PRELIMINARY IO&M AND TESTING PLAN
D7.2.2
ADVANCED TIDGEN® POWER SYSTEM
DE:EE0007820

April 30, 2018

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Purpose

This document presents the Preliminary IO&M and testing plan completed during Budget Period 1 (BP1) by ORPC and its partners for the Advanced TidGen® Power System Project, DE- EE0007820. The document is excerpted from the Continuation Application submitted by ORPC on April 30, 2018.

From Section 3.2.2 of the Continuation Application:

IO&M

In 2012, the first TidGen® device was installed in Cobscook Bay utilizing a piled foundation, which required extensive, costly geotechnical survey and on-water effort on the order of several weeks to install the system. The Advanced TidGen® 2.0 Power System has adapted the Buoyant Tensioned Mooring System (BTMS) that reduces on-water deployment time to within a tidal cycle. The device has been designed to match the resources typically available in remote regions, such as Igiugig, Alaska, which are the immediate commercial market for ORPC's technology.

The system has been designed to meet requirements throughout the entire lifecycle concept of operations, detailed in Table 4.

Table 1. TidGen 2.0 Concept of Operations Overview

#	ConOps Phase	High Level Description
1	Component Fabrication, QA/QC, Shipping	Project development and site characterization, project specific design modifications, component fabrication and verification, subsystem validation (including system alignment), system shipping.
2	Subsystem Integration & Land Based Testing	On-site system receiving, assembly, and final pre-installation system validation tests. Modular shipping components can be lifted with standard lifting equipment and integrated using specialized assembly jig.
3	Deployment	Mooring system installation using specialized deployment barge. P&D cable installation. Transition of device from the staging location to water. Device towing and connection to mooring system.
4	Commissioning	Initial system start-up, operational checks, completion of training for local personnel, and system hand-off.
5	Normal (Deployed) Operations	In water operations and power production, monitoring, and data collection.
6	Annual (routine) Maintenance	Routine in-situ inspections of the device and mooring system using submersible inspection equipment.
7	5 yr (routine) Maintenance	Device removal to laydown area using specialized deployment barge system. On land device inspections and component replacement. Re-deployment following initial deployment procedures.
8	Unplanned Shutdown/ Maintenance	This mode includes troubleshooting for any unexpected operational conditions as well as possible device retrieval and repairs.
9	Decommissioning/ Removal	Following the completion of the project life, this step includes device retrieval, device removal, and the removal of P&D cables and the mooring system. This step represents the completion of on-water operations.

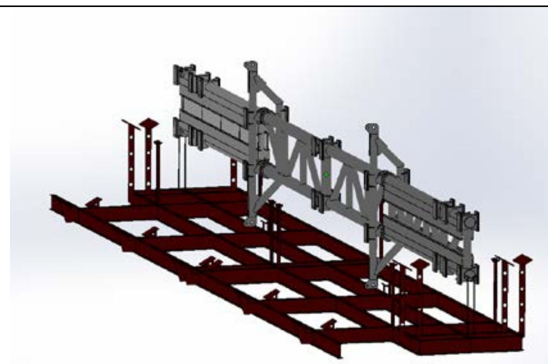
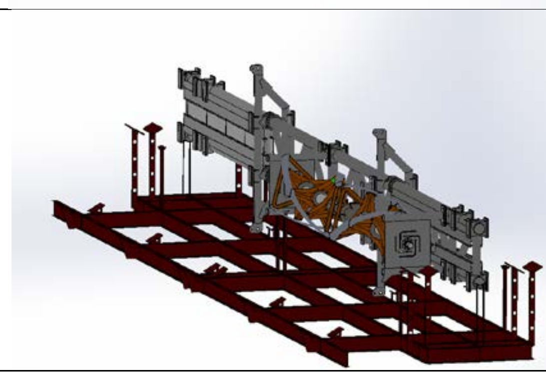
10	Disassembly & Disposal	This step includes on-site disassembly, component shipping out of the project location, and disposal/reconditioning of all Sub-Systems and components.

