connector-9
244	-5.42633	Shear Force (N)	2.44E+05	0	2.43E+05	-23063	Pin Connector-10
28	1.20E+04	Shear Force (N)	27852	-11971	25148	0	Pin Connector-18
40	1.70E+04	Shear Force (N)	39671	17049	-35820	0	Pin Connector-22
28	1.20E+04	Shear Force (N)	27852	11971	-25148	0	Pin Connector-24
40	1.70E+04	Shear Force (N)	39671	-17049	35820	0	Pin Connector-26
389	-36.0684	Shear Force (N)	3.89E+05	0	3.15E+05	-2.29E+05	Pin Connector-6
142	35.93933	Shear Force (N)	1.42E+05	0	1.15E+05	83323	Pin Connector-8

Design

Mooring System – Task 3

TidGen® Moorings

Project Overview

Cobscook Bay

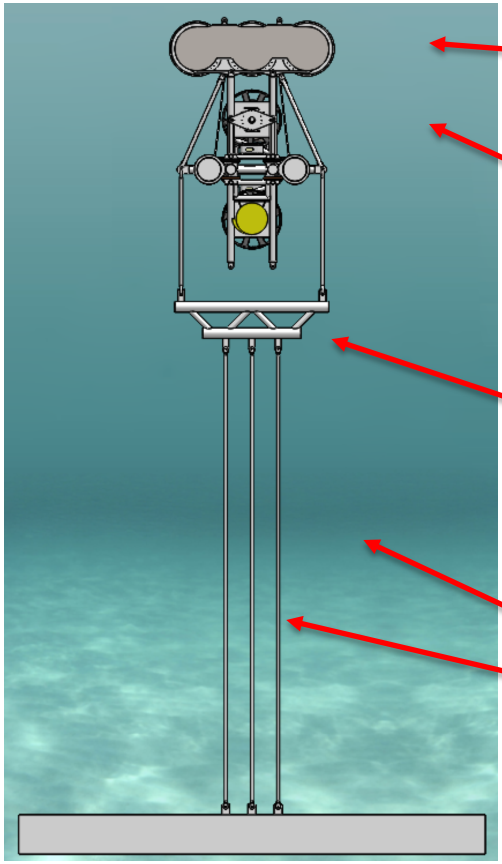
- Mooring system and anchors rated for 2.25m/s
- Drag and lift values for turbines taken from LExCoSS and no additional correction
- Deployment and subsystem testing used to verify CFD results for Western Passage deployment.

Western Passage

- Mooring system and anchors rated for 3.5m/s
- Drag and lift values for turbines taken as measured values from subsystem testing and from CB deployment.
- Anchors and moorings are inexpensive compared to heavy lift operations required if using CFD at face value.

Mooring Assembly

High Level Overview



Bridle Line
2-3/4” Chain

Limit state	Load factor	Risk	
		Normal	High
ULS	γ_{mean}	1.30	1.50
ULS	γ_{dyn}	1.75	2.20
ALS	γ_{mean}	1.00	1.00
ALS	γ_{dyn}	1.10	1.25

Rigid Bridle
Fabricated I-Beam or HSS Truss

Primary Line
2-3/4” Chain

Redundant Line
2-3/4” Chain (1 link longer than Primary Line)

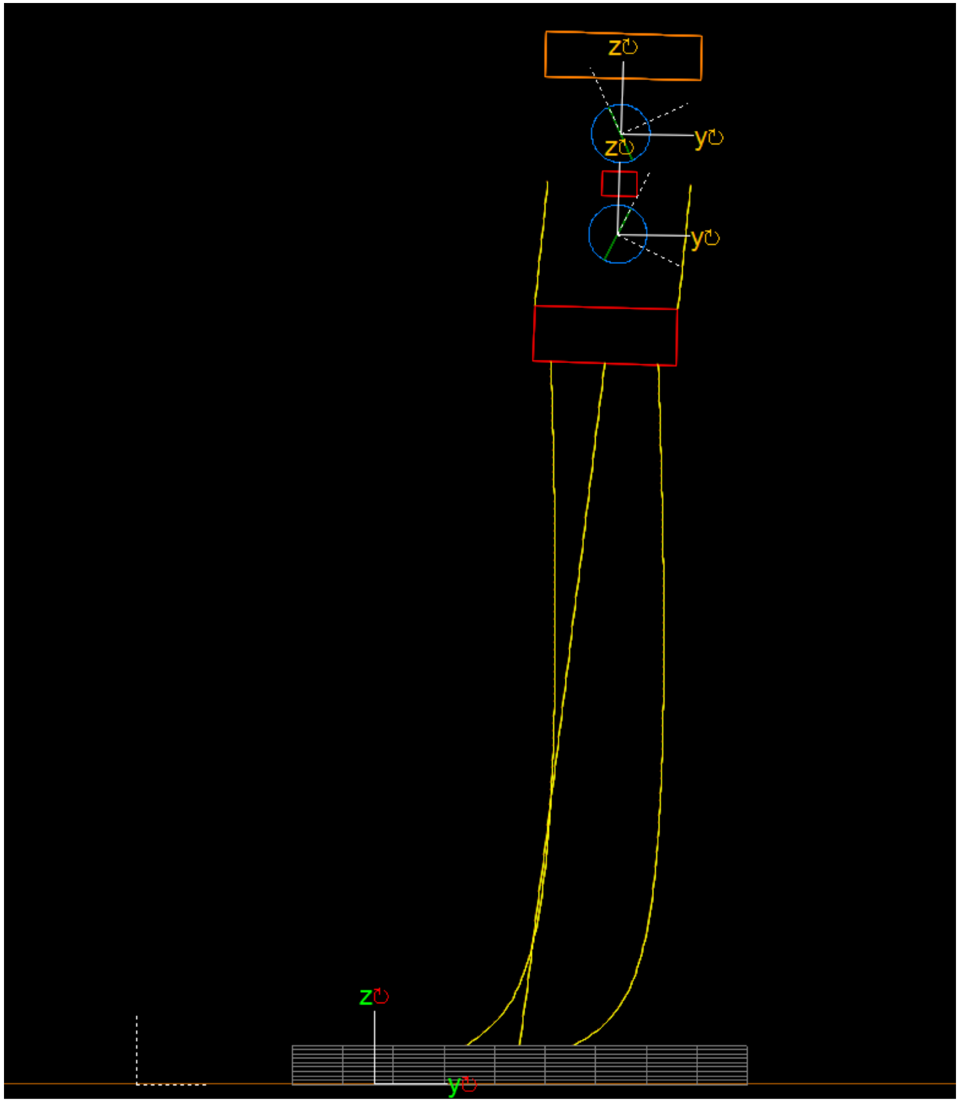
ORPC

Analysis Overview

Critical Results: Line Clashing

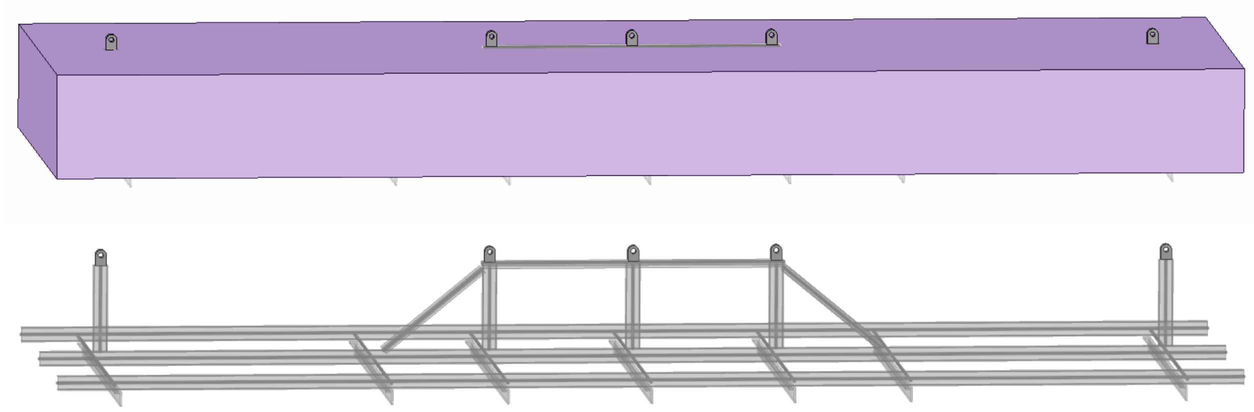
- Adding a rigid spreader bar, connected from each redundant line to the primary line, to ensure that there is always space between the lines
- Increasing the separation distance between the anchor connection points of the redundant lines and the primary line

