LCOE GUIDANCE DOCUMENTS

Next Generation MHK River Power System, Optimized for Performance, Durability, and Survivability

FOR **DE-EE0007348**

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1 Purpose

The purpose of this LCOE Guidance Document is to provide documentation of LCOE calculations and base data for ORPC's RivGen 1.F Power System, The "Baseline" configuration that was demonstrated in the Kvichak River at Igiugig, Alaska in 2015.

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Project Title:	Next Generation MHK River Power System, Optimized for Performance, Durability, and Survivability
Prime Recipient:	Igiugig Village Council
Principal Investigator:	Alexanna Salmon

2 LCOE Calculations

The following equation is used to calculate LCOE:

$$\text{LCOE} = \frac{(\text{ICC} \times \text{FCR}) + \text{O\&M}}{\text{AEP}}$$

Where:

- **ICC**, installed capital costs, represents all capital expenditures associated with the planning, design, manufacturing, deployment, and project management of a project.
- **FCR**, fixed charge rate, is the annual return, represented as a fraction of installed capital costs, needed to meet investor revenue requirements.
- **O&M**, operations and maintenance, includes all routine maintenance, operations, and monitoring activity (i.e. non-depreciable).
- **AEP**, annual energy production, describes the average annual energy generated (after accounting for device or array availability) and delivered to the point of AC grid interconnection (i.e., the measurable basis for power purchase contracts).

2.1 Operating Parameters

Table 1 summarizes the operating parameters for baseline project, which consists of 1 35kW RivGen®-1.F unit.

Table 1. Operating Parameters for Baseline Project

Category	Baseline
Device Rating (kW)	22.5
System Design Life (years)	20
Max Sustained Flow (m/s)	2.5
Water Density (kg/m^3)	1,025
Capture Radius (m)	0.7
Total length (m)	8.2
Cut in Speed (m/s)	0.7
Ideal Turbine C_p	0.43
Max Tip Speed Ratio	1.9
Mechanical Losses	10%
Generator Efficiency	80%-95%
Energy Loss	1%
Transmission Loss	4%
Power Conversion Efficiency	93%
Availability	76%

2.2 Capital Costs

Estimated baseline capital costs (Table 2) were established by ORPC, strictly following the DOE guidelines based on the CBS included in Appendix A.

Table 2. Summary of Baseline Capital Costs

Component	Baseline $
Marine Energy Converter	**$1,165,937**
Balance of System	**$1,004,831**
Development and Engineering	$697,000
Equipment	$161,664
Assembly & Installation	$146,167
Financial Costs	**$215,727**
Total Capital Expenditures	**$2,386,495**

3.3 Annual Operating Expenses

The annual operating expenses for demonstration units are highly dependent on the failure frequency of primary components and typically require substantially more time to repair. A consequence of this, amplified by the DOE guidelines, is that the O&M for the baseline project is many time larger than what would be expected for a commercial installation. In this particular instance, maintenance costs for the demonstration unit installed in Igiugig are representative of full driveline replacement every 4 years, 100% chance of generator, ballast system, and transmission cable full replacement once in the 20 year lifetime of the project, a 50% chance of power electronics and turbine replacement over the 20 year project lifetime and a 25% chance of mooring system and pontoon replacement over the 20 year project lifetime. Due to the lack of reliable data for failure occurrences, most replacement costs were estimated based on infield experience. Costs associated with non-maintenance (i.e., environmental monitoring) were scaled based on the Igiugig incurred costs for the deomonstration phase with a learning curve model applied over time.

Results of the O&M analysis are presented in Table 3.

Table 3. Summary of Baseline Operations & Maintenance

Category	Baseline
Operations	**$151,253**
Environmental, Health & Safety Monitoring	$84,122
Annual Leases/Fees/Admin	$40,678
Insurance	$26,552
Maintenance	**$106,339**
Total O&M	**$257,592**

3.3 Annual Energy Production

ORPC has gone through many steps to calculate an annual energy production estimate and is detailed further in a separate spreadsheet. Based on the DOE LCOE Guidance document ORPC calculated the LCOE based on AEP as defined in the Gudiance Document. The sequence of caculations to determine AEP is depicted in FIGURE 1 below.