The strategy for onsite build and installation is as follows:

- The TGU device will be fully assembled, aligned and tested in a manufacturing facility.
- The device will be disassembled into modular sections suitable for transportation using commonly used shipping containers or standard flatbed trailers. Modular sections will maintain turbine, drivetrain, generator and chassis alignment in such a manner to minimize onsite reassembly resource and labor requirements.
- Onsite assembly of the device will utilize equipment typically available in remote regions. ORPC has assumed equipment is limited to a 20T crane, CAT 966 loader, CAT 330 excavator or equivalent, with sections limited to 10,000kg based on preliminary discussions with a shipper in northern Quebec regarding likely available equipment for shipping and transportation.
- Onsite assembly and maintenance of the device will not require technically skilled labor, and maintenance strategies will be limited to inspections and unit replacements.
- Onsite marine vessel power limit, for tug of system and anchors to deployment site, is equal to 250Hp (total net power).

Table 5 provides a storyboard for onshore assembly. An assembly platform/jig will be quickly constructed, and modular sections will be lifted or slid out of containers for sequential assembly.

Table 2. Major assembly steps for the TidGen® device

Assembly Step 1: Assemble the main structural chassis in the assembly frame using bolted connections. Mooring connection spars pin to frame to avoid overturning moment	
Assembly Step 2: Attach turbine pairs to main structural chassis (x4) Connections are pre-aligned bolted Chockfast connections. Driveline components connect via flexible couplings and ETP connections.	