Possible that aft line touches down on anchor



Subsystem Overview

Anchor Design



Dry Weight: 463 ton
Buoyant Weight: 246 ton

Anchor Weight	2,400kN
Length	17.2m
Width	7.5m
Height	1.5m

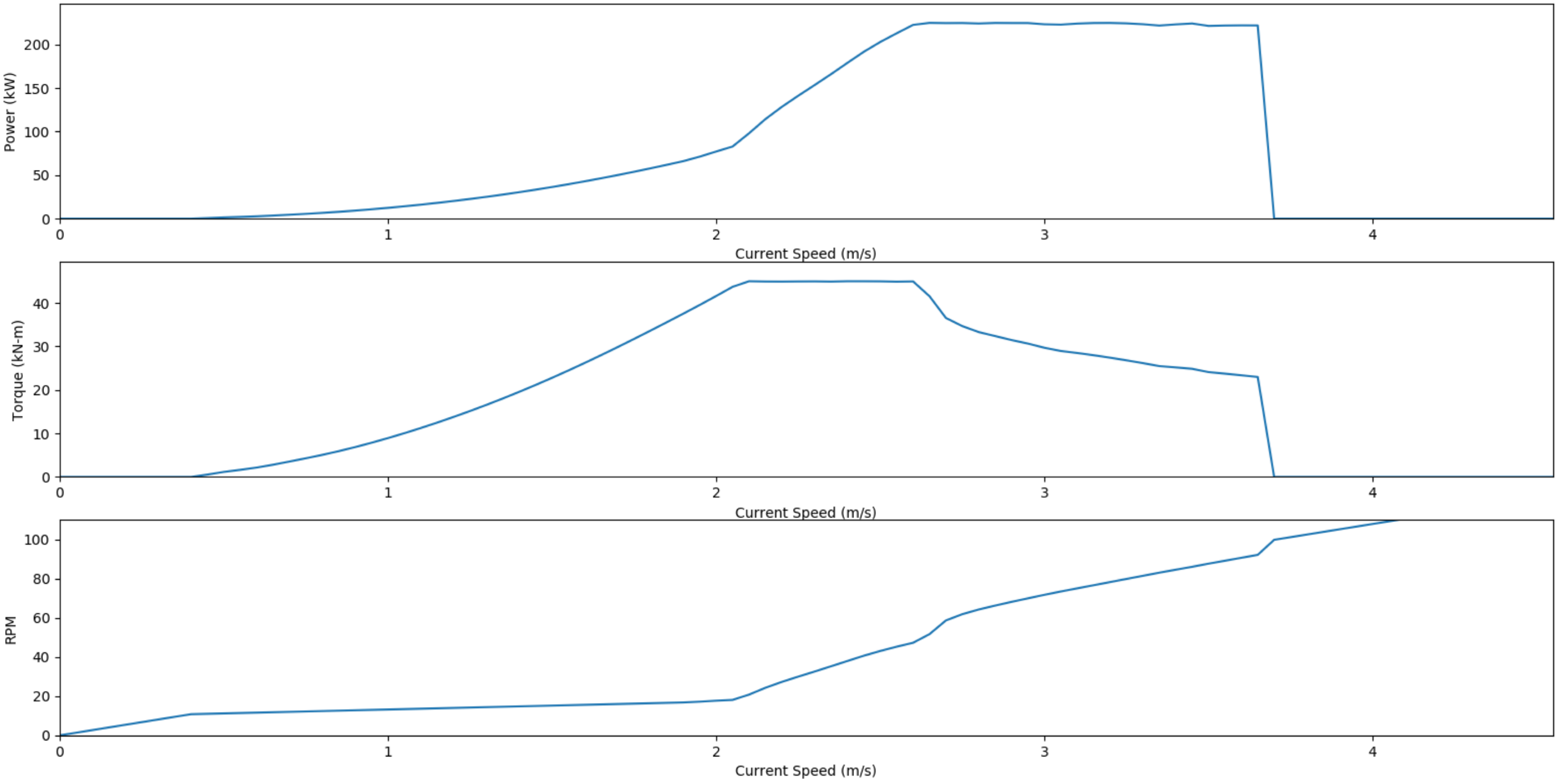
Design

Electrical and Control System – Tasks 3 and 4

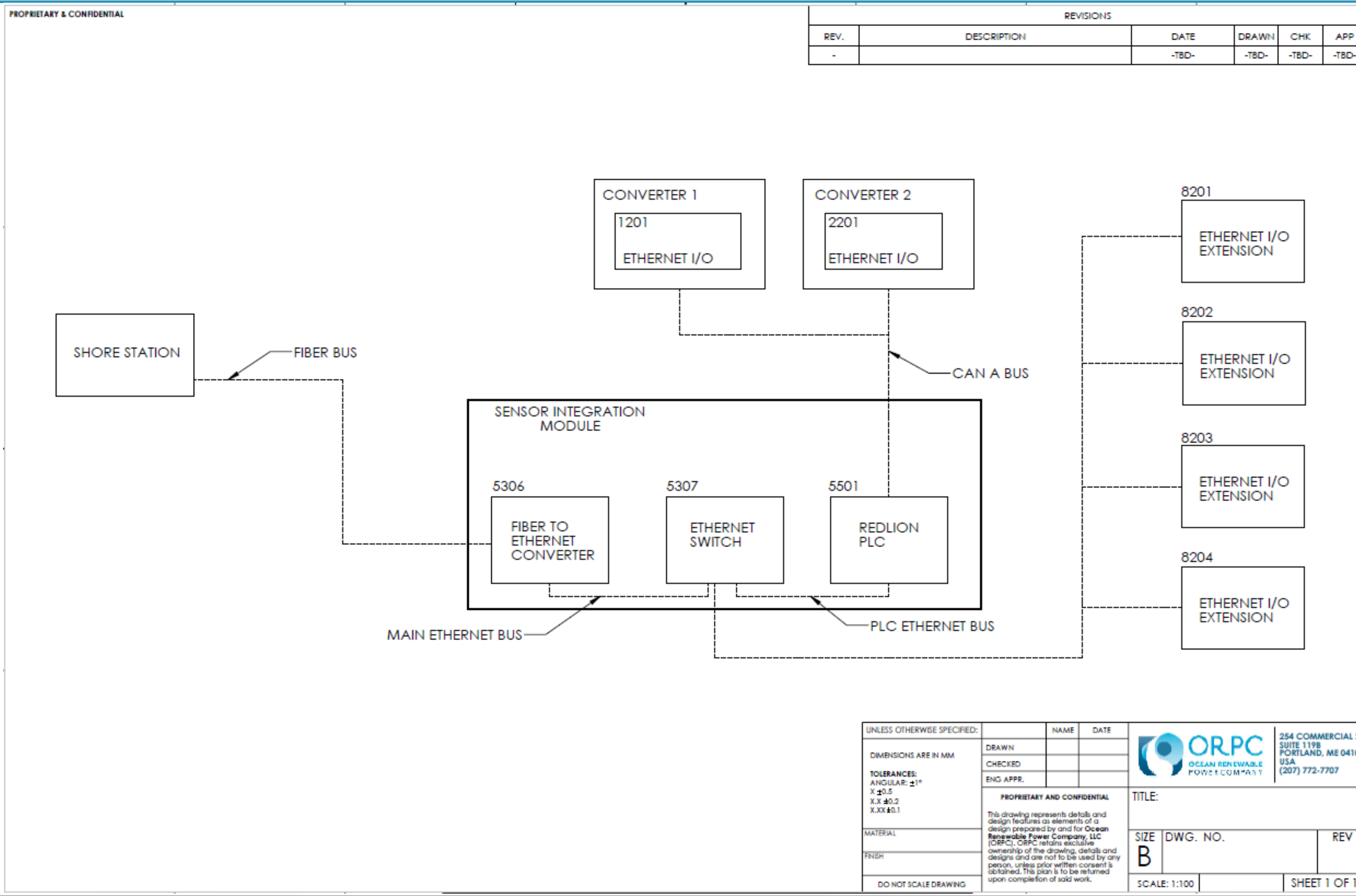
Condition Monitoring System

- Enclosure Temperature and Humidity (leaks and electronics)
- Mooring line tension
- Bearing temperatures
- Buoyancy pod leaks
- Device position
- Water velocity

Power Curve



Power (kW)
200
150
100
50
0
0
1
2
3
4
Current Speed (m/s)
Torque (kN-m)
40
30
20
10
0
0
1
2
3
4
Current Speed (m/s)
RPM
100
80
60
40
20
0
0
1
2
3
4
Current Speed (m/s)


PROPRIETARY & CONFIDENTIAL
REVISIONS
REV.
DESCRIPTION
DATE
DRAWN
CHK
APP
-
-TBD-
-TBD-
-TBD-
-TBD-
CONVERTER 1
1201
ETHERNET I/O
CONVERTER 2
2201
ETHERNET I/O
8201
ETHERNET I/O EXTENSION
8202
ETHERNET I/O EXTENSION
8203
ETHERNET I/O EXTENSION
8204
ETHERNET I/O EXTENSION
SHORE STATION
FIBER BUS
CAN A BUS
SENSOR INTEGRATION MODULE
5306
FIBER TO ETHERNET CONVERTER
5307
ETHERNET SWITCH
5501
REDLION PLC
MAIN ETHERNET BUS
PLC ETHERNET BUS
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN MM
TOLERANCES:
ANGULAR: ±1°
X ±0.5
X.X ±0.2
X.XX ±0.1
DRAWN
CHECKED
ENG APPR.
MATERIAL
FINISH
DO NOT SCALE DRAWING
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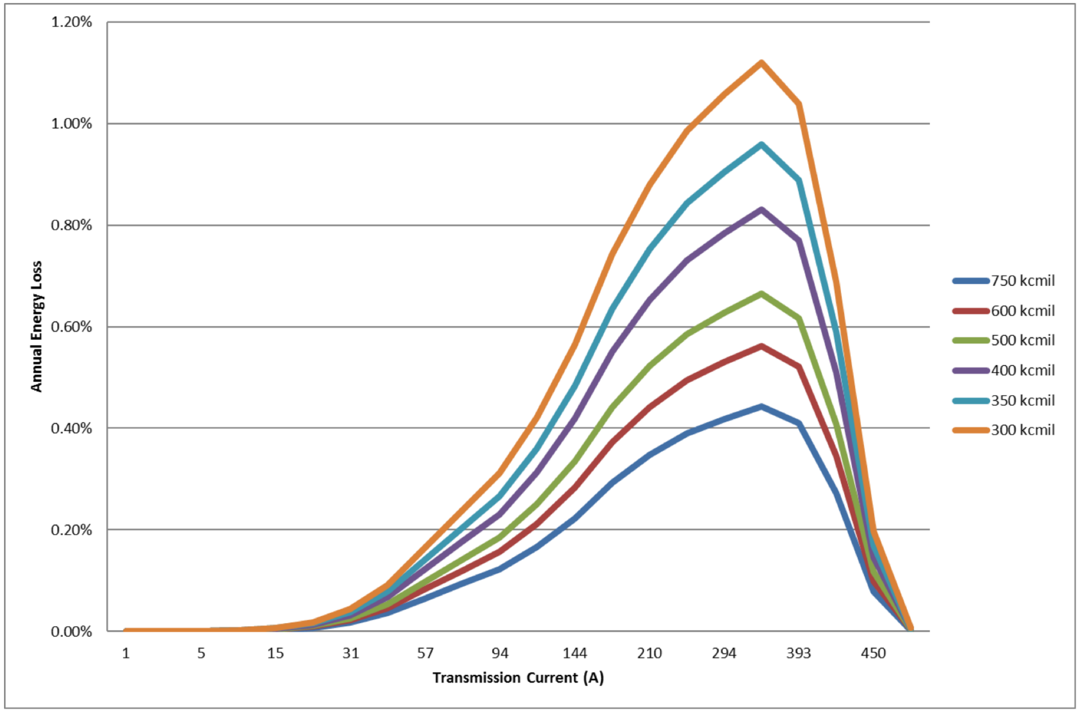
TITLE:
SIZE
B
DWG. NO.
REV
SCALE: 1:100
SHEET 1 OF 1

Specifications & Requirements

Power Cable

Conductor Size	Energy Loss	Revenue Loss
300 kcmil	8.6%	$12,615
500 kcmil	5.1%	$9,345
750 kcmil	3.4%	$4,985

**Annualized losses at $0.22/kwh*



Verfication Testing

- Bench testing of components
- Integration of electrical system before deployment
- Communications tests with full cable or cable length simulator
- With TidGen® 2.0 delay, utilize SCADA architecture on RivGen® 2.0
- Early bench and systems tests on smaller system
- Scale up and include improvements.

IO&M

Deployment and Retrieval System (Task 3)

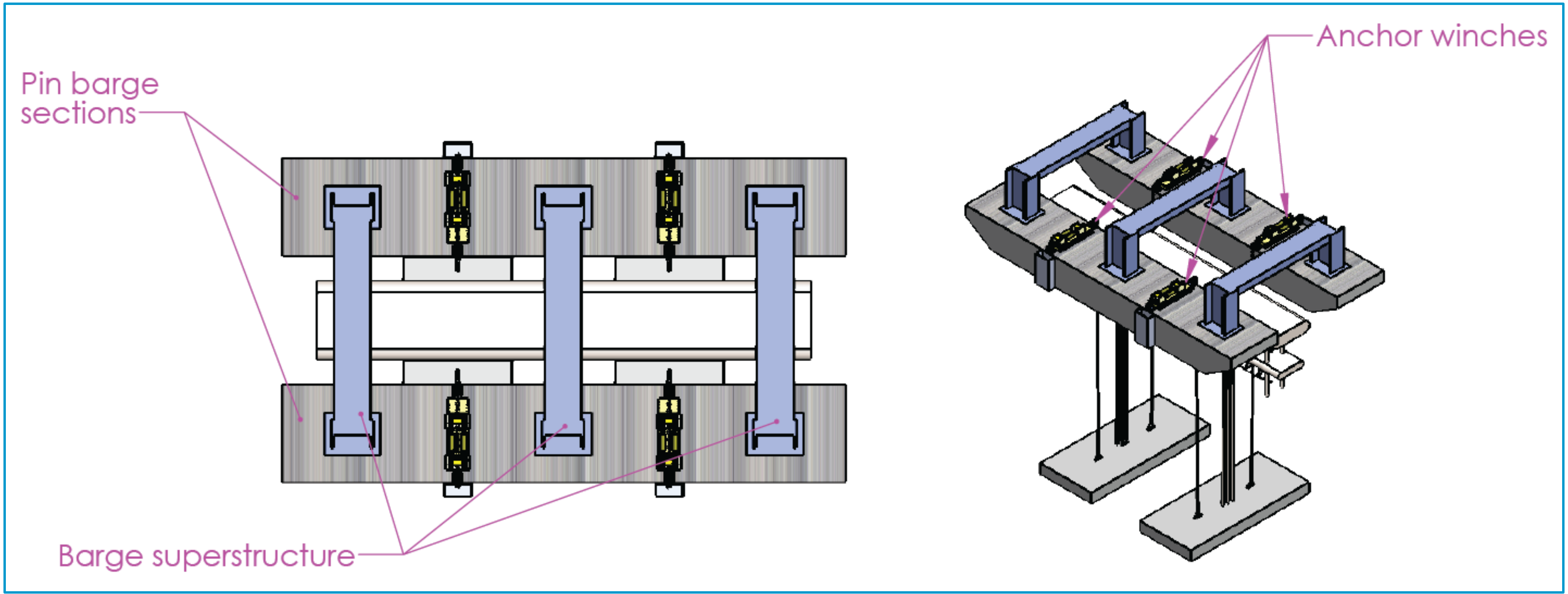
Subsystem Overview
Functional Description & Performance

Able to lift, transport, and lower a full TidGen power system with accurate positional station keeping during minimal flow periods.

Device will be used in all deployment, maintenance, and decommission activities.