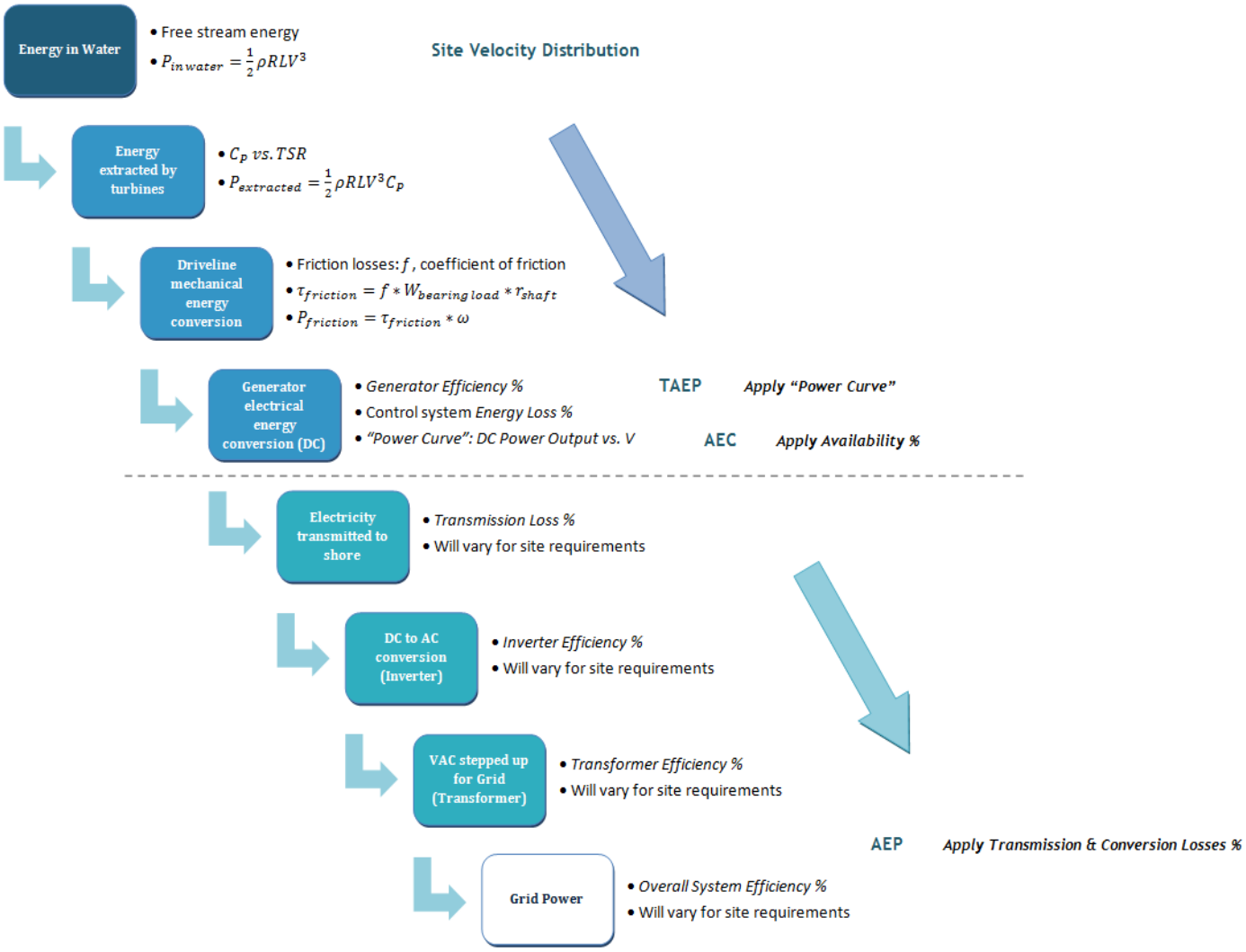

Figure 1. Derivation path for LCOE

3.3.1 Site Velocity Distribution

The baseline AEP modeled here utilizes data from the Kvichak River near Igiugig Alaska. The velocity distribution of this reference resource is shown in FIGURE 2. This data this is based on is presented in Appendix B section A.5.

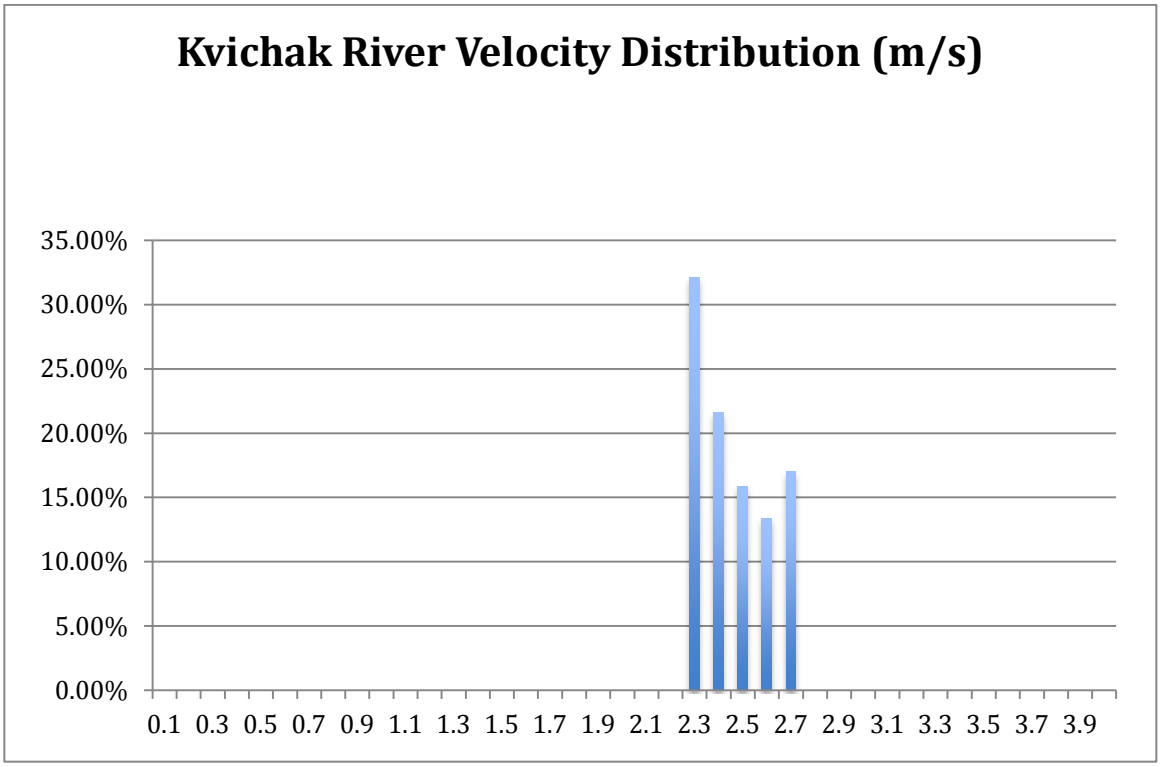

Figure 2. Kvichak River velocity distribution

For a given Tip Speed Ratio (TSR) the Coefficient of Performance (Cp) was plotted based on data collected in 2015 and analyzed by researchers at the University of Washington (Figure 3).

Using the Cp, cut in speed, and power limited operation; the power curve for the baseline generator can be created, and is represented in Figure 4.