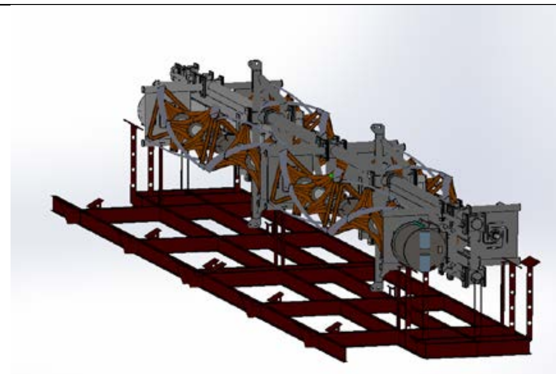
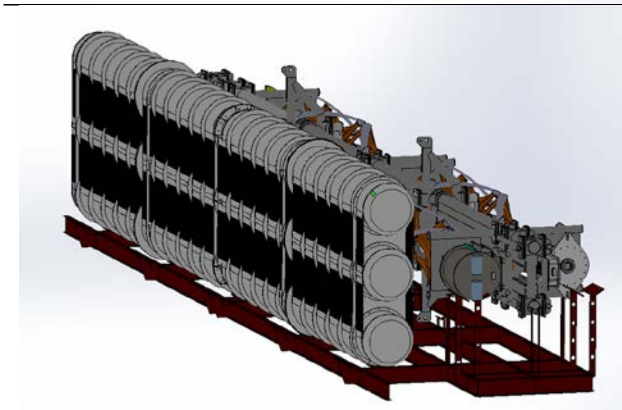
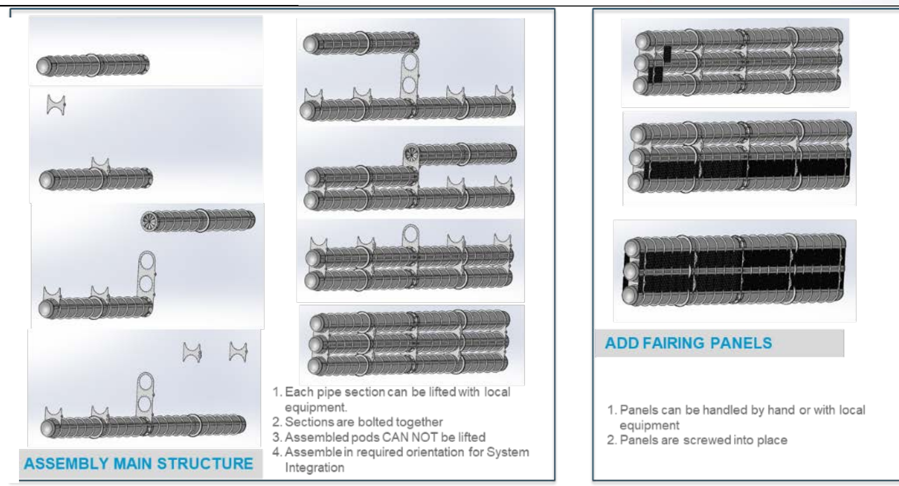
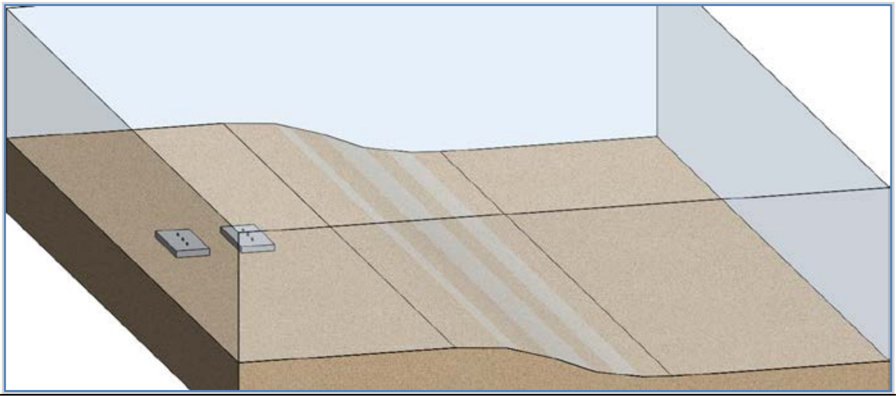
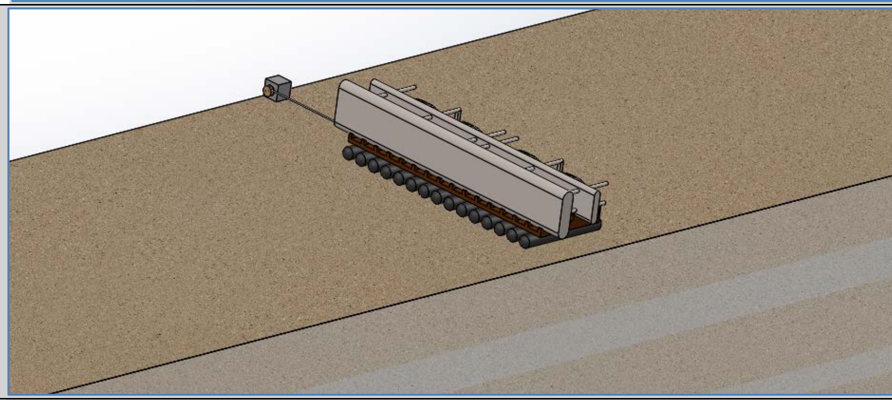
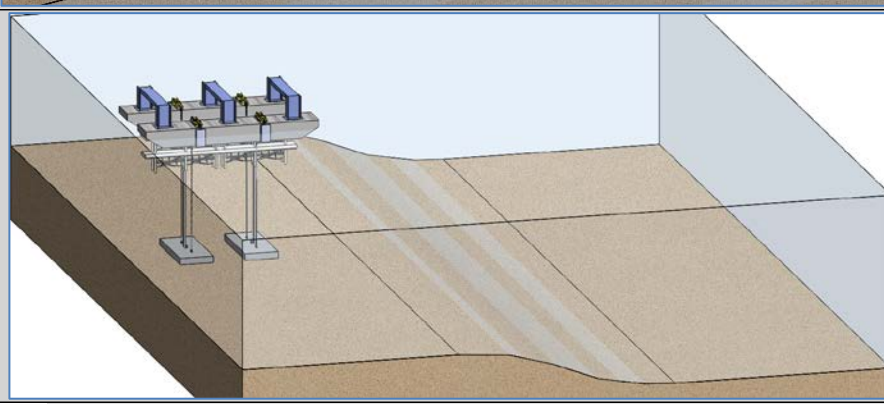
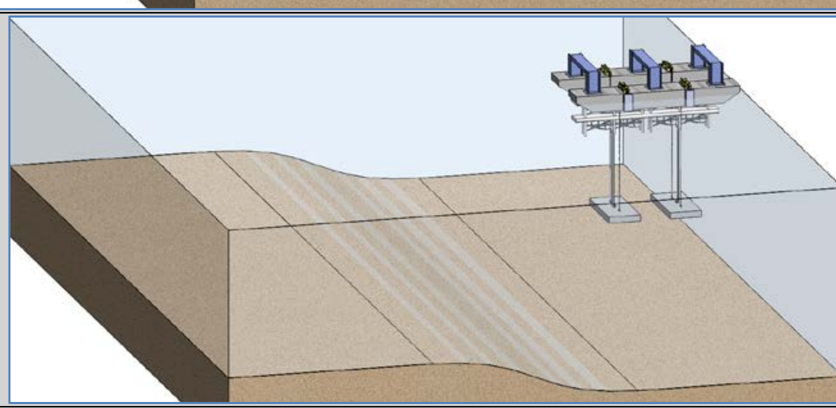
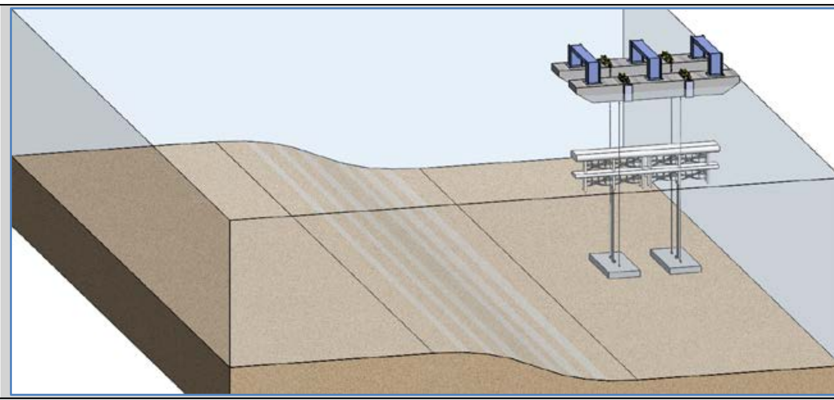
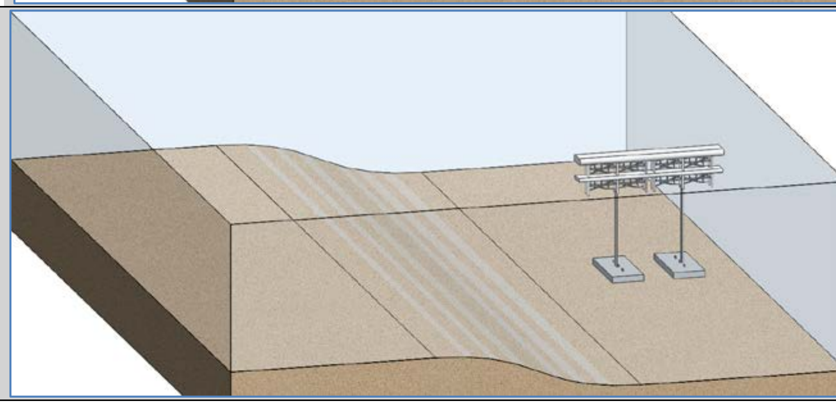
Assembly Step 3: Attach generator assemblies and mechanical brake / converter frame assemblies (x2 each) Connections are pre-aligned bolted Chockfast connections. Driveline components connect via flexible couplings and ETP connections.	
Assembly Step 4: Buoyancy pod sections one at a time (x6 – see below) Pod-to-pod connections utilize bolted flange connections. Pod-to-chassis connections are pinned.	
Assembly Step 4 (detail): Buoyancy pod sections are built in place on the assembly rig. Sections are bolted together and pinned to the chassis as they are “stacked”	

