DELIVERABLE D2.1:
MATERIAL SET SELECTION FOR COMPOSITE CHARACTERIZATION PROGRAM

ADVANCED TIDGEN® POWER SYSTEM
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1 Purpose

This document is deliverable D2.1, a technical report on the composite trade study, which fulfills milestone 2.1 for the project.

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Project Title:	Advanced TidGen® Power System
Prime Recipient:	ORPC Maine
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The document provides details regarding material set selection for Task 2 of the Advanced TidGen® Power System project. The material sets selected are to be tested by Montana State University (MSU) for evaluation to select a single material set for production of the turbine foils.

2 Required Material Properties

A key element to achieve deliverable 2.2, *Test report on characterization program, composite testing and selected composite structure*, is the need for a master set of materials that can be down selected. A material set consists of a resin and a reinforcement material in different orientations and quantities. Each of the resin types have different mechanical properties, as do the reinforcement materials.

The turbine foils will experience a reversing load with each turbine revolution. The cyclic loading on each foil is in the range of one hundred million cycles over the turbine life.

3 Material Set Selection

The material sets for this project were compiled by BluSource Energy, LLC, based on their experience and expertise with composites, as well as with input from Composites Engineering Research Laboratory (CERL) based on their expertise with resin chemistry selection. Three resin types and two reinforcement materials were selected for the initial round of testing. The marine hydrokinetic (MHK) database published by Montana State University (MSU) and Sandia National Laboratories was also used in the selection of candidate material sets.

3.1 Resin

When selecting resin systems for the candidate material sets the following parameters were considered:

- Elongation (strain to failure)
- Glass transition temperature (Tg)
- Modulus
- Permeability rate
- Water absorption at saturation
- Pot life
- Cost of materials
- Availability

The resins of interest are epoxy, vinyl ester, and urethane acrylate. Two epoxy manufactures were selected, Pro-Set Inc. and Hexion Inc., both for their products' mechanical properties as well as their availability in the U.S. The vinyl ester was provided by Ashland LLC, and the urethane acrylate was provided by Scott Bader Company Ltd. The vinyl ester is being evaluated in a glass only composite. The urethane acrylate resin is being evaluated as the manufacturer promotes this resin chemistry as able to deliver laminates with high strength, toughness and exceptional water and hydrolysis resistance. Each of these resins can be vacuum infused; the expected manufacturing process for the turbine foils.

3.2 Reinforcements

Glass and carbon reinforcement were selected for the candidate material sets. There are many manufactures of both materials and each material comes in many forms. The following parameters were used to determine the material suppliers and form factor:

- Infusibility
- Ease of handling
- Fiber straightness (uni fabric architecture)
- Compression strength of interest
- Cost
- Availability

Because of the long span of the foils and the proposed vacuum infusion manufacturing process, sheet form as opposed to strands form was selected. There was also an option to select pre-preg material, which have resins impregnated into the material that are activated when heat is applied. These pre-preg materials were more expensive, require cold storage, and in-autoclave processing, and so they were eliminated from the selection process.

3.2 Laminate Layup

The baseline TidGen® 1.0 turbine foils consisted of both glass and carbon with an epoxy resin system. The glass was orientated with a +/- 45-degree angle, and the carbon was in the unidirectional orientation. The carbon was orientated to take the tensile and compressive loads and provide rigidity while the glass provided rigidity and mechanical support. For the Advanced TidGen® turbine foils, the same basic principles were applied.

The material sets utilizing the epoxy resin and urethane acrylate have +/-45-degree glass layered with unidirectional carbon. Vinyl ester performed best with a glass only composite, so for this reason the unidirectional carbon was replaced by unidirectional glass for vinyl ester resin. The material set selection (Table 1) comprised seven materials sets shown with the resin type, reinforcement type and the post cure schedule.

3.3 Post Cure Schedule

The post curing of each material set differs slightly. Utilizing the MHK Wind & Materials database[1] and the manufacturers specifications, the desired post curing schedule for each material set was identified. It is desirable to post cure at the lowest possible temperatures when working with large parts to reduce the need for large high temperature ovens. Typically, the manufacture will specify different post curing temperatures for different durations, so it may be possible to cure a part at lower temperatures over a longer period.

3.3 Material Set Selection

Based on the above considerations, the Project team (ORPC, BluSource, CERL) selected 7 material sets for testing (Table 1).

TABLE 1: MATERIAL SET SELECTION

Set	Resin Type	Resin/Hardener	Uni Fiber	Laminate	Post Cure*
#1	Epoxy	PRO-SET INF-114 Resin/ 211	Zoltek UD600	#1 Carbon/Glass Hybrid	Baseline 8hrs @ 60°C
#2	Epoxy	PRO-SET INF-114 Resin/ 211	Vectorply CLA-1812	#1 Carbon/Glass Hybrid	Baseline 8hrs @ 60°C
#3	Epoxy	Hexion EPIKOTE™ Resin MGS™ RIMR035c/0366	Zoltek UD600	#1 Carbon/Glass Hybrid	Baseline 12hrs @ 70°C
#4	Epoxy	Hexion EPIKOTE™ Resin MGS™ RIMR035c/0366	Vectorply CLA-1812	#1 Carbon/Glass Hybrid	Baseline 12hrs @ 70°C
#5	Urethane Acrylate	Crestapol 1250LV	Zoltek UD600	#1 Carbon/Glass Hybrid	5hrs @ 80°C
#6	Urethane Acrylate	Crestapol 1250LV	Vectorply CLA-1812	#1 Carbon/Glass Hybrid	5hrs @ 80°C
#7	Vinyl ester	Ashland AME 6001	Vectorply ELT 2900-10	#2 All Glass	Baseline 24hrs @ 60°C

**Source: PM28 BLS ORPC TidGen Testing Materials and Laminates Rev 3.*

The final laminate thickness for the foils will be roughly 9 mm thick, depending on the mechanical performance of the chosen material set. The laminate thickness for the coupon testing is roughly 4mm thick, with a layup representative of the proposed foil design (Veil, (+/-45), $(0)_2$, (+/-45), Veil). The turbine foil design will have alternating layers of +/-45 and 0-degree reinforcement material until the desired laminate thickness is reached.

[1] http://energy.sandia.gov/energy/renewable-energy/water-power/technology-development/advanced-materials/mhk-materials-database/

4 Conclusion

The list of selected material sets covers a wide range of performance characteristics. Carbon fiber is more expensive, and so by evaluating the glass only vinyl ester composite it will be possible to determine if this material set is acceptable for the Advanced TidGen® turbine design. If it proves to perform in an equal manner to that of a carbon and glass composite it will be an attractive material choice.

REVISION HISTORY

Revision	Date	Description	Author	Reviewer
00	8/17/17	Initial release	M. Barrington	J. McEntee