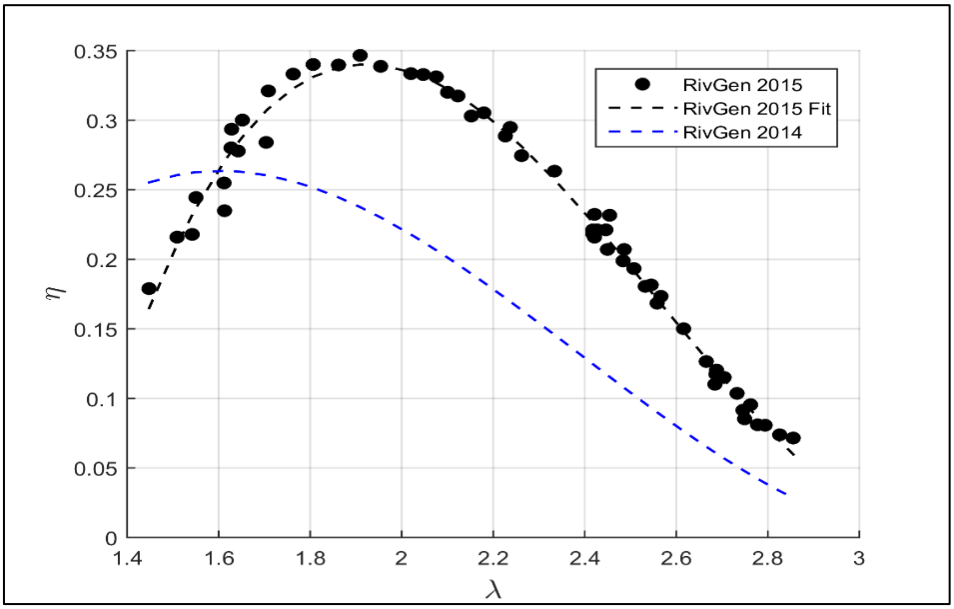

Figure 3. Coefficient of performance vs. tip speed ratio

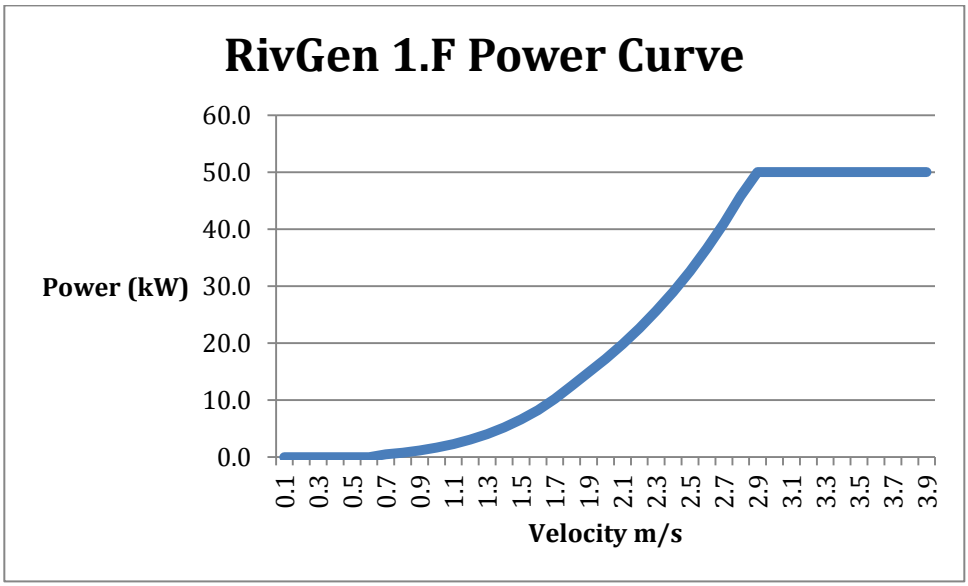

Figure 4. Baseline power curve

The Cp, coupled with the parameters in Table 1, and the resource probability for Kvichak River yield the calculated AEP in Table 4. The following inputs and assumptions are used to calculate the AEP:

- Power limited operation (max output of 50 kW)
- Coefficient of Performance at optimum TSR of .431 – derived from field operation measurements and loss estimates
- Mechanical losses – estimated as %10. Drivetrain with roller bearings and a moderately compliant design.Due to evidence of water penetration in the bearings, the estimate is slightly better than the

original TidGen® estimates of 13-15% , that used Vesconite sleeve bearings and a stiffer overall design more sensitive to static and dynamic misalignments

- Generator efficiency based on manufacturers generator performance curve (Appendix B, FIGURE 7)
- Power transmission and conversion efficiency of 89%
- Annual availability of 76.3% with the following assumptions:
    - 42 days of planned down time per year per unit
    - 38 days of un-planned down time per year per unit
    - 5 days of grid outages
    - 2% additional downtime for remainder of faults

Table 4. Summary of baseline annual energy production

Category	Baseline
Availability (%)	76.3 %
TAEP (MWh/unit)	276.6
Net AEP (MWh/unit)	188.8
Number of Units in array	1
Total AEP (MWh/project)	**188.8**

The following are reporting requirements for AEP calculations per the LCOE guidance, and can be found in Appendix C:

- Device C_P Curve
- Device Power Curve
- Itemized Losses between Device Mechanical Power and Power Capture Matrices, preferably in "curve" form
- Description of Device Losses Estimation (i.e. field test data or modeled performance)
- Array Loss Factor
- Description and Justification of Array Calculations
- Availability Losses
- Description and Justification of Availability Loss Calculations
- TAEP
- AEC and AEP at device and array scales
- (Optional) Additional Resource Location and Deployment Depth
- (Optional) Additional Resource Velocity Distribution

- (Optional) Additional Resource Array Scale
- (Optional) Additional Resource Description and Justification

1.1 Baseline LCOE Estimate

A summary of the baseline LCOE as calculated using the DOE reference documentation and fixed charge rate is provided in Table 5, below.

Table 5. LCOE Estimate for Baseline Project

Category	Baseline
Net Annual Energy Production (MWh/yr)	188
Capital Cost ($)	$2,386,495
Annual Operating Expenses ($/yr)	$257,591
Fixed Charge Rate (%)	0.108
Baseline LCOE ($/kWh)	**$2.73**

The high cost reported here is a reflection of the increased cost and decreased energy production associated with demonstration projects, which was the basis of this LCOE estimate.

Appendix A – CBS

DRAFT :: Proposed CBS by NREL :: As of 1 Aug 2014 :: Future iterations expected :: Comments Welcome

Draft Generalized Cost Breakdown Structure (CBS) for MHK Projects, with descriptions

Notes for Reviewers: [1] Please review and provide comments on as much of the Cost Breakdown Strucuture (CBS) as possible. Building consensus on levels 1, 2 and 3 is most important, but your thoughts about levels 4 and 5 are also very valuable [2] Feel free to provide comments directly to the "Community Discussion" page on OpenEI (http://en.openei.org/community/group/water-power-forum) or by email to Ben Maples at NREL (Ben.Maples@nrel.gov)

NOTE: it is acceptable (and expected!) for some line items to be populated with a "0" or "NA", depending on the particular project