Table 6 provides a storyboard of the launch and deployment of the power system. The anchors will be built nearshore by either pumping a slurry into a containment structure and frame, or by dropping smaller modular concrete or iron slurry into the frame. The TGU will be launched on roller bags, similar to what is done in the shipping industry, on top of its assembly frame. The TGU will be oriented for assembly with divers to the mooring system, with the aid of the deployment rig, mirroring the operations performed for the OCGen® mooring project in 2014.

Table 3. Illustration of the deployment operations, utilizing roller bags for launch and a deployment rig that carries the fully assembled TidGen® TGU and mooring system to site.

Deployment Step 1: Stage/Build gravity anchors at a near shore, low flow site.	
Deployment Step 2: Use airbag rollers to deploy the assembled device.	
Deployment Step 3: Attach device to deployment barge and position over anchors and connect device to anchors	
Deployment Step 4: Lift full system with tide and bring device to deployment site.	

Deployment Step 5: Lower device and anchors and detach from barge.	
Deployment Step 6: Connect device to pre staged power and data cables with a pig tail connection on the surface.	

A major goal of Budget Period 2 will be to de-risk these operations during deployment subsystem testing and then the system verification installation in Cobscook Bay, which is a low-energy resource site. ORPC will verify tooling and validate supply chain, assembly, operations and maintenance procedures.

Development Test Plan

Budget Period 2 (BP2) will entail subsystem testing focused on refining design models and risk mitigation, ending with a full system verification installation in Cobscook Bay. The test program will be based on a sequential approach that addresses conservative design factors based on DNV GL standards to reduce likely overdesign in the system.