Subsystem Overview

Subsystem Components

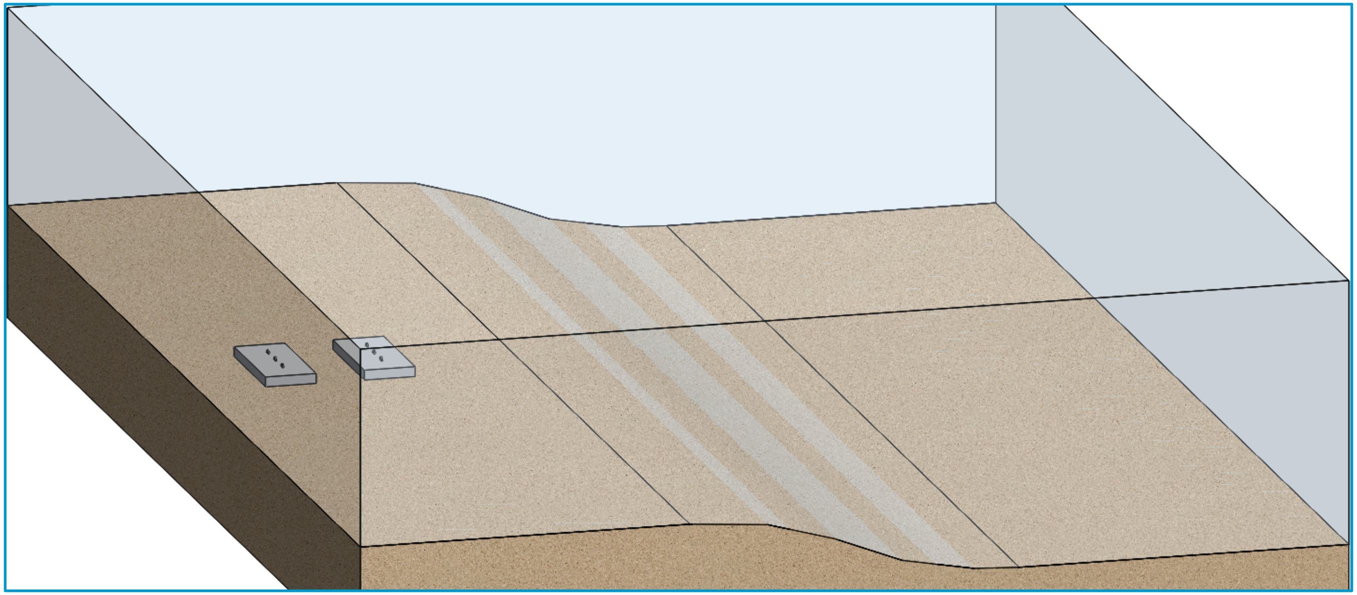


*** Additional equipment / subsystems

- Hydraulic / electric power unit
- Tow/Push positioning equipment/vessels
- Power / data cable equipment
- On-water safety equipment

Assembly, Installation, & Maintenance

Subsystem Installation Strategy



Build / stage anchors near shore

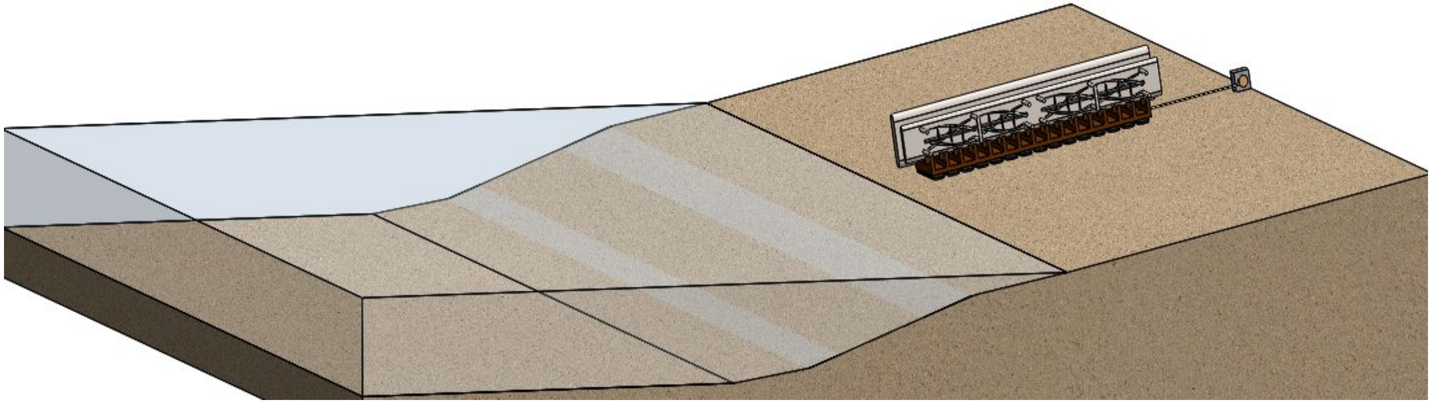
- Each anchor will weigh ~200 tons
- Staging site will need to be 30 m deep at low tide.

Assembly, Installation, & Maintenance

Subsystem Installation Strategy

Bring device into water

- Use airbag roller to bring device down shore ramp into water / tidal area

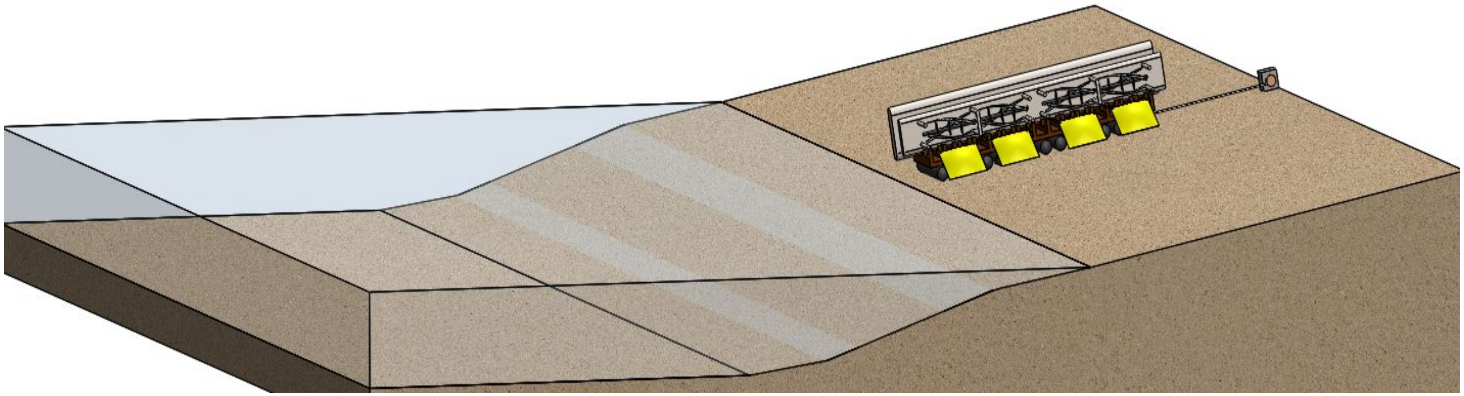


Assembly, Installation, & Maintenance

Subsystem Installation Strategy

Bring device into water

- Connect float bags to bottom of device

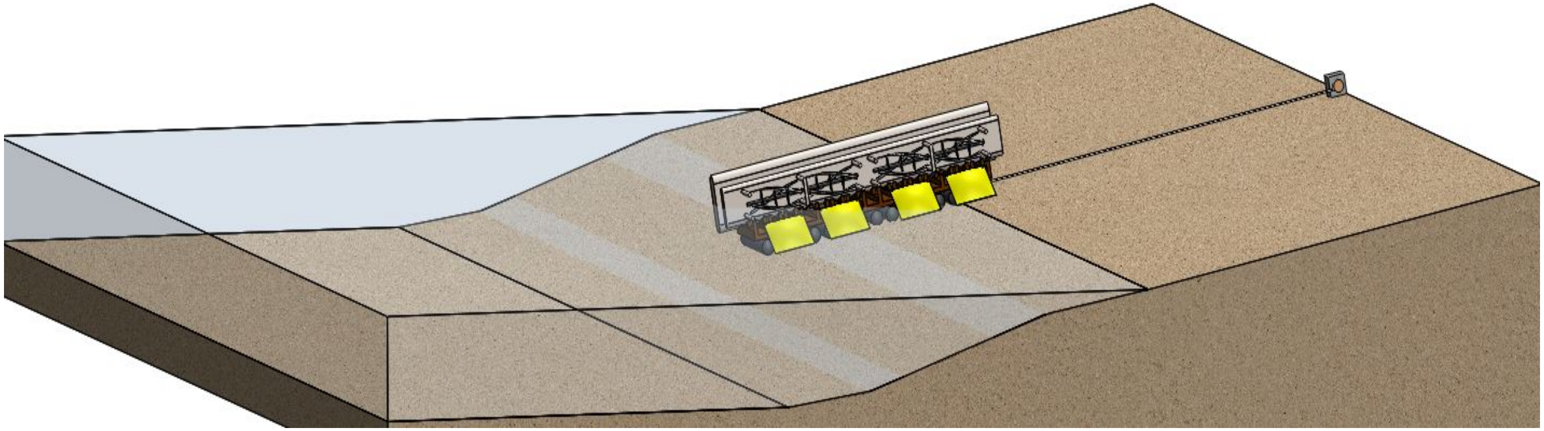


Assembly, Installation, & Maintenance

Subsystem Installation Strategy

Bring device into water

- Continue to lower device into water

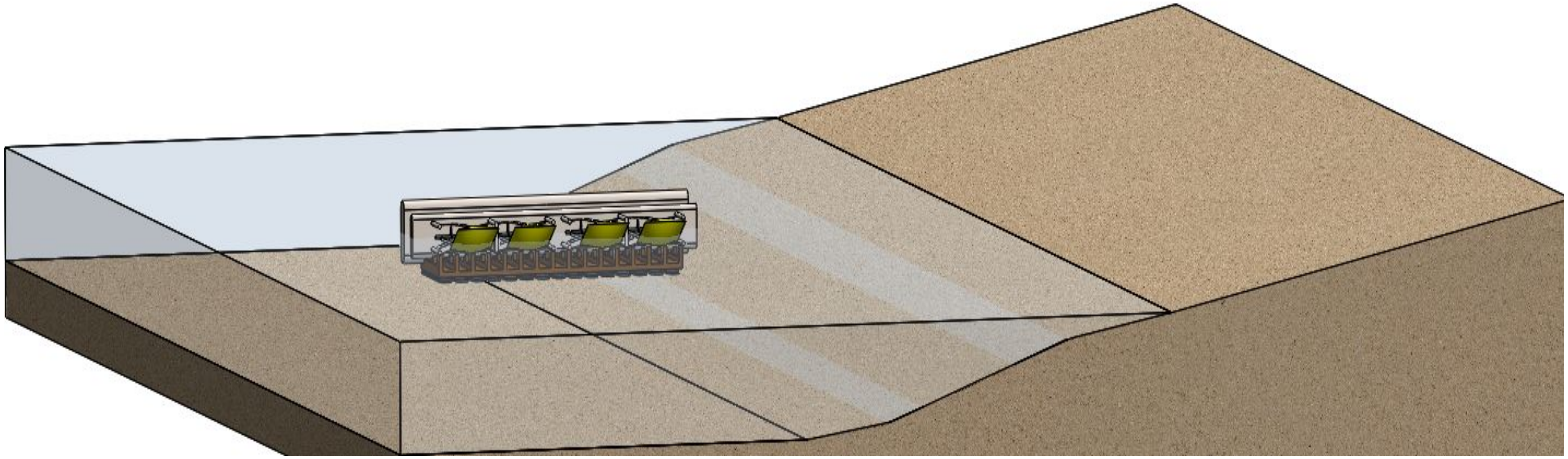


Assembly, Installation, & Maintenance

Subsystem Installation Strategy

Bring device into water

- Move device into water intil floating

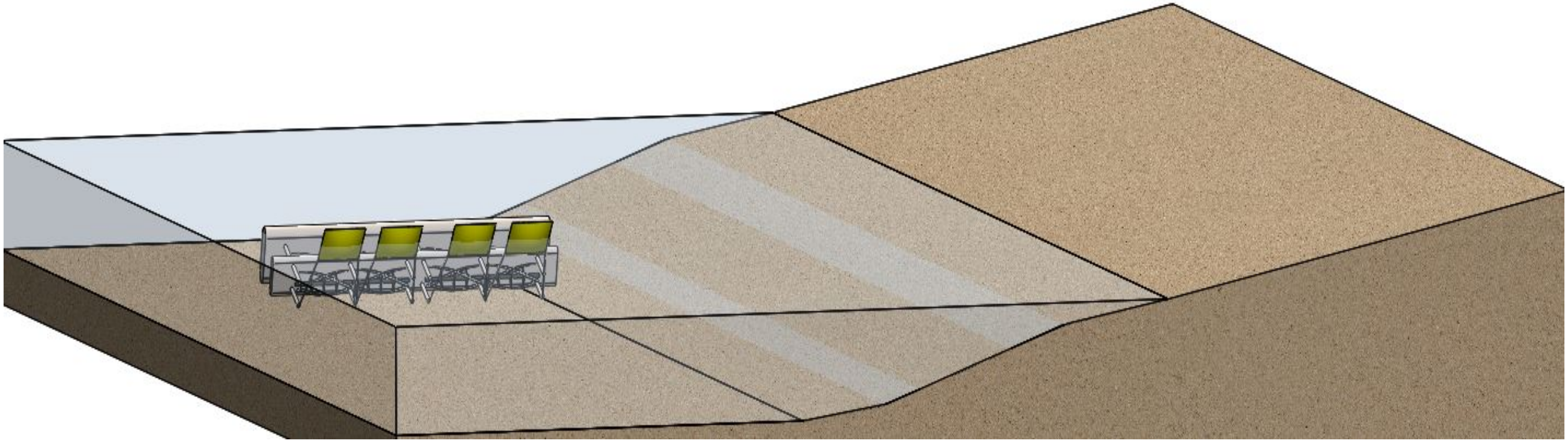


Assembly, Installation, & Maintenance

Subsystem Installation Strategy

Reorient Device

- Slowly deflate air bags allowing the device to move from the assembly position to the deployed position (with the buoyancy pod at the top of the device)