			Installed Capital Cost (ICC) [$]	
CBS #	Level	Category	Value	Description
1	1	Capital Expenditures (CAPEX)	2386495	All installed costs incurred prior to commercial operations date (COD). CAPEX components include marine energy converter, balance of system, and financing.
1.1	2	Marine Energy Converter (MEC)	1165937	Converts kinetic energy from water into three phase alternating current (AC) electrical energy.
1.1.1	3	Structural Assembly	332851	Primary energy capture (e.g. float paddle, turbine, flap, etc.) and supporting structural components.
1.1.1.1	4	Primary Energy Capture	238359	Primary energy capture (e.g. float paddle, turbine, flap, etc.).
1.1.1.2	4	Additional Structural Components	0	Any additional supporting structural components not included in the Structure category.
1.1.1.3	4	Marine Systems	9129	Ancillary systems on the marine energy converter (MEC) device.
1.1.1.3.1	5	Personnel Access System (Device Access)	0	Additional components on marine energy converter (MEC) device to support personnel access.
1.1.1.3.2	5	Ballast System	8935	Ballast to control draft/stability of floating systems, ballast can be fixed or variable (active or passive).
1.1.1.3.3	5	Navigation Lighting	194	Navigation lighting placed on the structure of the marine energy converter (MEC).
1.1.1.4	4	Control & Communication System (SCADA)	82364	Connects the marine energy converter (MEC) device with an onshore operations center, provides water project operator with information about the status of MEC systems and allows remote control of some functions.
1.1.1.4.1	5	Marine Energy Converter (MEC) Controller		Control capabilities of various marine energy converter (MEC) components.
1.1.1.4.2	5	Communication System		Analog I/O unit, digital I/O unit, Ethernet module, field bus master, field bus slave, frequency unit, controller internal communication system.
1.1.1.4.3	5	Condition Monitoring System (CMS)	56462	Sensors, cables, data logger, protocol adapter card for data logger.
1.1.1.4.4	5	Ancillary Equipment	3902	Cables, connectors, contactor/circuit breaker fuse.
1.1.1.4.5	5	Marine Energy Converter (MEC) Plant Control Equipment		Any advanced marine energy converter (MEC) plant control equipment installed on the device or distributed throughout the plant.
1.1.1.5	4	Coatings		Coatings to protect from corrosion in marine environment.
1.1.1.6	4	Transportation of Structure	2999	Costs of transporting the marine energy converter (MEC) structure components from the manufacturing facility to the staging area.
1.1.2	3	Power Conversion Chain (PCC)	746349	Power conversion chain is comprised of a drivetrain (converts the energy captured by the device into mechanical power), a generator (converts mechanical power into electrical power), short term storage, and power electronics.
1.1.2.1	4	PCC Structural Assembly	185000	Main structure of the power conversion chain.
1.1.2.2	4	Drivetrain (i.e., Prime Mover)	111310	Components of the power conversion chain (PCC) to transfer mechanical energy.
1.1.2.2.1	5	Gearbox		Provides speed and torque conversion between the primary energy capture device and the generator. Only applicable for geared designs.
1.1.2.2.1.1	6	Gears		Planet carrier, planet gear, ring gear, sun gear, spur gear, hollow shaft.
1.1.2.2.1.2	6	Bearings		Planet bearing, carrier bearing, shaft bearing.
1.1.2.2.1.3	6	Housing		Bushing, case, mounting, torque arm system.
1.1.2.2.1.4	6	Sensors		Debris sensors, oil level sensors, pressure 1 & pressure 2 sensors, and temperature sensor.
1.1.2.2.1.5	6	Lube System		Primary filter, secondary filter, primary motor, primary pump, hose/fitting, seal, and reservoir.
1.1.2.2.1.6	6	Cooling System		Pump, radiator, hoses.
1.1.2.3	4	Hydraulic System		Hydraulic system to transfer mechanical energy from marine energy converter to electrical energy.
1.1.2.3.1	5	Hydraulic Motor		Motor to supply electrical power to hydraulic system
1.1.2.3.2	5	Hydraulic Reservoir		Reservoir to contain hydraulic fluid.
1.1.2.4	4	Electrical Assembly	402319	Power off-take system elements.
1.1.2.4.1	5	Generator	402319	Converts mechanical energy to electrical energy.
1.1.2.4.1.1	6	Cooling System		Hoses, filter, cooling fan, motor, radiator.
1.1.2.4.1.2	6	Lubrication System		Pump, pump motor, reservoir.
1.1.2.4.1.3	6	Rotor		Commentator, exciter, resistance controller, rotor lamination, rotor winding, slip ring, rotor magnets, brush.
1.1.2.4.1.4	6	Sensors		Core temperature sensor, encoder, watt meter.
1.1.2.4.1.5	6	Stator		Stator magnets, stator lamination, stator windings.
1.1.2.4.1.6	6	Structural & Mechanical		Front bearing, rear bearing, silent block, housing, and shaft.

1.1.2.5	4	Frequency Converter		Coverts variable frequency from asynchronous generator to grid-compliant power of the right 'quality' and with a stable frequency of either 50 Hz or 60 Hz.
1.1.2.5.1	5	Converter Auxiliaries		Power supply, cabinet, heating system, cabinet sensor, communication & interface unit, control board, generator side fan, grid side fan, measurement unit, power supply, power supply 24 V, tachometer adapter, thermostat.
1.1.2.5.2	5	Converter Power Bus		Branching unit, capacitors, contactors, generator side converter, generator side power module, grid side converter, grid side power module, inductor, load switch, pre-charge unit.
1.1.2.5.3	5	Power Conditioning		Common mode filter, crowbar system, DC chopper, generator side filter, line filter assembly, voltage limit unit.
1.1.2.6	4	Short-Tem Energy Storage		Temporary storage of electrical energy.
1.1.2.7	4	Power Electrical System		System to covert generator voltage to array cable system voltage for collection.
1.1.2.7.1	5	Power Circuit		Insulated-gate bipolar transistor (IGBT) module, rectifier bridge, crowbar system, driver/control board, cables, machine contractor, M Busbar/Isolator/Circuit Breaker, M Switchgear/Disconnect, motor contractor, soft starter, grounding system.
1.1.2.7.2	5	Main Transformer		Main marine energy converter transformer.
1.1.2.7.3	5	Measurements		Equipment to measure the function of the power electric system.
1.1.2.7.4	5	Switchgear		Marine energy converter switchgear.
1.1.2.8	4	Coatings	20000	Coatings to protect from corrosion in marine environment.
1.1.2.9	4	Transportation of Power Conversion Chain	27720	Costs of transporting the marine energy converter (MEC) power conversion chain (PCC) components from the manufacturing facility to the staging area.
1.2	2	Balance of System	1004831	Balance of equipment, labor, and material costs (other than marine energy converter) incurred prior to commercial operation date (COD).
1.2.1	3	Development	600000	All activities from project inception to financial close, where financial close is the date when project and financing agreements have been signed and all the required conditions have been met.
1.2.1.1	4	Permitting & Leasing	377500	Acquisition of permits and leases required for site assessment, construction, and operation at the project site.
1.2.1.1.1	5	Permit Acquisition Activities	350000	Activities necessary to obtain permits from relevant authorities.
1.2.1.1.2	5	Lease Acquisition Activities	7500	Activities necessary to obtain commercial or research lease to operate the project from relevant authorities.
1.2.1.1.3	5	Public Outreach	20000	Stakeholder education, marketing, and other efforts to facilitate public acceptance of a project.
1.2.1.2	4	Professional Advisory Services	10000	Legal support, external consultants, accounting, etc., during development.
1.2.1.3	4	Initial Engineering	10000	Engineering studies to specify the design of the project (e.g., technology, layout) and understand economics and risks associated with the design.
1.2.1.3.1	5	Pre-FEED	2000	Preliminary engineering design studies to develop general design of project, identify a short list of technologies for further evaluation, and identify fatal flaws.
1.2.1.3.2	5	FEED	8000	Engineering activities to develop final design specification, address areas of risk/uncertainty, determine technical & economic feasibility, and develop necessary specifications to begin procurement process. (20% to 30% design level). Additional engineering (preliminary, detailed, final) are covered in Engineering and Management.
1.2.1.3.3	5	Engineering Certification	0	Review by 3rd party, independent verification agent to assess feasibility of design basis, resulting in Certification Report.
1.2.1.4	4	Site Characterization	142500	Equipment, material and labor costs required for collecting/analysis of wind resource, ocean conditions, and geological data at project site. Defines parameters for engineering assessments as data becomes available.
1.2.1.4.1	5	Siting & Scoping	2500	Initial desktop-level studies to select project location, develop a conceptual design, identify regulatory requirements, and create preliminary business case.
1.2.1.4.2	5	Studies & Surveys		Environmental and social surveys/studies required by regulators or otherwise necessary for the project.
1.2.1.4.3	5	Water Monitoring Stations		Buoys, benthic node, Acoustic Doppler Current Profilers, instrumentation (meteorological and oceanographic), and data acquisition systems.
1.2.1.4.4	5	Water Monitoring Installation		Vessels, labor, and equipment required to install instrumentation and data acquisition system.
1.2.1.4.5	5	Water Resource Analysis	70000	Collection, cleaning, and analysis of data to develop water resource profile and power production estimates for a selection of marine energy converter types at project site. May include array layout optimization surveys.
1.2.1.4.6	5	Geotechnical & Geophysical Surveys	70000	Vessels, labor, and equipment required to establish bathymetry, seabed features, water depth, stratigraphy, and identify hazards on seafloor. Performed for project site and potential cable routes to interconnection.
1.2.1.5	4	Interconnection & Power Marketing		Activities to gain access to the transmission grid and negotiate contracts to sell or otherwise market power.