In 2018, efforts will primarily focus on composite development and production of the first turbine assembly, targeting barge testing for performance and drag loads. Composite analysis will refine characterization models for the selected material sets and begin an accelerated life testing program focused on high stress areas of the turbines. Loading results from turbine testing will inform cumulative damage models to quantify anticipated component life of the composite turbines. Results will also hone-in our assumptions to reduce both structure and weight, particularly for anchor requirements. Post-test inspection data will be compared to characterization testing results prior to production of the full system set of turbines.

Primary activities in 2019 will focus on model-scale anchor evaluation in Western Passage and deployment system testing. Anchor holding efficiency estimates will be derived from the model-scale testing, which will be used as well to reduce conservative design assumptions and overall anchor weight.

The results will inform full-system anchor design as well as the test mooring requirements for the deployment system testing. The deployment system testing will target critical operational risks, such as near-shore anchor construction, connections between the mooring system and TidGen® TGU (turbine generator unit – the device without the mooring system and electrical transmission infrastructure). Development and verification of assembly, launch and deployment procedures, in terms of operational safety and risks, are priorities of the testing.

DNV GL will be utilizing testing activities and full system integration to complete several steps in the certification process, including final design assessments, manufacturing and transportation assessments, and full system test plan certification.

The following overviews development test activities for the DOE Advanced TidGen® Project.

Turbine load / performance testing

- **Components under test:** Turbine and fairing structure. The turbine will be the first build of the TidGen® 2.0 turbine.
- **Description:** This test includes a single full-sized turbine mounted in a controlled environment (on a test barge) to measure single turbine loads. The test barge will be subject to a range of inflow velocities which will also be measured. The general test set-up is similar to previous ORPC tests, with load cells added to a holding frame as the primary measurement instruments. (Reference Figure 1.)
- **Objectives:** A performance curve will be generated and drag loads will be measured to reduce conservative design assumptions primarily for the mooring system requirements, especially for anchor holding capacity. CFD models will be refined. As part of the composite development effort, the turbine will be inspected before and after operation to assess any degradation of the composite structure, particularly for the impact of manufacturing defects under operational loading.
- **Key risks:** Integrity and performance of first composite turbine build; sensor/instrumentation package for load measurements.
- **Schedule:** Testing is targeted for Q4 2018 through Q1 2019.
- **Facilities, equipment & resources:** Barge testing will occur off the coast of Maine, in either Cobscook Bay or Castine, Maine. Equipment includes a test barge used by ORPC in prior projects for similar test purposes and power electronics / load for controlling the generator torque and dissipating power.