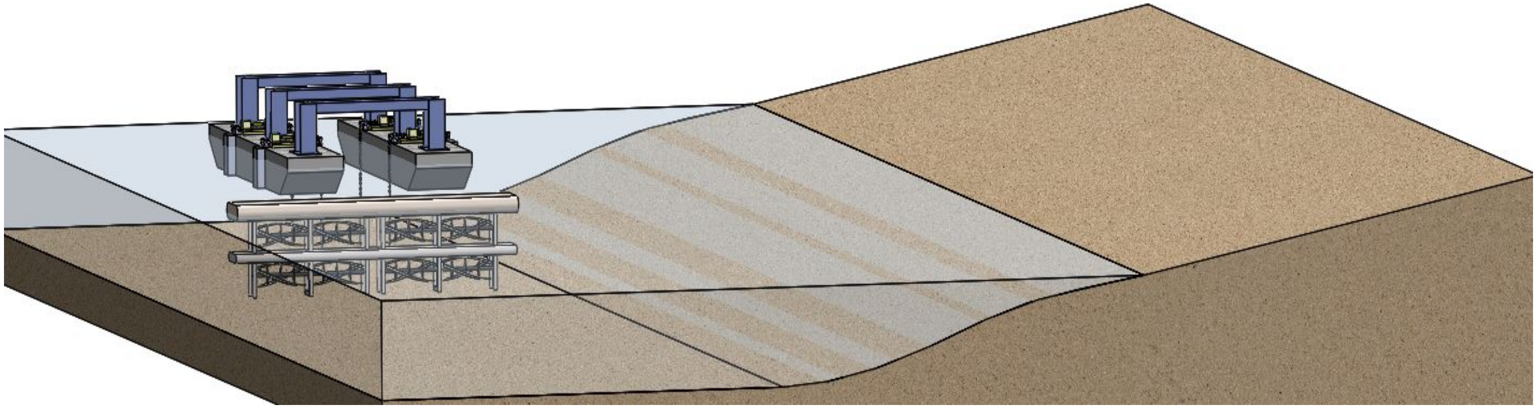


Assembly, Installation, & Maintenance

Subsystem Installation Strategy

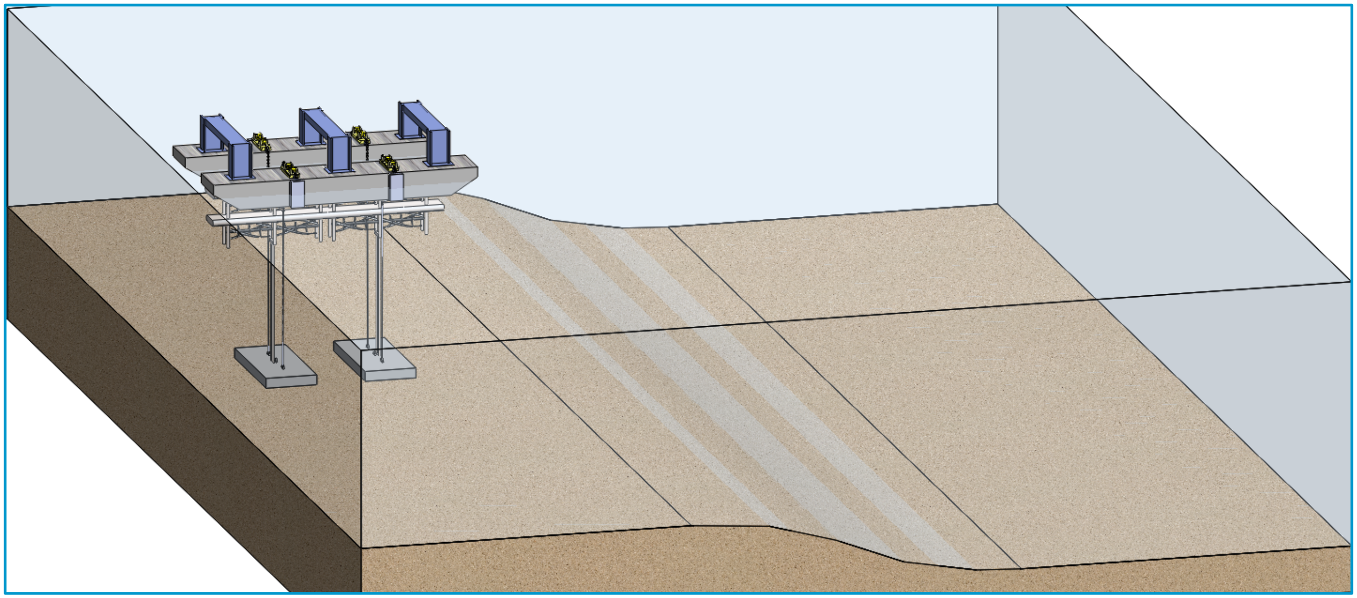
Connect to the Deployment System

- Position deployment barge around device and attach winches
- Move device to pre-staged anchors



Assembly, Installation, & Maintenance

Subsystem Installation Strategy

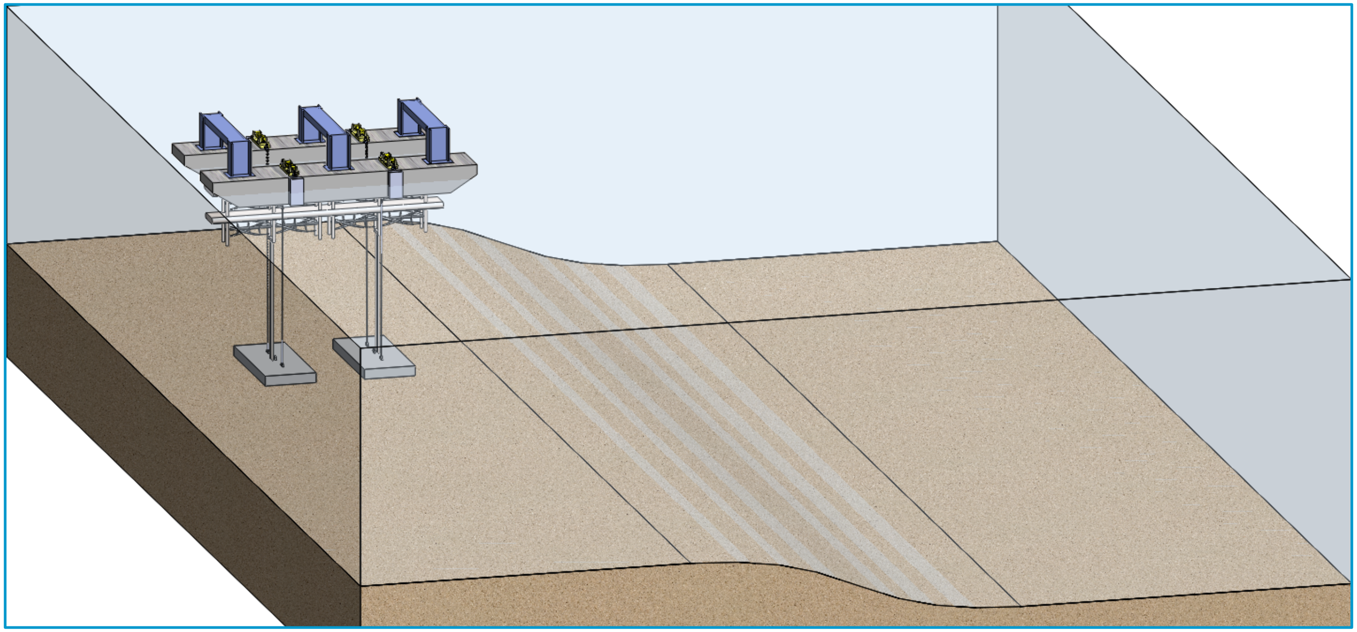


Attach device to anchors

- This will be done at low tide
- Mooring line connections will be made at surface.
- Anchor lifting line connections can be made at surface or at anchors.

Assembly, Installation, & Maintenance

Subsystem Installation Strategy

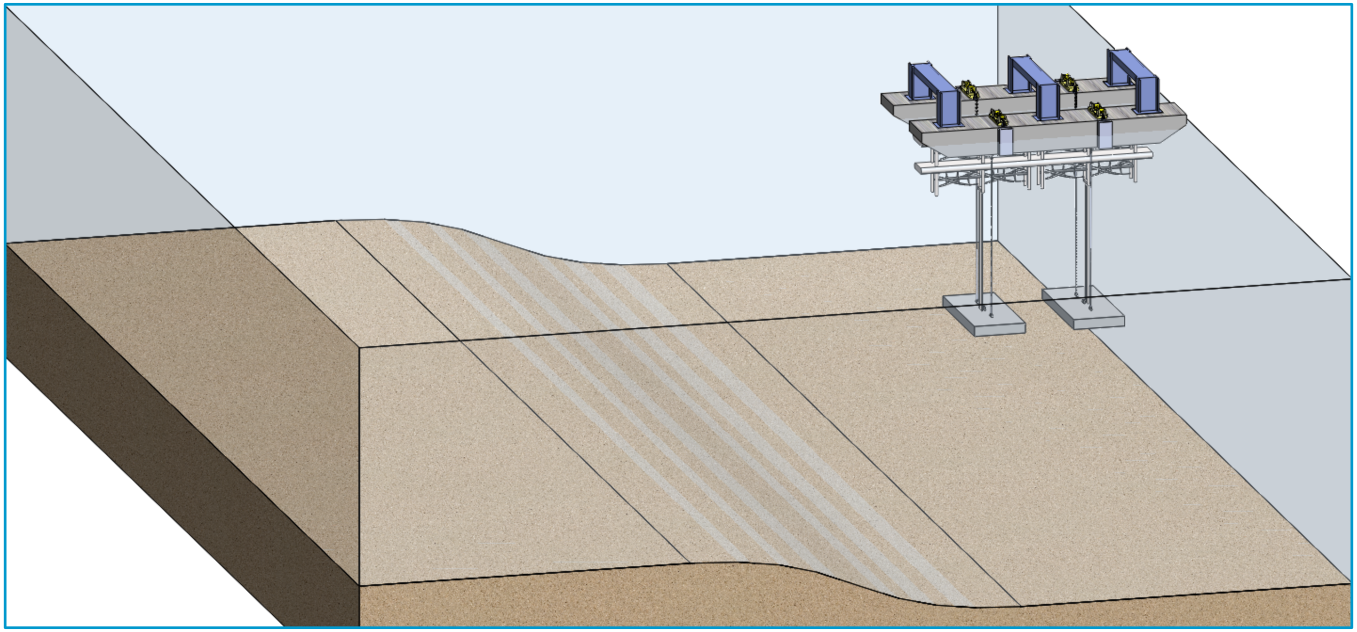


Lift anchors with tide

- Lift lines will be locked off.
- Buoyancy of device and barge will lift anchors.

Assembly, Installation, & Maintenance

Subsystem Installation Strategy

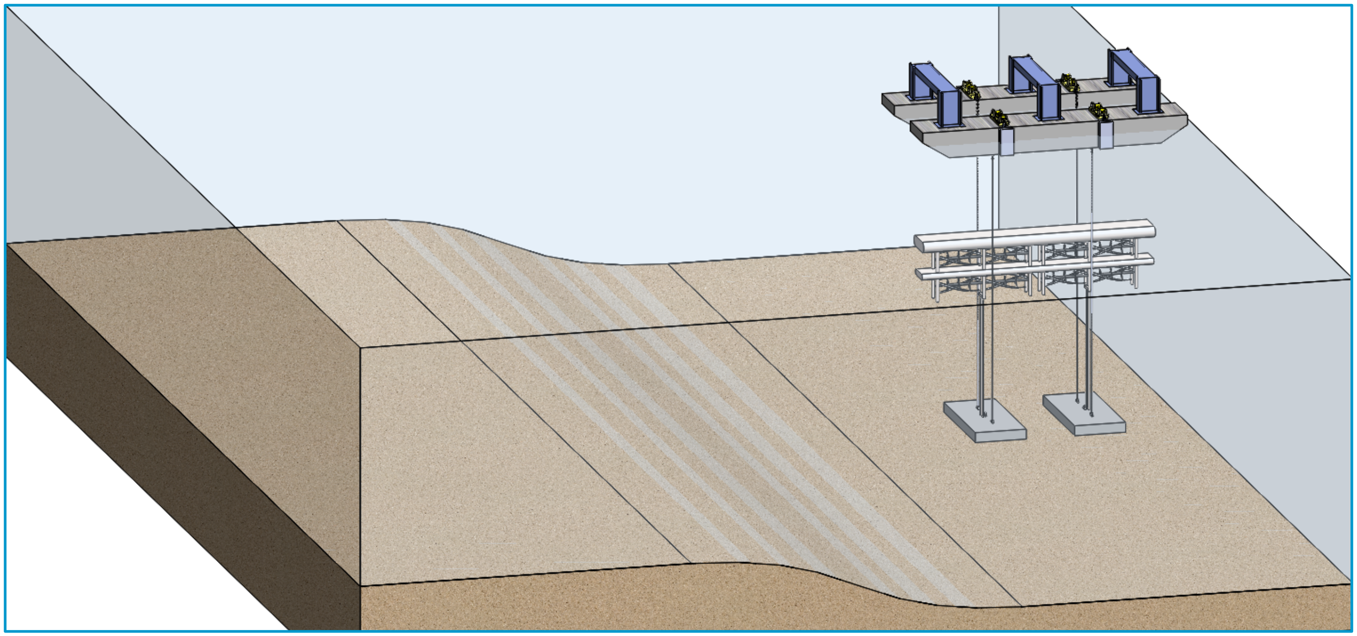


Move to deployment site

- Can use tidal flow to help with transport.
- Want to arrive at site at slack tide.