1.2.1.5.1	5	Interconnection Studies & Fees		Activities required to obtain a Large Generator Interconnection Agreement from Federal Energy Regulatory Commission (FERC), prepared in coordination with transmission system operator. Studies cover technical considerations of interconnecting project with grid, while maintaining system balance and within grid operating limits.
1.2.1.5.2	5	Transmission Rights of Way		Costs of obtaining or expanding transmission rights of way for any onshore electric infrastructure (e.g., overhead transmission lines), includes any costs to permit onshore transmission.
1.2.1.5.3	5	Power Marketing		Efforts to develop power marketing strategy, forecast pricing, and negotiate Power Purchase Agreements (PPAs).
1.2.1.6	4	Project Management During Development	35000	Project Management from the start of the development phase through financial close.
1.2.1.6.1	5	Procurement	5000	Preparation of tenders for each work package, evaluation of bids, negotiations with suppliers.
1.2.1.6.2	5	Salaries	25000	Salaries for management and support staff on payroll of developer, some overlap with categories above is expected, depending on amount of work that is completed internally vs. contracted.
1.2.1.6.3	5	Sales, General, & Administrative	5000	Overhead for the project company including administrative salaries and benefits, rent, utilities, depreciation, insurance, etc.
1.2.1.6.4	5	Profit (if private developer)	0	Any margin earned by the developer upon sale of the project at financial close, does not include the cost to a new owner of any stake that a developer might retain in the project.
1.2.1.7	4	Financing and Incentives	15000	Fees, closing costs, and staff and consultant efforts to arrange and secure equity, debt financing, and government incentives.
1.2.1.7.1	5	Due Diligence	5000	Activities performed by potential investors to investigate technical and economic aspects of the project and estimate value prior to executing a financial commitment. Typically conducted by 3rd party technical consultant(s) hired by investor(s).
1.2.1.7.2	5	Incentives	0	Efforts performed by the developer to secure and demonstrate qualification for local, state, and federal incentives.
1.2.1.7.3	5	Closing Costs	5000	Administrative costs incurred by investors (debt and equity) during the evaluation of the investment.
1.2.1.7.4	5	Legal Support	5000	Developer's legal support to during negotiations to arrange financing.
1.2.2	3	Engineering and Management	97000	Engineering and management activities from financial close through commercial operation date (COD).
1.2.2.1	4	Detailed Design and Construction Engineering	32000	Detailed design and construction engineering costs.
1.2.2.2	4	Procurement Management	20000	Bid management, purchasing, negotiations, contract management.
1.2.2.3	4	Construction Management	10000	Quality control and assurance.
1.2.2.3.1	5	Salaries	10000	Salaries for management and support staff on payroll of project owner and/or construction manager.
1.2.2.3.2	5	Sales, General, & Administrative	0	Overhead for the project company and/or construction manager including administrative salaries and benefits, rent, utilities, depreciation, insurance, etc.
1.2.2.3.3	5	Profit	0	Any margin earned by an independent construction management firm.
1.2.2.4	4	Project Certification	25000	Review by a 3rd party independent verification agent to assure that project is in compliance with design basis as well as technical standards and regulatory requirements. Results in project certificate.
1.2.2.5	4	Health, Safety, & Environmental Monitoring	10000	Coordination and monitoring to ensure compliance with health, safety, and environmental monitoring requirements during construction.
1.2.2.5.1	5	Health and Safety Monitoring	0	Coordination and monitoring to ensure compliance with health and safety requirements during construction.
1.2.2.5.2	5	Environmental Monitoring	10000	Coordination and monitoring to ensure compliance with environmental requirement during construction.
1.2.3	3	Electrical Infrastructure	144104	All electrical infrastructure to collect power from generators and deliver to the grid.
1.2.3.1	4	Array Cable System	9800	Collects power generated by the marine energy converter(s) and transports to the offshore substation(s).
1.2.3.1.1	5	Array Cables	8782	High- or medium-voltage cable to connect the marine energy converters (MECs) with offshore substation or export MEC.
1.2.3.1.2	5	Protection	1018	Equipment and materials used to protect cable from damage (strikes, over-bending, etc.)
1.2.3.1.2.1	6	Scour Protection	0	Rock fill, sand bags, or concrete mattresses to protect from scouring, used where burial is not possible.
1.2.3.1.2.2	6	Seabed Protection Mats	0	Concrete, sand bags, polyurethane mats to route cables over existing electric/telecommunications cables.
1.2.3.1.2.3	6	Ducting System		Protective sheath that can be fitted around cables where burial is not an option.
1.2.3.1.2.4	6	Bend Restrictors		Prevents the over-bending of static cables during installation and operations.
1.2.3.1.2.5	6	Bend Stiffeners		Limit bending stresses and maintain acceptable curvature for dynamic cables at hang off point and touch down.
1.2.3.1.3	5	Ancillary Equipment		Other elements providing necessary functions to the array cable system.