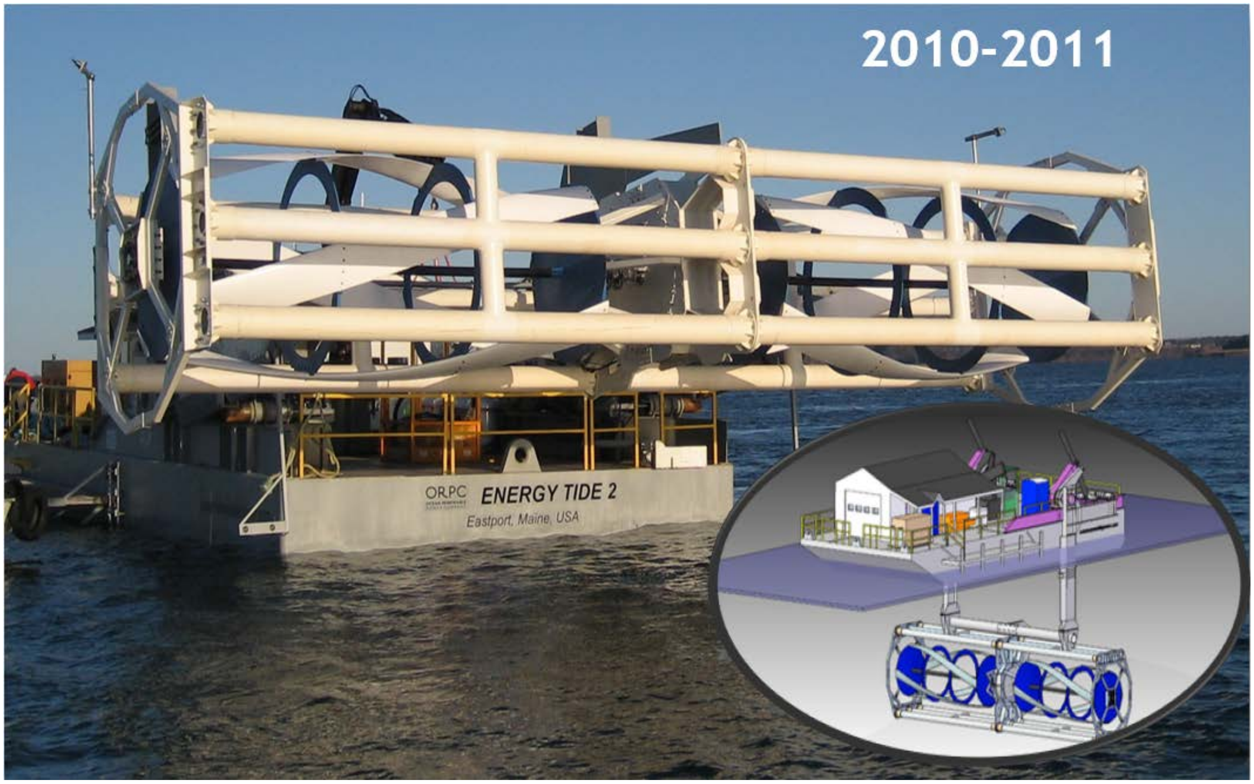


Figure 1. The turbine performance testing of the Advanced TidGen® turbines will be performed in a barge tow test similar to several tests performed by ORPC on earlier turbine designs.

Anchor-holding capacity validation

- **Components under test:** Model-scale gravity anchors.
- **Description:** Pull tests on scaled anchors (1 metric ton) at the deployment site will measure frictional forces between gravity anchors and bottom. Skirts and other potential modifications will be assessed. Several “pulls” will be performed around the deployment area. Primary measurements will be anchor position and applied mooring line loads. (Reference Figure 2.)
- **Objectives:** Anchor efficiency measurements will be used to reduce conservative design assumptions. The effect of skirts or other modifications will be assessed for effectiveness. The results will inform final anchor design, as well as the deployment subsystem testing to occur later in the year.
- **Key risks:** Bottom profile/interface uncertainty; sensor/instrumentation package for load measurements.
- **Schedule:** Testing is targeted Q1 to Q2 2019.
- **Facilities, equipment & resources:** Testing will occur at the deployment site area identified in Western Passage, off the coast of Eastport, Maine. Equipment includes a test barge and/or large boat with a crane capable of managing metric ton anchors.

Figure 2. Anchor pull testing will be performed off a boat capable of deploying a 1 metric ton anchor, with instrumentation capable of determining pull loads for holding capacity estimates.

System deployment & retrieval testing

- **Components under test:** Subsystem testing of buoyancy pod, bridle interface with mooring system, mooring system and anchor.
- **Description:** The testing will assess and verify the deployment and mooring system design including critical operations from onsite assembly, near shore assembly, transit, and deployment offshore. A section of the buoyancy pod will utilize the bridle and mooring system rigging to smaller scale anchors. The test well replicate ORPC's prior deployment of the 2014 OCGen® buoyant tensioned mooring system project sponsored by the U.S. Dept. of Energy. A deployment rig with external equipment, such as winches and float bags, will be assessed for safety and functionality, as well as the connecting and detachment of anchors in critical operations during deployment and retrieval. The system will be moored over a short duration to verify dynamic stability and predicted movements of the system throughout a tidal cycle. (Reference Figure 3.)
- **Objectives:** The test will verify the bridle and mooring system interface design, and of attachment and detachment methods. Critical operations will be verified for anchor deployment, system launch, and on-water operations of external equipment. Tooling requirements for full system deployment will be finalized.
- **Key risks:** New component interfaces, offshore attachment/detachment operations, bridle functionality throughout tidal cycle, test anchor holding capacity.
- **Schedule:** Testing will be performed in Q3 2019.
- **Facilities, equipment & resources:** The test will require a deployment site with launch ramp and required crane for test system assembly and launch, either in Cobscook Bay or Western Passage. A tug and barge outfitted with winches will be used for transit and offshore deployment and retrieval.

Figure 3. Potential test system for the deployment and retrieval subsystem test. Diver is included only for size reference, as it is not anticipated that a diver will be required except for near shore connections to the anchors. Anchors will be gravity anchors of undetermined design.