Assembly, Installation, & Maintenance

Subsystem Installation Strategy

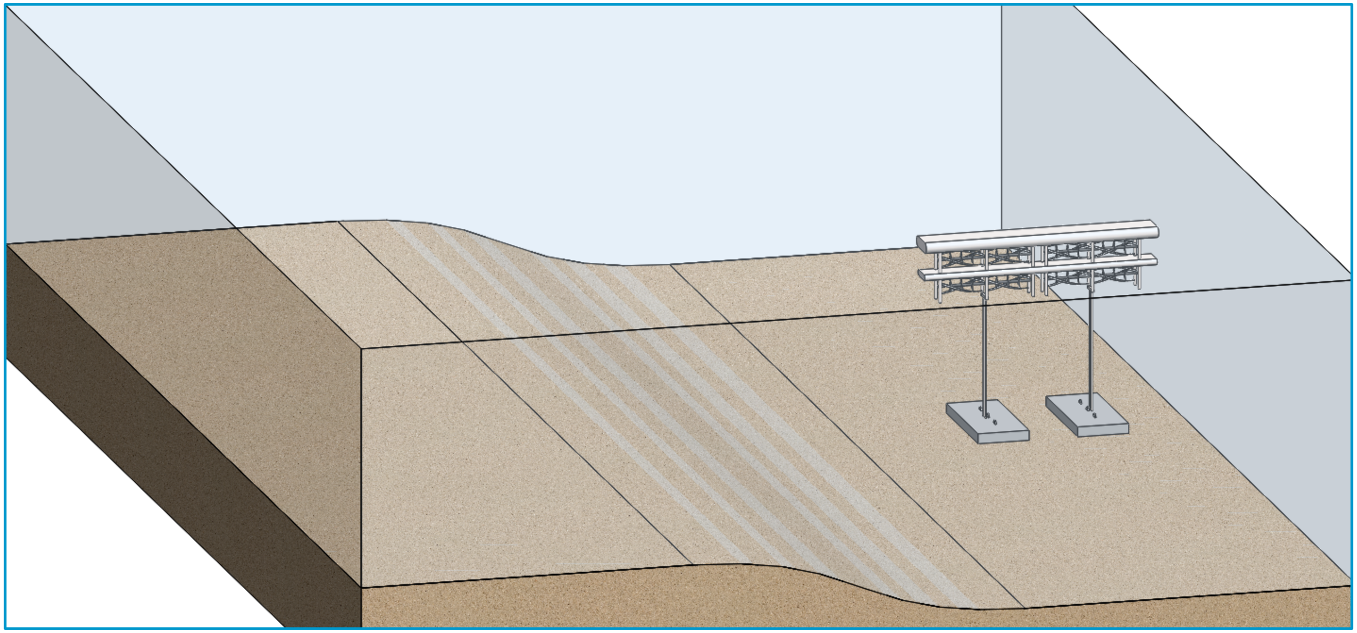


Lower device

- Chain jacks / winches will feed out chain.

Assembly, Installation, & Maintenance

Subsystem Installation Strategy



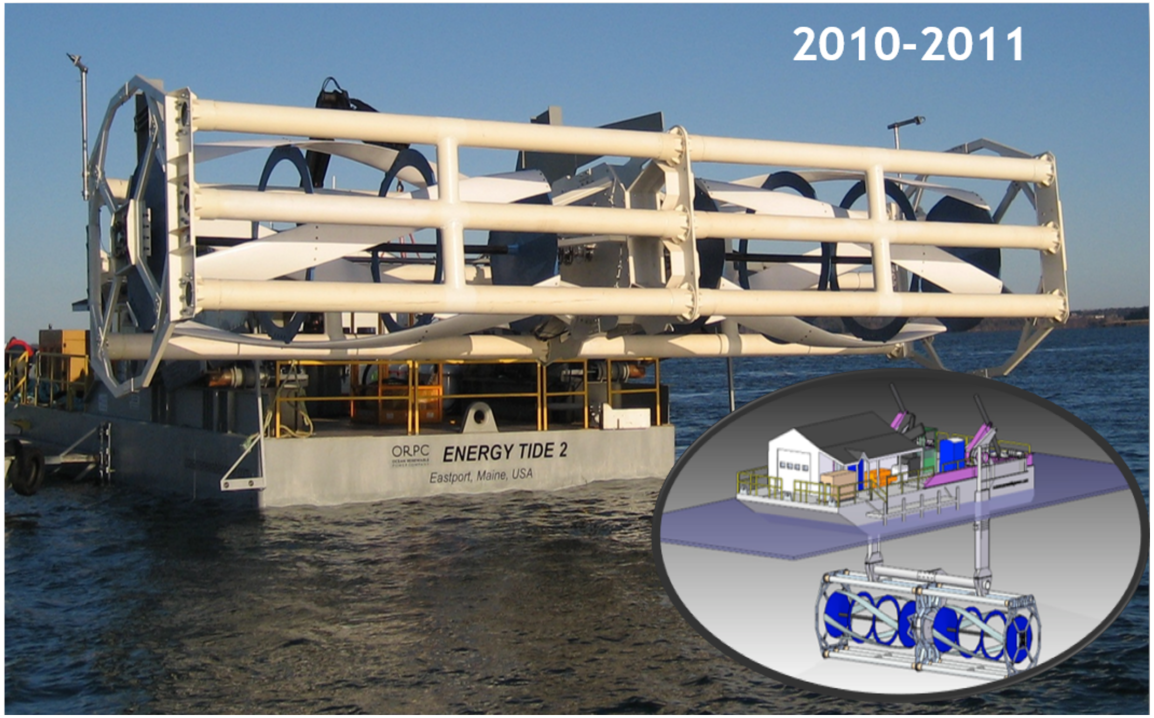
Detach and leave device

- Anchor lines will either detach from anchors at depth or at surface and then lowered to the seafloor with tag retrieval lines.

Development Tests

Development Tests
Tow Testing

- 1st production turbine
- Measure performance curve and drag loads to reduce conservative design assumptions
- Assess impact of manufacturing defects under operational loading.
- Q4 2018 through Q1 2019, off the coast of Maine (Cobscook Bay or Castine)



Development Tests

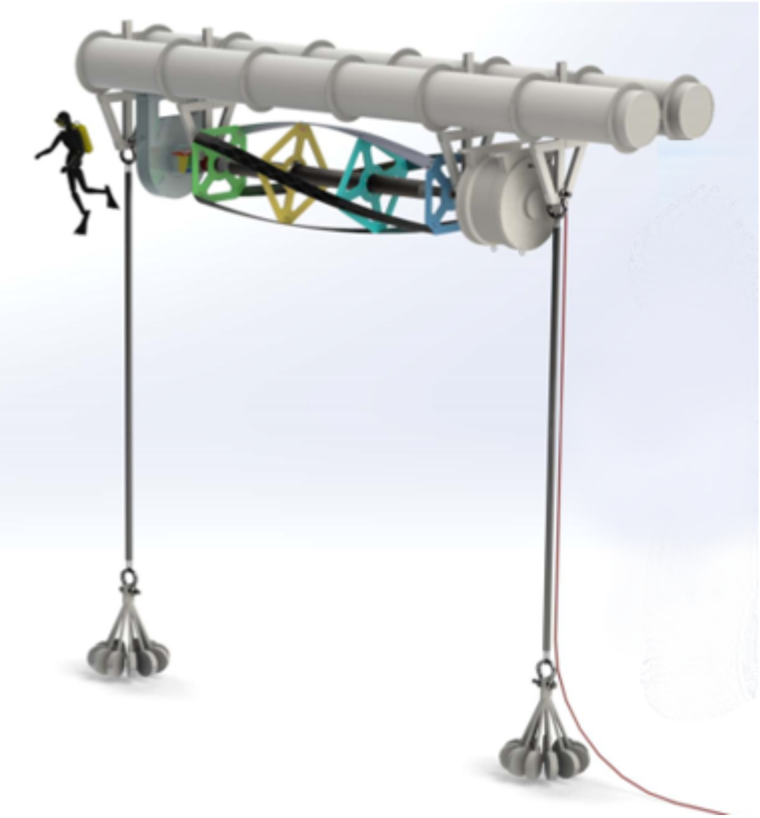
Anchor-holding capacity

- Pull tests on scaled anchors (1 metric ton) at WP deployment site
- Measure lateral holding efficiencies to reduce conservative design assumptions
- Skirts and other potential modifications will be assessed
- Q1 to Q2 2019

Development Tests

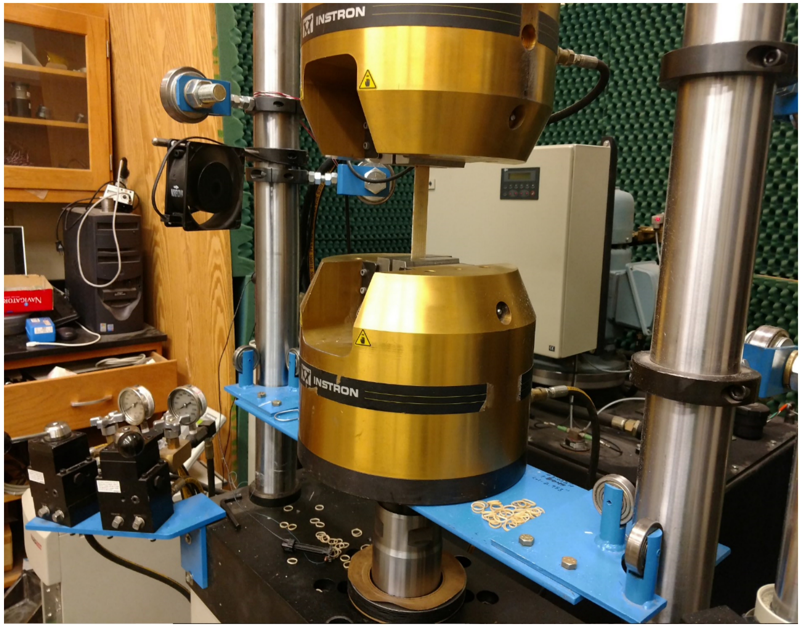
Deployment Subsystem Testing

- Buoyancy pod, bridle interface, mooring system
- Assess critical operations: onsite and near shore assembly, transit, offshore deploymen, operational stability
- Q3 2019, either in Cobscook Bay or Western Passage



Development Tests
Composite Life Testing

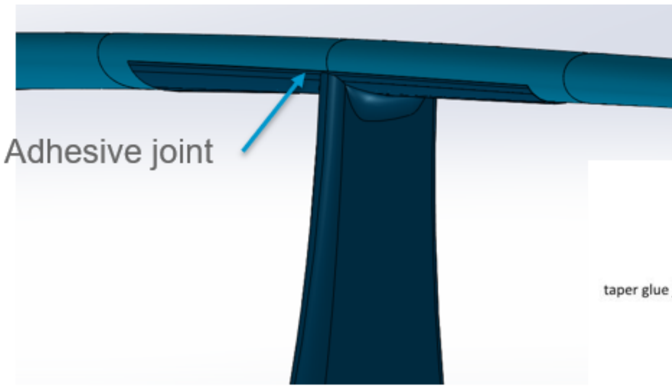
- Composite coupons, high stress sections of the turbine
- Static and fatigue testing, hydrophilic resin and hydrophobic resin
- Failure mechanisms under representative loading, impact of manufacturing defects
- Accelerated life tests towards component life models
- Inform second through eighth TidGen® turbines
- Q3 2018 through Q2 2020