1.2.3.1.3.1	6	Termination Kit		Necessary components to for connection of array cable to each marine energy converter (MEC) transformer.
1.2.3.1.3.2	6	Connectors		Equipment to connect individual sections of cable together, in the event of long cable runs or damage.
1.2.3.1.3.3	6	Buoyancy Modules		Used to manage buoyancy in some dynamic cable configurations and control load transfer.
1.2.3.1.3.4	6	Anchorage		Used to maintain the station of dynamic cable at touchdown point.
1.2.3.1.3.5	6	Messenger Lines & Buoys		Ancillary equipment used during the installation of static and dynamic cable systems.
1.2.3.1.3.6	6	Array Cable System Commissioning		Process of assuring that all array cable systems and components are operational through a predefined series of tests and checks.
1.2.3.1.4	5	Array Cable System Transportation		Costs of transporting the array cable components from the manufacturing facility to the staging area
1.2.3.2	4	Export Cable System	22441	Export cables and associated infrastructure to connect marine energy converter(s) or offshore substation(s) with onshore electric infrastructure or offshore convertor station(s) if using direct current (DC).
1.2.3.2.1	5	Export Cables	19265	High- or medium-voltage cable to connect marine energy converter (MEC) or offshore substations with onshore electric infrastructure or offshore convertor station (if DC).
1.2.3.2.2	5	Protection	0	Equipment and materials used to protect cable from damage (strikes, over-bending, etc.)
1.2.3.2.2.1	6	Scour Protection	0	Rock fill, sand bags, or concrete mattresses to protect from scouring, used where burial is not possible.
1.2.3.2.2.2	6	Seabed Protection Mats	0	Concrete, sand bags, polyurethane mats to route cables over existing electric/telecommunications cables.
1.2.3.2.2.3	6	Ducting System	0	Protective sheath that can be fitted around cables where burial is not an option.
1.2.3.2.2.4	6	Bend Restrictors	0	Prevents the over-bending of static cables during installation and operations.
1.2.3.2.2.5	6	Bend Stiffeners	0	Limit bending stresses and maintain acceptable curvature for dynamic cables at hang off point and touch down.
1.2.3.2.3	5	Ancillary Equipment	1918	Other elements providing necessary functions to the export cable system.
1.2.3.2.3.1	6	Termination Kit	0	Necessary components for connection of cable to substation and to onshore electric infrastructure.
1.2.3.2.3.2	6	Connectors	0	Equipment to connect individual sections of cable together, in the event of long cable runs or damage.
1.2.3.2.3.3	6	Buoyancy Modules	0	Used to manage buoyancy in some dynamic cable configurations and control load transfer.
1.2.3.2.3.4	6	Anchorage	0	Used to maintain the station of dynamic cable at touchdown point.
1.2.3.2.3.5	6	Messenger Lines & Buoys	0	Ancillary equipment used during the installation of static and dynamic cable systems.
1.2.3.2.4	5	Export Cable System Transportation	1258	Costs of transporting the export cable components from the manufacturing facility to the staging area.
1.2.3.3	4	Offshore Substation(s)		Electric conversion equipment required to step-up or convert power for export to the onshore grid and support structure, also onboard work platforms, accommodation, equipment storage, helicopter access, etc.
1.2.3.3.1	5	Topside		Structure that provides support and climate controlled housing for electrical conversion equipment, also can provide work platforms, accommodation, equipment storage, helicopter access, etc.
1.2.3.3.1.1	6	Structure		Material, equipment, and labor costs of fabricating structural steel or concrete structure.
1.2.3.3.1.2	6	Helicopter Deck		Onboard helicopter landing platform.
1.2.3.3.1.3	6	Accommodations		Refuge, temporary, or permanent accommodations for project personnel.
1.2.3.3.1.4	6	Outfitting Steel		Additional non-structural elements attached to the primary structure.
1.2.3.3.1.5	6	Topside Marine Systems		Ancillary systems required for marine operations.
1.2.3.3.1.6	6	Substation Topside Integration, Assembly, Test, and Checkout		Activities performed by manufacturer to integrate, assemble, test, and checkout (IATC) the Substation Topside before delivery to customer. Does not include commissioning activities.
1.2.3.3.1.7	6	Transportation		Costs to transport substation topside from manufacturer to staging port.
1.2.3.3.2	5	Substructure & Foundation		All elements of the offshore substation below the point of connection with the topside.
1.2.3.3.2.1	6	Foundation		Main structural interface that transfers the loads into the seabed.
1.2.3.3.2.2	6	Substructure		Main structure that connects the foundation to the substation topside.
1.2.3.3.2.3	6	Substructure Marine Systems		Ancillary systems for marine operations, major element is the ballast system for floating offshore substations.
1.2.3.3.2.4	6	Scour Protection		Rock fill or concrete mattresses to protect substructures from scouring at point of connection to seafloor.
1.2.3.3.2.5	6	Substation Substructure & Foundation Integration, Assembly, Testing, and Checkout		Activities performed by manufacturer to integrate, assemble, test, and checkout (IATC) the Substation Substructure & Foundation before delivery to customer. Does not include commissioning activities.
1.2.3.3.2.6	6	Transportation		Costs to transport substation topside from manufacturer to staging port.
1.2.3.3.3	5	19863.16	19863	Equipment to step up power from array cable voltage to the export voltage and/or to convert power to DC

1.2.3.3.3.1	6	0		0	Power convertors that step up generated power from array cable voltage to export voltage
1.2.3.3.3.2	6	0		0	Equipment used to control, protect and disconnect the high voltage connection,
1.2.3.3.3.3	6	0		0	Equipment used to control, protect and disconnect the medium voltage connection
1.2.3.3.3.4	6	0		0	Onboard reactive compensation equipment
1.2.3.3.3.5	6	0		0	Equipment to convert power from HVAC to HVDC for export to shore
1.2.3.3.3.6	6	0		0	Filters to address harmonics generated by HVDC convertors
1.2.3.3.3.7	6	0		0	Activities performed by manufacturer to integrate, assemble, test, and checkout (IATC) the Substation Topside before delivery to customer. Does not include commissioning activities.
1.2.3.3.3.8	6	0		0	Costs of transporting the electrical conversion equipment from the manufacturing facility to the staging area
1.2.3.3.4	5		19863.16	19863	Other elements providing necessary functions to offshore substation during operations
1.2.3.3.4.1	6	Diesel Generator Back Up			Generators to provide power to substation if grid connection is lost
1.2.3.3.4.2	6	Fire Protection System			Fire alarms and fire response equipment
1.2.3.3.4.3	6	Water Tanks			Fresh water tanks and pumping equip.
1.2.3.3.4.4	6	Fuel Tanks			Fuel tanks and pumping equip. for generator and possibly emergency fueling of service/crew transfer vessels
1.2.3.3.4.5	6	Control & Communication System			Connects the substation with an onshore operations center, provides project operator with information about the status of substation systems and allows remote control of some functions
1.2.3.3.4.6	6	Safety and Security Systems			Systems including access control, to safeguard personnel from hazards arising from the installation, maintenance, or operation of substation equipment
1.2.3.3.4.7	6	Transportation			Costs of transporting the ancillary systems from the manufacturing facility to the staging area
1.2.3.4	4	Onshore Transmission Infrastructure	92000		Any onshore transmission or conversion equipment required to connect project to onshore grid.
1.2.3.4.1	5	Land Leases			Land Lease or Right of Way payments for transmission corridor prior to commercial date of operations.
1.2.3.4.2	5	Underground Cable System			Any underground cables required for the connection of export cables to the onshore substation.
1.2.3.4.2.1	6	Underground Cables			Connect export cables to the onshore substation directly or via overhead lines.
1.2.3.4.2.2	6	Ancillary equipment			Ancillary equipment required for underground cable system including ducts.
1.2.3.4.3	5	Self-Supporting Towers with Insulators			Structures to support any overhead lines required for the connection of export cables to the onshore substation.
1.2.3.4.3.1	6	Foundations			Support tower structures, typically reinforced concrete.
1.2.3.4.3.2	6	Transmission Towers			Structures to support overhead transmission lines.
1.2.3.4.3.3	6	Insulators			Insulating supports used to attach overhead transmission lines to the towers.
1.2.3.4.4	5	Overhead Lines			Lines that transmit power and enable communications with the marine energy converter project.
1.2.3.4.4.1	6	Conductors			Conductors that transmit power between export cable and onshore substation (three phase system).
1.2.3.4.4.2	6	Communications			Fiber optic wire routed to the control center, transmits information from data acquisition system (DAS), condition monitoring system (CMS), and allows land-based control of project systems.
1.2.3.4.4.3	6	Shield Wire			Grounded conductor to protect phase conductors from surges (lightning).
1.2.3.4.5	5	Onshore Substations		87000	Facility to house electric conversion equipment to transform or convert power from the export voltage to the onshore grid voltage.
1.2.3.4.5.1	6	Buildings/Facilities		20000	Structures to house electric conversion equipment, climate controlled.
1.2.3.4.5.2	6	Civil Infrastructure			Improvements to construction site (e.g., roads) necessary for substation construction and operation.
1.2.3.4.5.3	6	Electric Conversion Equipment		40000	Equipment to transform generated power from export cable voltage to interconnection voltage and/or convert from DC to AC (e.g., AC transformers, switchgears, shunt reactors, DC convertors).
1.2.3.4.5.4	6	Ancillary Systems		27000	Other elements providing necessary functions to substation during operations (e.g., metering equipment, Safety and Security Systems, fire protection, gas detection).
1.2.3.4.6	5	Onshore Transmission Infrastructure Transportation		5000	Costs of transporting the onshore transmission infrastructure components from the manufacturing facility to the staging area.
1.2.4	3	Plant Commissioning	10000		Cost incurred by owner or prime contractor to test and commission the integrated power plant.
1.2.5	3	Site Access, Port & Staging			Activities and physical aspects of a staging port. Elements needed to support the delivery, storage, handling, and deployment of marine energy converter (MEC) components.
1.2.5.1	4	Facilities			Port facilities or space leased to support the installation of the project.
1.2.5.1.1	5	Laydown Area			Leased space at staging port to store marine energy converter (MEC) components and foundations.
1.2.5.1.2	5	Assembly Areas			Leased space at staging port with high load bearing capacity to perform onshore assembly activities.