Composite structural testing & accelerated life testing

- **Components under test:** Composite coupons of candidate material sets, critical high stress structural sections of the turbine (foil/strut joint)
- **Description:** Static and dynamic (fatigue) testing will be performed on carbon fiber/glass fiber epoxy laminates, one with hydrophilic resin and the other with hydrophobic resin, for further characterization of failure mechanisms of saturated composites under representative loading. Water uptake and diffusion rates will be analyzed, along with the impact on resin to fiber bonding, both for carbon and glass fibers. The impact of typical manufacturing defects on material degradation will be characterized, particularly with respect to water uptake, stress concentrations and static and dynamic failure. A second phase of testing will be an extensive accelerated life program for the finalized turbine composites towards development of component life models, to be performed in parallel with on-water system installations. (Reference Figure 4).
- **Objectives:** Testing will inform final composite designs of the second through eighth TidGen® turbines, along with inspection of the first turbine after its performance testing. Cumulative damage models will be developed, for utilization and validation for eventual full system deployments.

- **Key risks:** Durability of composite material sets determined from accelerated life testing; inadequate manufacturing quality or process control methods; inability to get statistically significant results
- **Schedule:** Testing will occur over an extended duration, from Q3 2018 through Q2 2020.
- **Facilities, equipment & resources:** Coupons will be produced by the turbine manufacturer and tested at laboratory facilities at CERL (Composites Engineering Research Laboratory) and Montana State University.

Figure 4. Coupon testing performed at Montana State University in budget period 1. Static and dynamic (fatigue) tension testing were performed as a preliminary evaluation of composite material sets in both dry and saturated (aged) states. Efforts in budget period 2 will focus on two material sets for comprehensive characterization of failure in accelerated life testing.

Composite turbine joint testing

- **Components under test:** Candidate joint geometries of foil to strut connection
- **Description:** Structural testing will be performed prior to and during the first turbine build to evaluate structural integrity and fatigue performance.
- **Objectives:** Determine the best joint geometry in terms of durability for the composite turbine from a selection determined by ORPC and the manufacturer.
- **Key risks:** Primary risks are schedule and manufacturer's resources to perform sufficient testing for evaluation prior to the first turbine build; results of test may require an additional turbine to be built to replace the first one for the final system integration.
- **Schedule:** Q3 through Q4 2018
- **Facilities, equipment & resources:** Testing will be performed either at the manufacturer's facility or at Montana State University.