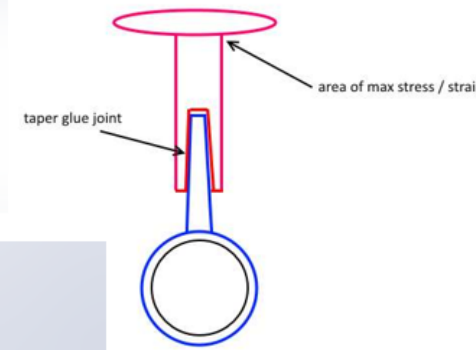


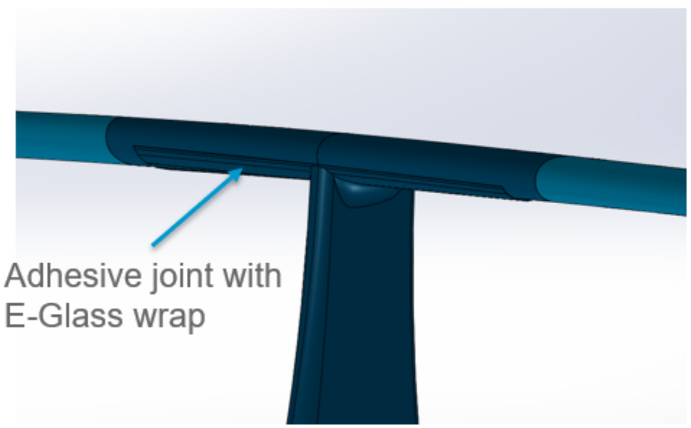
Development Tests

Composite Joint Testing

- Candidate joint geometries of foil to strut connection
- Prior to first turbine build for best joint geometry in terms of durability
- Q3 through Q4 2018



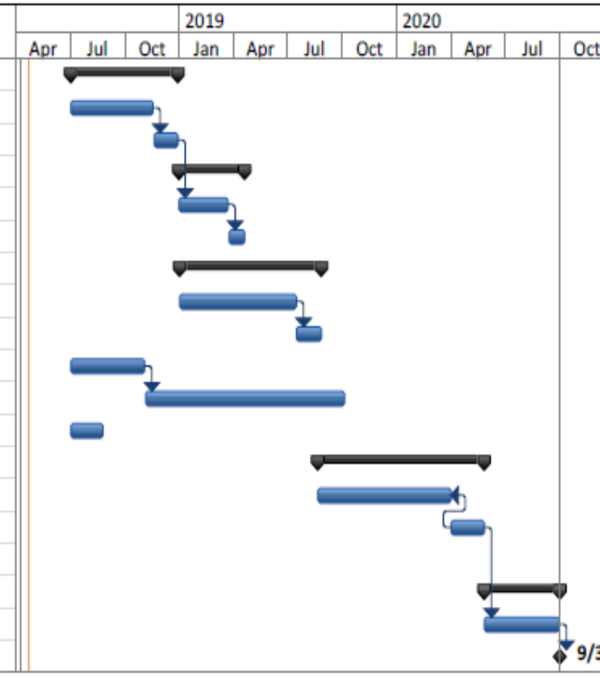




Development Tests

Schedule

ID	Task Name	Duration	Start	Finish	Predecessors
1	**Turbine load / performance testing**	**130 days**	**Mon 7/2/18**	**Fri 12/28/18**	
2	Build and test prep	5 mons	Mon 7/2/18	Fri 11/16/18	
3	Conduct tests	1.5 mons	Mon 11/19/18	Fri 12/28/18	2
4	**Anchor-holding capacity validation**	**80 days**	**Mon 12/31/18**	**Fri 4/19/19**	
5	Build and test prep	3 mons	Mon 12/31/18	Fri 3/22/19	3
6	Conduct tests	1 mon	Mon 3/25/19	Fri 4/19/19	5
7	**System deployment & retrieval testing**	**170 days**	**Tue 1/1/19**	**Mon 8/26/19**	
8	Build and test prep	7 mons	Tue 1/1/19	Mon 7/15/19	
9	Conduct tests	1.5 mons	Tue 7/16/19	Mon 8/26/19	8
10	Composite structural & coupon testing	4.5 mons	Mon 7/2/18	Fri 11/2/18	
11	Composite accelerated life testing	12 mons	Mon 11/5/18	Fri 10/4/19	10
12	Composite turbine joint testing	2 mons	Mon 7/2/18	Fri 8/24/18	
13	**Full system verification in Cobscook Bay**	**200 days**	**Wed 8/21/19**	**Tue 5/26/20**	
14	System integration	8 mons	Wed 8/21/19	Wed 4/1/20	15SF
15	Deploy in CB	2 mons	Wed 4/1/20	Tue 5/26/20	
16					
17	**Full system validation deployment in Western Passage**	**91 days**	**Wed 5/27/20**	**Wed 9/30/20**	
18	Site and system preparation	4.5 mons	Wed 5/27/20	Tue 9/29/20	15
19	Deploy TidGen® in Western Passage	0 days	Wed 9/30/20	Wed 9/30/20	18FS+1 day

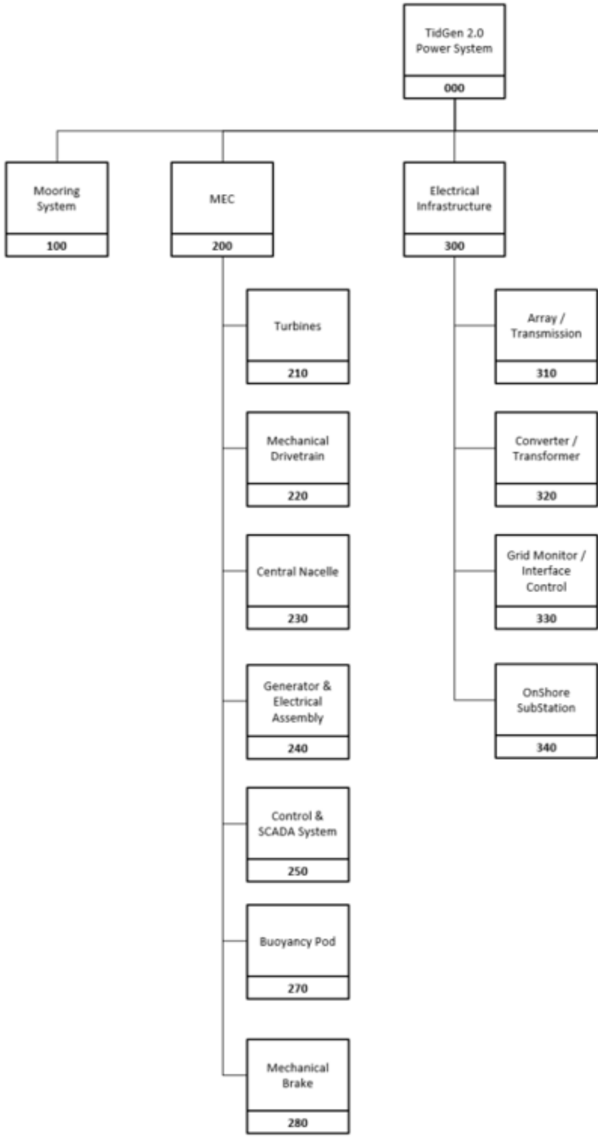


OCEAN RENEWABLE POWER COMPANY

System Fabrication Plan

Design Fabrication Plan

Product Breakdown Structure (PBS)



000 TidGen System
- 100 Buoyancy Tension Mooring System (BTMS
  - 110 Anchors
  - 120 Mooring chain / lines
  - 130 Anchor jewlery
- 200 MEC
  - 210 Turbines
  - 220 Mechanical Drivetrain
  - 230 TGU Chassis Frame
  - 240 Generator & Electrical Assembly
  - 250 SCADA and Controls
  - 260 Middle Nacelle
  - 270 Buoyancy Pod
  - 280 Mechanical Brake
- 300 Electrical Infrastructure
  - 310 Array / Transmission
  - 320 Converter / Transformer
  - 330 Grid Monitor / Interface Control
  - 340 Onshore Substation
- 400 Environmental Monitoring System
- 500 Auxillary Operational Systems
  - 510 Ballast / Deployment Systems
  - 520 Assembly / maintenance equipment

OCEAN RENEWABLE POWER COMPANY

Design

Fabrication Plan – Development Testing Through CB

Budget Period 2, tasks 8 through 15:

- 1st turbine in 2018; 2nd through 8th turbines in 2019
- Deployment system testing in summer 2019; target reuse of any purchased equipment
- CB installation in Q2 2020
  - Task 12 electrical work, Task 13 system integration and test
- WP site electrical installation in 2020 as part of Task 12
  - Onshore substation will be transported from CB to WP
- Environmental monitoring equipment reused from CB to WP
  - Equipment is external to the device

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Design

Fabrication Plan – Western Passage

Budget Period 3, tasks 16 through 18:

- The mooring chains will be replaced, and the system reconfigured for the deeper site at Western Passage.
- Environmental monitoring equipment will be transported and redeployed for the system validation testing in Western Passage.

Risk Management

Risk Management

- DNV GL prototype certification, rigorous risk management
  - Meets or exceeds all requirements of the NREL Marine and Hydrokinetic Technology Development Risk Management Framework
- DNV GL standards:
  - DNVGL-SE-0163 Certification of tidal turbines and arrays
  - DNVGL-ST-0164 Tidal turbines.
- Risk Register – 2 documents to satisfy DNV GL requirements
  - D-TD20-10011 FMEA, TidGen® 2.0: a formal failure modes and effects analysis
  - D-TD20-10129 TidGen® 2.0 DNV Technology Assessment, a more detailed FMECA breakdown to the component and project phase levels.

Environmental Monitoring Approach

Task 5

Task 5: Environmental Approach

Budget Period 1: System Feasibility and Design

Focus Area	Status
1. Background and lessons learned	• Review completed and informs subsequent BP1 focus areas
2. Determine monitoring methods (and test)	• Methods identified and tested in fall 2017 • ORPC presented approach to AMT on January 25, 2018
3. Develop thresholds	• ORPC seeking guidance from AMT on the approach

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Regulatory Engagement

- Adaptive Management Team (State, Federal regulators and technical advisors) meeting help in Bangor, Maine on January 25, 2018. Agenda included:
  - Introductions and purpose
  - Adaptive management overview
  - ORPC company update
  - Advanced TidGen® design
  - Deployment schedule and licensing
  - Advanced TidGen® environmental monitoring
  - Next Steps
- The AMT provided positive feedback on ORPC's presentation and concurred with the proposed approach.
- ORPC met with the U.S. Coast Guard in April 2018.

Fish and marine mammal assessment activities in Downeast Maine

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School of MARINE SCIENCES
ORPC OCEAN RENEWABLE POWER COMPANY
U.S. DEPARTMENT OF ENERGY

Objectives

- understand ecosystem influence of carbon-neutral marine renewable energy (MRE)
- establish monitoring approaches for fish and marine mammals
- define quantitative indices of change in habitat use

Tide Generating Unit (TGU) designed by Ocean Renewable Power Company (ORPC)

Study Site
Western Passage and Cobscook Bay

Western Passage Characteristics:
- *tide range:* 6 meters
- *current speed:* 6 knots
- *potential annual energy extraction:* 3.5 GWh

Western Passage Pelagic Ecosystem:
- *marine mammals:* fin, minke, humpback, right, porpoise, dolphin, seals
- *fish:* herring, mackerel, cod, haddock, pollock, hake, salmon

Approaches to Ecosystem Assessment

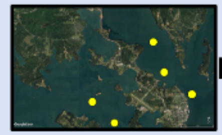
Fish
Hydroacoustic Surveys

SCHEDULE
- peak: May, Jun, Aug, Sep
- non-peak: Nov, Jan, Mar
- neap tide

ADVANTAGES
- non-invasive observation of spatial distribution
- high-spatial resolution sampling in vertical and horizontal dimensions
- quantitative sampling supports quantitative measures of habitat-use change associated with TGU presence

CHALLENGES
- high-velocity tide channels
  - high-turbulence
  - precludes physical sampling for groundtruthing
  - entrained air obfuscates biological backscatter

previous PROJECT
single TGU test deployment Cobscook Bay



STATIONARY single TGU
- 24-hour on-station surveys
- day/night
- 2 full tide cycles
- Simrad echosounders
- single-beam and split-beam
- 38 kHz and 200 kHz

current PROJECT
single TGU test deployment Western Passage preparing for an array

TRANSECTS array of TGUs
- 12-hour transects
- day
- 1 full tide cycle
- Simrad echosounders
- single-beam and split-beam
- 38 kHz and 200 kHz

Marine Mammal
Visual Observations

SCHEDULE
- 4-hour observation periods
- peak (Jun-Oct): twice weekly
- non-peak (Nov-May): weekly
- installation/removal: continuous

ADVANTAGES
- air-breathers must surface
- animals not required to vocalize in order to be included
- low barriers to training and "deployment"
- inclusive for local volunteers

CHALLENGES
- dependent on visual conditions (night, fog, whitecaps)
- physically challenging (cold)
- intensive personnel effort to collect the data

BINOCULARS
- 10 x 50 magnification
- clipboard
- range finder sticks
- digital SLR camera w/telephoto

Fujinon BIGEYES
- 25 x 150 magnification
- military-grade
- superior field of view
- better depth perception
- greater detail
- calibrated

Marine Mammal
Acoustic Detection

SCHEDULE
- year round coverage
- multiple deployments to refresh batteries and harddrive
- duty-cycling to extend deployment durations

ADVANTAGES
- monitoring is not dependent on climatological conditions
- day/night coverage, year round
- monitor 3-dimensional use of their habitat

CHALLENGES
- ambient noise conditions
- silent individuals not detected
- difficult to establish individuals for counting
- large $ investment for instruments, deployment, and recovery
- investment in signal processing software and training

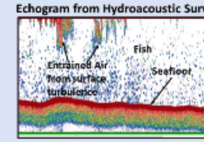
No previous monitoring

TR-ORCA
by Turbulent Research, Inc.
- 5 synchronous hydrophone inputs
- record autonomously or stream
- continuous or duty-cycle
- 4 TB onboard data storage .wav files
- up to 384,000 samples per second
- record sounds: 10 Hz to 150 kHz

Data Products

Fish
Echogram and Echometrics

Echogram from Hydroacoustic Survey



Indices of Spatial Change	
Density	Abundance
Dispersion	Occupied Area
Evenness	Aggregation

Urmy et al. (2012). Measuring the vertical distributional variability of pelagic fauna in Monterey Bay. ICES Journal of Marine Science, 69(2), 184-196.