1.2.5.1.3	5	Utilities			Temporary power, restrooms, and water located at Facilities to be used by subcontractors during construction phase.
1.2.5.1.4	5	Fabrication Facilities			Workshops to support fabrication, construction or assembly of components.
1.2.5.2	4	Cranage			Cranage fees to use and operate crawler cranes, tower cranes, harbor cranes, self-propelled modular transporters (SPMTs) used for land-based assembly of components and load out onto installation vessels.
1.2.5.3	4	Port Improvements			Any improvement to existing port infrastructure paid for by project owner (e.g., quayside reinforcement).
1.2.5.4	4	Port Fees			Fees for vessel access, docking and loading/unloading.
1.2.5.4.1	5	Entrance/Exit Fees			Charges levied upon entry of vessels into the port, generally calculated on standard formula basis upon Gross Registered Ton (GRT).
1.2.5.4.2	5	Quayside Docking Fees			Charges levied for the use of a berth either occupied by a vessel or by pre-assembly activities.
1.2.5.4.3	5	Wharfage Fees			Charges for loading or unloading cargo from vessels, generally calculated by tonnage and equipment requirements for loading/unloading the cargo.
1.2.6	3	Assembly & Installation	79367		Assembly and installation activities conducted at the staging port and at the project site. Assume financial costs related to warranties, contractor insurance, Selling, General & Administrative (SG&A), profit margin, etc., are loaded in day rates for vessels, labor, and equipment.
1.2.6.1	4	Substructures & Foundations	43677		Vessel, labor, and equipment costs to complete installation of foundations and substructures.
1.2.6.1.1	5	Foundation		43677	Vessel, labor and equipment costs to complete foundation installation procedures
1.2.6.1.2	5	Substructure		0	Vessel, labor and equipment costs to complete substructure installation procedures
1.2.6.1.3	5	Scour Protection		0	Vessel, labor and equipment costs to complete scour protection installation procedures
1.2.6.2	4	Marine Energy Converter Device	8578		Vessel, labor, and equipment costs to complete marine energy converter installation procedures for the entire project.
1.2.6.2.1	5	Structural Assembly		8578	Cost to assemble and install the primary energy capture (e.g., float paddle, turbine, flap, etc.) device and supporting structural components.
1.2.6.2.2	5	Power Conversion Chain (PCC)		0	Cost to assemble and install the power conversion chain which is comprised of a drivetrain (converts the energy captured by the device into mechanical power), a generator (converts mechanical power into electrical power), short-term storage, and power electronics.
1.2.6.3	4	Electrical Infrastructure	27112		Vessel, labor, and equipment costs to install electrical infrastructure.
1.2.6.3.1	5	Array Cables		11880	Installation of subsea array cable system.
1.2.6.3.1.1	6	Laying	11400		Vessel, labor and equipment costs to lay array cables.
1.2.6.3.1.2	6	Trenching	0		Vessel, labor and equipment costs to bury array cables.
1.2.6.3.1.3	6	Protection	480		Vessel, labor and equipment costs to protect array cables.
1.2.6.3.1.4	6	Terminations	0		Vessel, labor and equipment costs to pull array cables through J-Tubes and connect to transformers.
1.2.6.3.2	5	Export Cables		5000	installation of subsea export cable system.
1.2.6.3.2.1	6	Laying/Trenching	0		Vessel, labor and equipment costs to lay and bury export cables.
1.2.6.3.2.2	6	Protection	0		Vessel, labor and equipment costs to protect export cables.
1.2.6.3.2.3	6	Terminations	0		Vessel, labor and equipment costs to pull export cables through J-Tubes and connect to transformers.
1.2.6.3.2.4	6	Landfall Operations	0		Vessel, labor and equipment costs to transition export cable from subsea trench to onshore jointing pit.
1.2.6.3.3	5	Offshore Substation(s)		0	Costs of installing offshore substations at the project site.
1.2.6.3.3.1	6	Substructure	0		Vessel, labor and equipment costs to install substation substructure(s).
1.2.6.3.3.2	6	Topside	0		Vessel, labor and equipment costs to install substation topside(s).
1.2.6.3.4	5	Offshore Accommodations Platform(s)		0	Costs of installing offshore accommodations platforms at the project site.
1.2.6.3.4.1	6	Substructure	0		Vessel, labor and equipment costs to install offshore accommodations platform substructure(s).
1.2.6.3.4.2	6	Topside	0		Vessel, labor and equipment costs to install offshore accommodations platform topside(s).
1.2.6.3.5	5	Onshore Electric Infrastructure		10232	Onshore Electric Infrastructure: costs of installing onshore electric infrastructure.
1.2.6.3.5.1	6	Underground Cable System	0		Labor and equipment costs to install underground cables onshore.
1.2.6.3.5.2	6	Overhead Transmission Lines	0		Labor equipment costs to install overhead transmission lines.
1.2.6.3.5.3	6	Onshore Substation	10232		Labor and equipment costs to install onshore substation.
1.2.7	3	Other Infrastructure	21800		Other capital investments made by the project company prior to commercial operation date (COD).
1.2.7.1	4	Offshore Accommodations Platform(s)	17000		Permanent platform(s) at the project site to house project personnel during operations.
1.2.7.2	4	Dedicated O&M Vessel(s)			New build vessels owned by the project company that will be used exclusively to support operations at project.
1.2.7.3	4	Onshore O&M Facilities	0		Facilities on land, owned by the project company, to support the operation of the project.