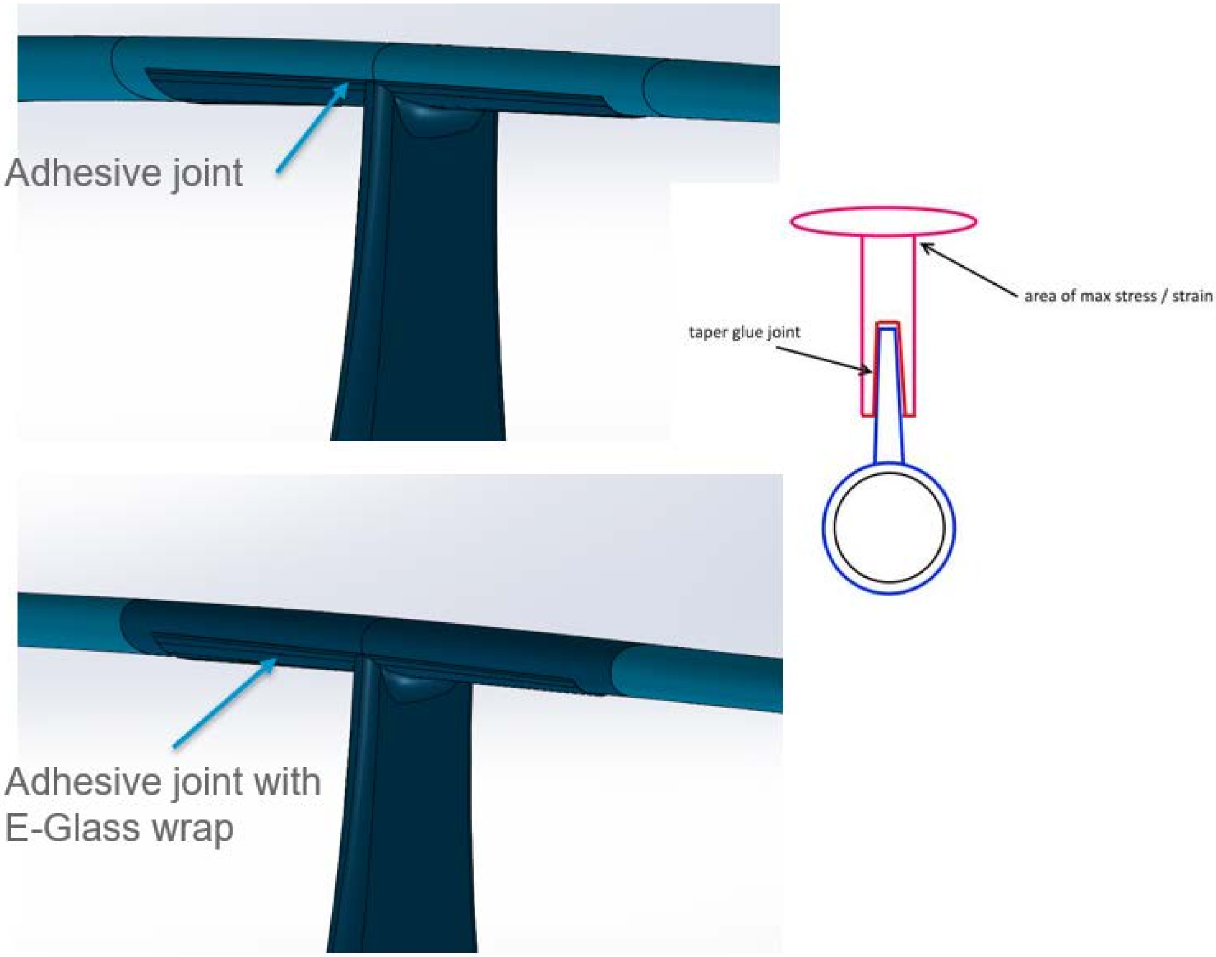


Figure 5. Potential bonded joints between foil and strut. Joint testing would be performed by the manufacturer to verify predicted structural properties prior to the first turbine build.

Full system verification deployment in Cobscook Bay

- **Components under test:** Full TidGen® system with mooring system adapted for Cobscook Bay's shallower depths and seabed type.
- **Description:** The system will be fully integrated and deployed at the lower flow resource in Cobscook Bay, where ORPC had previously deployed its first-generation system in 2013. The system will be validated and verified throughout the concept of operations, from supply chain through onsite assembly, deployment, operations and retrieval.
- **Objectives:** Validation of manufacturing, transportation, onsite assembly, launch, deployment and retrieval methods. Verification of system integration build, system shakedown, control system, instrumentation and SCADA systems. Verification of mooring system throughout tidal cycle. Verification of system performance throughout tidal cycle. Post-system inspection of components including composite turbines.
- **Key risks:** Risks are identified per the system FMEA; in addition, first time integration and operations have a higher likelihood of identifying design and operational issues requiring modification or major redesign.

- **Schedule:** Q2 2020
- **Facilities, equipment & resources:** Prepared deployment site; all required tooling for assembly, launch and deployment/retrieval; electrical infrastructure for grid transmission.

Notes on Additional Testing

Note that the driveline design concept was validated in a prior project sponsored by the U.S. Dept. of Energy. The testing was performed at the University of Maine ASCC in 2017, consisting of a driveline configuration with bearing housings encapsulated with water, and operated under representative full loads measuring deflections, torque and heat losses, including under induced misalignment. Critical outcomes were driveline frictional measurements and temperature changes under various loading conditions.

The full system validation installation will occur from Q3 2020 through Q4 2021 in Western Passage.

Development Testing Schedule

The following is the anticipated schedule for performing the development tests.

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

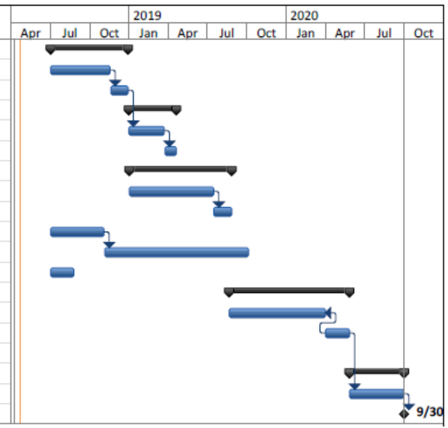


Figure 6. Development test schedule.