Marine Mammal
Presence and Distribution

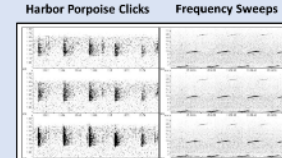
Spatial Distribution of Marine Mammal Sightings

Visual survey data Fall/Winter 2017.

Acknowledgement: Mark Baumgartner, WHOI, for loan of BIGEYES.

Marine Mammal
Presence and Vocalizations

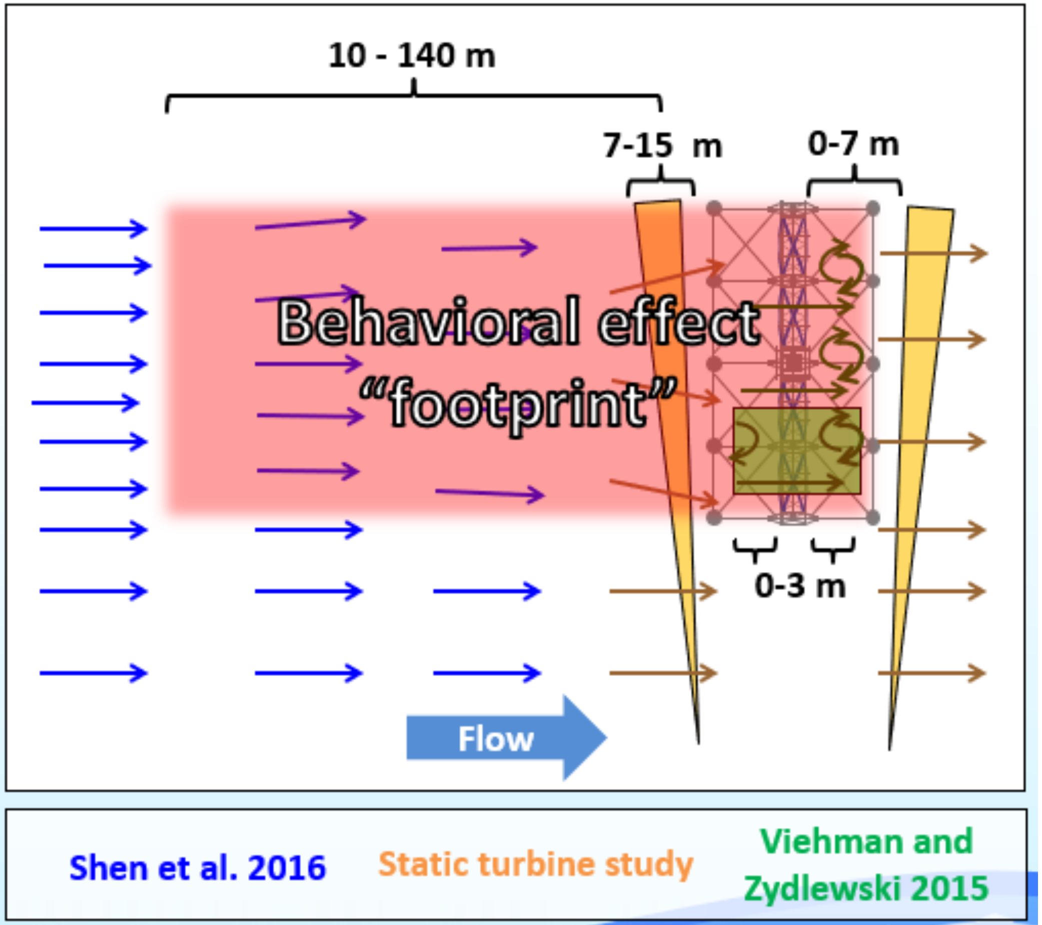
Harbor Porpoise Clicks — Calibration Synthetic Frequency Sweeps



Three-channel data records from TR-ORCA.

Acknowledgement: Danielle Cholewiak, NOAA, for loan of Lubell speaker.

Synthesis of Fish Studies CBTEP



Bevelhimer et al. 2015, Broadhurst et al. 2014, Hammar et al. 2013

Marine Mammals: Acoustic Detection
WPTEP

Fall 2017 Field Trials

Nov 26 – Dec 9

<u>14-day Deployment:</u>

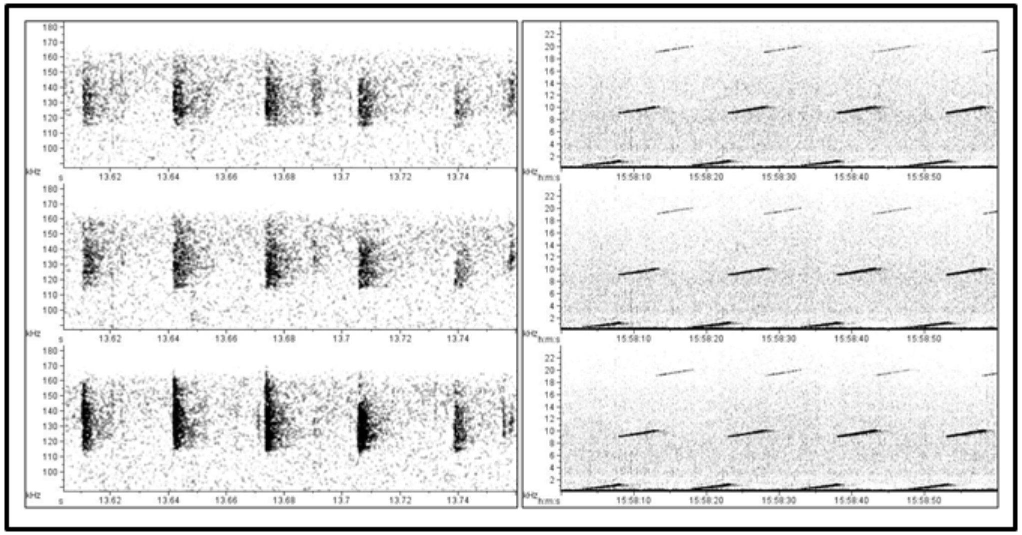
- passive acoustic monitoring (PAM)
- 2 TR-ORCA units
- 3 synchronous hydrophones on each unit
- continuous recording
- 384,000 samples per second
- record sounds: 10 Hz to 150 kHz

TR-ORCA by Turbulent Research, Inc.

Marine Mammals: Acoustic Detection
WPTEP

Harbor Porpoise Clicks

Calibration Synthetic Frequency Sweeps



Three-channel data records from TR-ORCA

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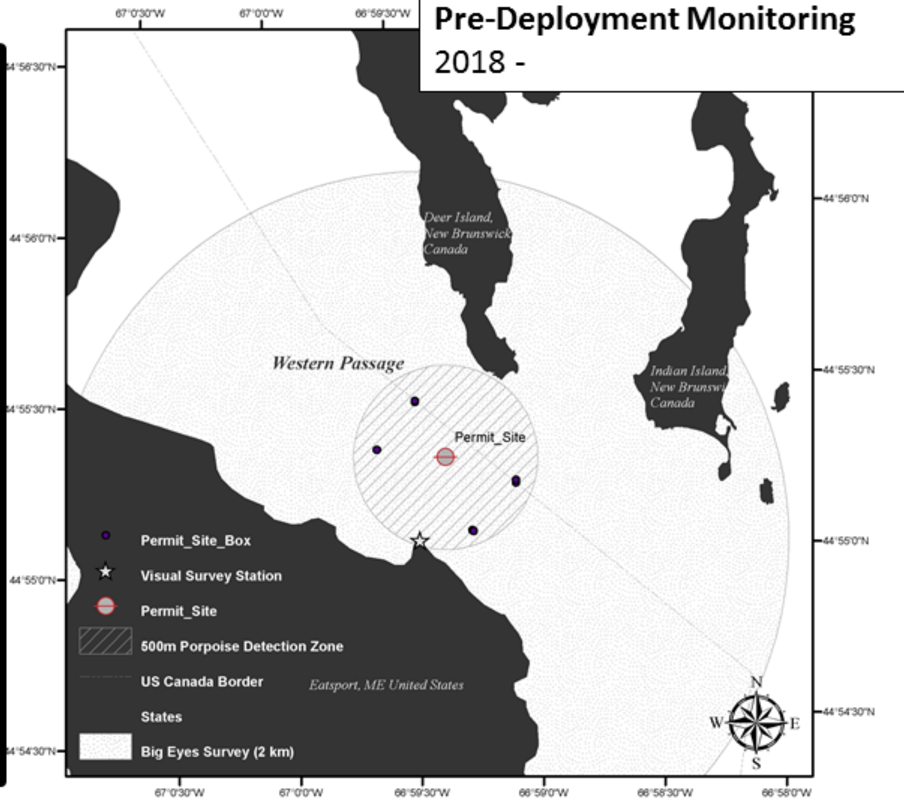
TR-ORCA by Turbulent Research, Inc.

Marine Mammals: Acoustic Detection
WPTEP

Pre-Deployment Monitoring
2018 -



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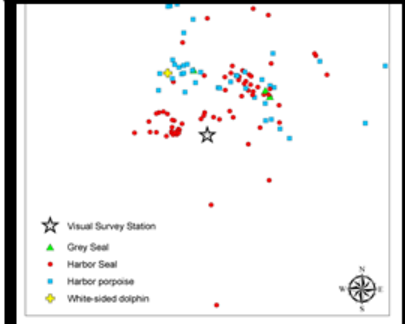
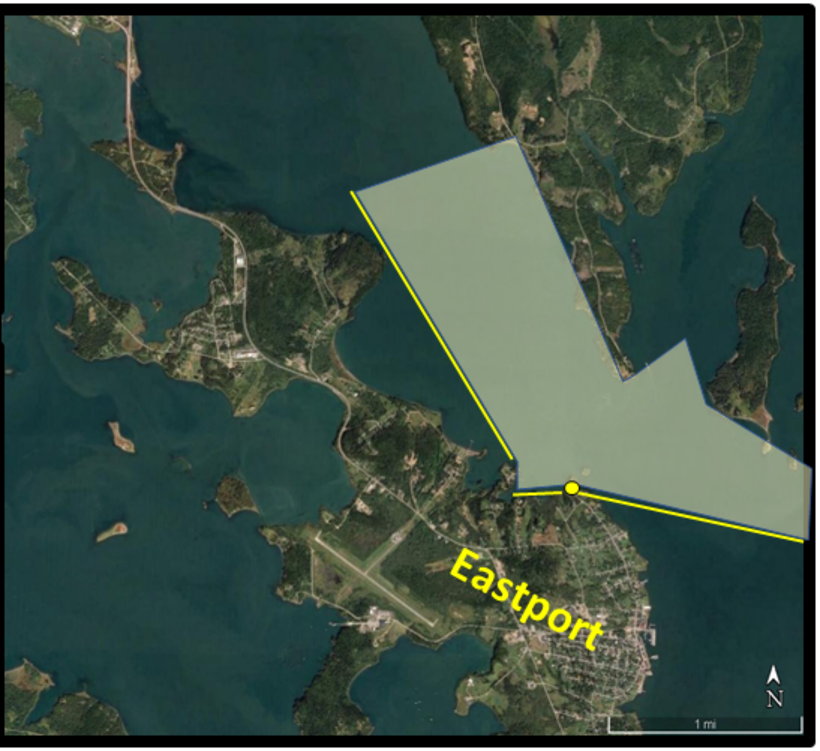
Marine Mammals: Visual Detection
WPTEP

Spatial Distribution of Marine Mammal Sightings Fall/Winter 2017/2018





Fall/Winter 2017/2018 Field Trials

non-peak (Nov-present): weekly

Weekly Observations:

- land-based
- 4-hour observation periods
- low slack, peak flood, high slack, peak ebb
- day
- Fujinon BIGEYES
- 25 x 150 magnification
- presence, abundance, surface behavior
- long-term platform installation
- 9-meter above sealevel

Acknowledgement: Mark Baumgartner, WHOI, for loan of BIGEYES.

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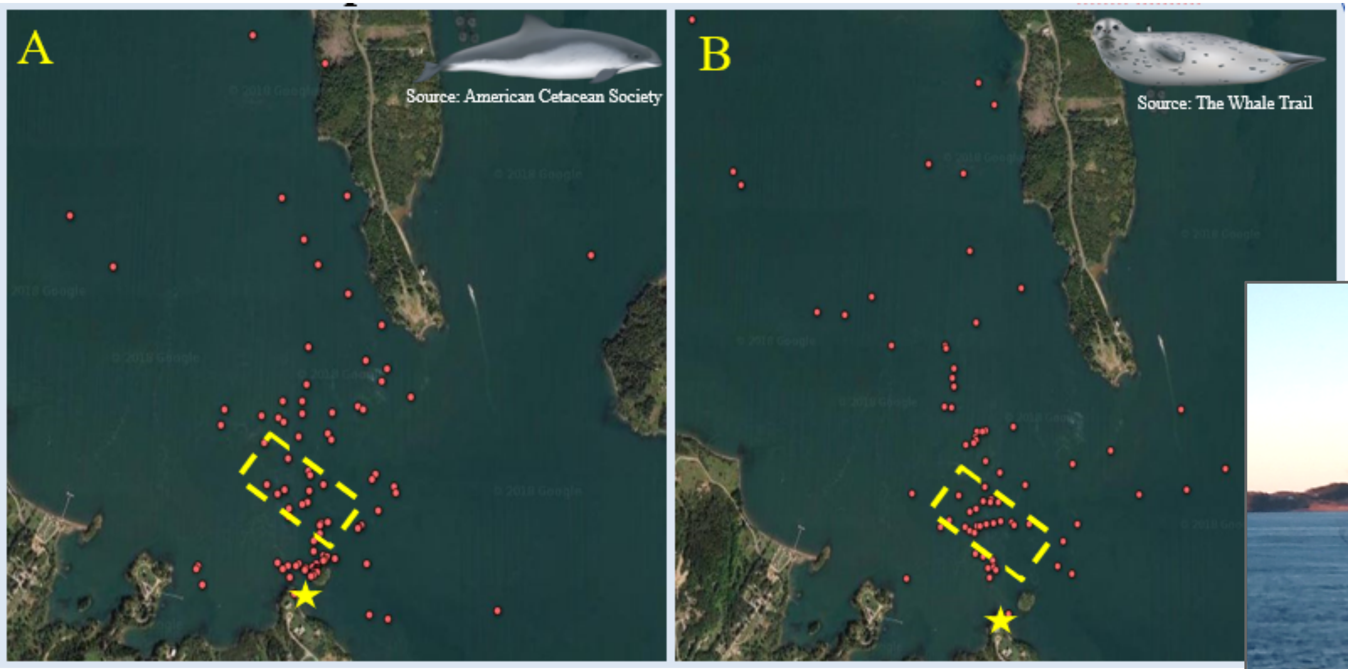
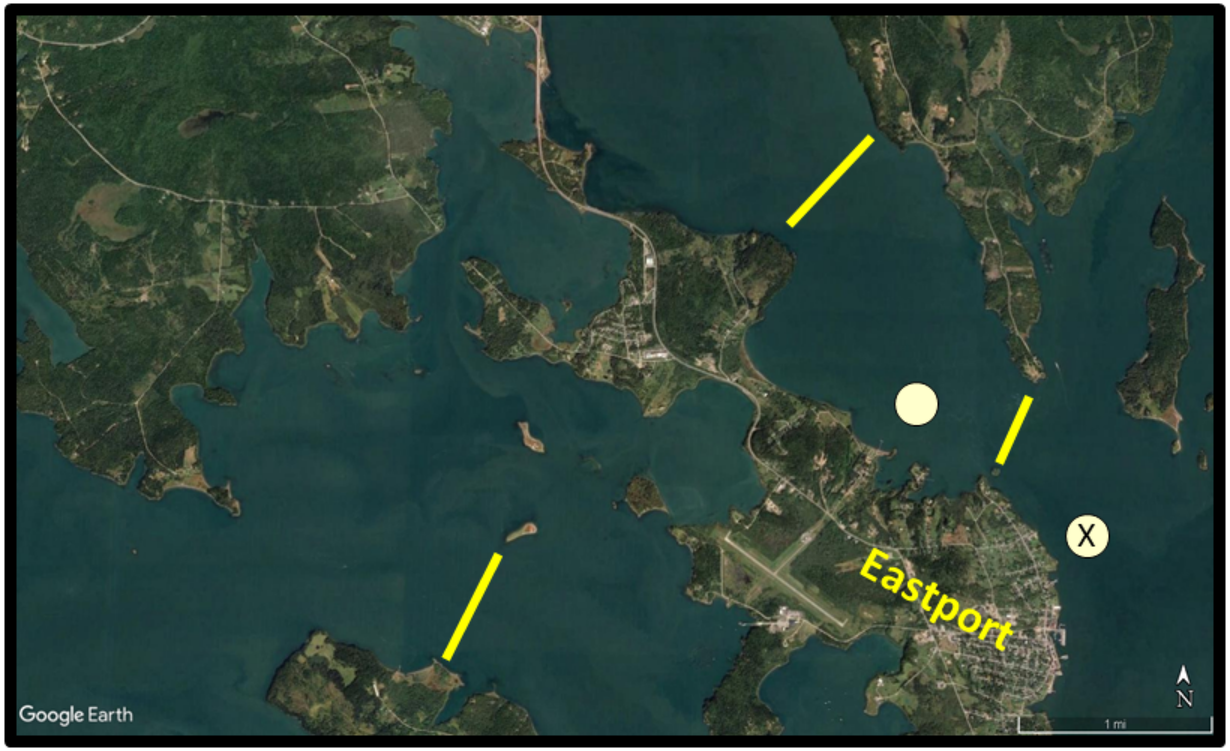


Preliminary visual sightings of porpoise (A) and seals (B) from Bishop's Point (yellow star) at 44.91787N, 66.99083W. Area of interest is marked by the yellow dashed box. Every point represents one sighting event from November through March.

Fish: Hydroacoustic Surveys
WPTEP



Pre-deployment Monitoring: 2018-

peak: May, Jun, Aug, Sep
non-peak: Nov, Jan, Mar

24-hour transects

- day/night
- 2 full tide cycles
- Simrad echosounders
- single-beam and split-beam
- 38 kHz and 200 kHz
- physical sampling

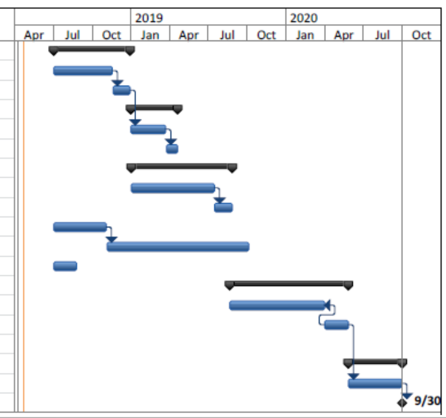
24-hour on-station surveys

- day/night
- 2 full tide cycles

NEPA Status

- ORPC aligning NEPA process with technology development stages:
  - Biological Assessment (BA) approved for Fall 2017 environmental monitoring tests conducted by UMaine
  - Per approval from NOAA on May 9, existing BA valid for UMaine hydroacoustic surveys in Q2 2018
  - BA modification (or new abbreviated BA) to incorporate trawl surveys into UMaine field activities in Q3 2018
  - New BA anticipated for subsystem testing in late 2018/2019.
- ORPC met with NOAA Protected Species Division on May 2 to discuss field activities and associated permitting.

ID	Task Name	Duration	Start	Finish	Predecessors
1	**Turbine load / performance testing**	**130 days**	**Mon 7/2/18**	**Fri 12/28/18**	
2	Build and test prep	5 mons	Mon 7/2/18	Fri 11/16/18	
3	Conduct tests	1.5 mons	Mon 11/19/18	Fri 12/28/18	2
4	**Anchor-holding capacity validation**	**80 days**	**Mon 12/31/18**	**Fri 4/19/19**	
5	Build and test prep	3 mons	Mon 12/31/18	Fri 3/22/19	3
6	Conduct tests	1 mon	Mon 3/25/19	Fri 4/19/19	5
7	**System deployment & retrieval testing**	**170 days**	**Tue 1/1/19**	**Mon 8/26/19**	
8	Build and test prep	7 mons	Tue 1/1/19	Mon 7/15/19	
9	Conduct tests	1.5 mons	Tue 7/16/19	Mon 8/26/19	8
10	Composite structural & coupon testing	4.5 mons	Mon 7/2/18	Fri 11/2/18	
11	Composite accelerated life testing	12 mons	Mon 11/5/18	Fri 10/4/19	10
12	Composite turbine joint testing	2 mons	Mon 7/2/18	Fri 8/24/18	
13	**Full system verification in Cobscook Bay**	**200 days**	**Wed 8/21/19**	**Tue 5/26/20**	
14	System integration	8 mons	Wed 8/21/19	Wed 4/1/20	15SF
15	Deploy in CB	2 mons	Wed 4/1/20	Tue 5/26/20	
16					
17	**Full system validation deployment in Western Passage**	**91 days**	**Wed 5/27/20**	**Wed 9/30/20**	
18	Site and system preparation	4.5 mons	Wed 5/27/20	Tue 9/29/20	15
19	Deploy TidGen® in Western Passage	0 days	Wed 9/30/20	Wed 9/30/20	18FS+1 day



Project Management

Project Management
Schedule

- One change proposed to current plan (MOD 0004)
- Extend BP2 by one month to October 2020 (detailed planning since February)
- Shift BP3 to right by one month, no change to duration
- Alternative plan to be discussed

Project Management

Issues

1. LCOE targets are met and project has been within budget to date, but total project costs have increased
   - Larger system proposed with considerable conservatism
   - Subsystem testing focused on reducing size of system and deployment vessel
   - ORPC will cover added budget
2. All costs are incurred in BP2, which includes full system deployment in Cobscook Bay

ORPC

Project Management

Summary of Project Costs

CATEGORY	Budget Period 1	Budget Period 2	Budget Period 3	Total Costs	% of Project
a. Personnel	$396,975	$437,533	$325,767	$1,160,275	10.00%
b. Fringe Benefits	$80,943	$89,213	$66,424	$236,580	2.04%
c. Travel	$12,145	$20,079	$23,420	$55,644	0.48%
d. Equipment	$0	$3,604,518	$0	$3,604,518	31.07%
e. Supplies	$4,500	$65,000	$15,000	$84,500	0.73%
f. Contractual					
Sub-recipient	$103,111	$496,191	$331,027	$930,329	8.02%
Vendor	$245,500	$1,335,500	$1,326,025	$2,907,025	25.06%
FFRDC	$0	$0	$0	$0	0.00%
Total Contractual	$348,611	$1,831,691	$1,657,052	$3,837,354	33.08%
g. Construction	$0	$0	$0	$0	0.00%
h. Other Direct Costs	$40,000	$150,000	$85,000	$275,000	2.37%
Total Direct Costs	$883,174	$6,198,033	$2,172,663	$9,253,871	79.76%
i. Indirect Charges	$367,047	$1,077,865	$902,959	$2,347,871	20.24%
Total Costs	$1,250,222	$7,275,898	$3,075,622	$11,601,742	100.00%

Project Management

Issues – Proposed Alternative

- End BP2 after subsystem testing, ORPC to propose modified design and new BP3 budget prior to full system procurement
- BP3 will include both installations in Cobscook Bay and Western Passage
- System procurement costs split over BP2 and BP3

Project Management

Issues - Proposed Alternative

- Schedule will shift out ~6 months due to delay in procurement
- Procurement will be split over BP2 and BP3
- DOE does not commit full project budget in BP2
- Budget is not committed until reduced design is completed

Questions?

ORPC

Thank you!