1.2.7.4	4	O&M Equipment Purchases	0	Other purchases necessary for the operation of the marine energy converter project after commercial operation date (COD). Examples include: safety equipment (e.g., harnesses, floatation devices), equipment to store replacement parts (e.g., climate control for spare electric cables), vehicles to support operations (e.g., fork trucks).
1.2.7.5	4	Other Infrastructure Transportation	4800	Cost of transporting other infrastructure components from the manufacturing facility to the staging area.
1.2.8	3	Substructure & Foundation	139297	All elements of the marine energy converter substructure and foundation.
1.2.8.1	4	Substructure	86737	Main structure that connects the foundation to the marine energy converter.
1.2.8.1.1	5	Primary Structure	86737	Structural steel or other material.
1.2.8.1.2	5	Fasteners	0	Hardware to secure connections between substructure & foundation elements.
1.2.8.1.3	5	Grout, Grout Lines, and Seals	0	Grout and ancillary equipment to secure connections between substructure & foundation elements.
1.2.8.1.4	5	Marine Coatings	0	Anti-corrosion marine coatings applied to substructure elements.
1.2.8.2	4	Foundation	32560	Main structural interface that transfers loads into seabed.
1.2.8.2.1	5	Bedding Stones	0	Layers of gravel and stone to provide a stable and level surface on which to place anchors.
1.2.8.2.2	5	Piles	0	Steel pipes driven into seabed to provide support and transfer loads acting on marine energy system into seabed.
1.2.8.2.3	5	Anchors	15500	Anchors are installed below mudline and transfer loads into the seabed.
1.2.8.2.4	5	Mooring Lines	5400	Chain, wire, or synthetic fiber ropes to connect marine energy converter with anchors on the seabed.
1.2.8.2.5	5	Connecting Hardware	11660	Connectors required to attach the mooring lines to anchors and marine energy converter.
1.2.8.2.6	5	Messenger Lines & Buoys	0	Ancillary equipment used during the installation of the mooring system.
1.2.8.3	4	Outfitting Steel	0	Additional non-structural elements attached to substructure elements.
1.2.8.3.1	5	Vessel Landing	5000	Provides interface between maintenance vessels and substructure to enable safe personnel access.
1.2.8.3.2	5	Service Platforms and Decks	0	Provides work platform for maintenance activities.
1.2.8.3.3	5	Ladders	0	Provides access from the vessel landing to the deck.
1.2.8.3.4	5	Railings	0	Encloses the deck to provide a safe working environment for personnel.
1.2.8.3.5	5	Marine Coatings	0	Anti-corrosion marine coatings applied to any outfitting steel elements.
1.2.8.4	4	Marine Systems	0	Ancillary systems for marine operations.
1.2.8.4.1	5	Cathodic Protection System	0	Active (impressed current) or passive (anodes) cathodic protection system.
1.2.8.4.2	5	Personnel Access System		Equipment installed on vessel landing, ladders, and deck to facilitate safe access to the marine energy converter (MEC).
1.2.8.4.3	5	Ballast System		Ballast to control draft/stability of floating systems, ballast can be fixed or variable (active or passive).
1.2.8.4.4	5	Condition Monitoring		Systems to monitor and control substructure systems (e.g., variable ballast).
1.2.8.5	4	Scour Protection		Rock fill or concrete mattresses to protect substructures from scouring (caused by currents).
1.2.8.6	4	Substructure & Foundation Integration, Assembly, Testing, and Checkout		Activities performed by manufacturer to integrate, assemble, test, and checkout for the foundation and substructure before delivery to customer. Does not include commissioning activities.
1.2.8.7	4	Substructure & Foundation Transportation	20000	Costs of transporting substructure and foundation components from the manufacturing facility to the staging area.
1.3	2	Financial Costs	215727	Financial expenditures for which the project owner is responsible prior to commercial operation date (COD), related to either payments for financial products, carrying charges on loans, or setting up financial instruments.
1.3.1	3	Project Contingency Budget	132760	Liquid financial instrument set up to respond to "known unknown" costs that arise during construction, does not include contingences set by manufactures and contractors as part of supply contract pricing.
1.3.2	3	Insurance During Construction	12165	Insurance policies held by owner during construction period, can include construction all risk, marine cargo, commercial general liability, workers compensation, environmental site liability, pollution liability, etc. Does not include insurance held by contractors.
1.3.3	3	Carrying Costs During Construction (Construction Financing Costs)		Carrying charges of expenditures on equipment and services incurred before commercial operation date (COD).
1.3.4	3	Reserve Accounts	70802	Payments (before commissioning) into reserve accounts. Generally required by either financiers or regulators.
1.3.4.1	4	Maintenance Reserve Account		Payments (before commissioning) into reserve accounts set up to cover major maintenance expenditures (MRAs), often required by debt service providers.
1.3.4.2	4	Debt Service Reserve Account		Payments (before commissioning) into reserve accounts set up to cover debt service expenditures (DSRAs), often required by debt service providers.

1.3.4.3	4	Decommissioning Reserve Account	70802	Payments (before commissioning) into reserve accounts to fund project decommissioning obligations (e.g., surety bonds).

Operations and Maintenance (O&M) [$/yr]				
CBS #	**Level**	**Category**	**Value**	**Description**
2	1	Operational Expenditures (OPEX)	257691	Expenditures required to operate the project and maintain availability. These expenditures are generally annualized.
2.1	2	Operations	151353	Operations is defined as non-equipment costs of operations for the project.
2.1.1	3	Environmental, Health and Safety Monitoring	84122	Coordination and monitoring to ensure compliance with health, safety, and environmental (HSE) requirements during construction.
2.1.1.1	4	Health, Safety Monitoring	10000	Coordination and monitoring to ensure compliance with health and safety requirements during operations.
2.1.1.2	4	Environmental Monitoring	74122	Coordination and monitoring to ensure compliance with environmental requirement during operations. Includes post-construction survey activities.
2.1.2	3	Annual Leases/Fees/Costs of Doing Business	5000	Ongoing payments, including but not limited to: payments to regulatory body for permission to operate at project site (terms defined within lease); payments to Transmissions Systems Operators or Transmission Asset Owners for rights to transport generated power.
2.1.2.1	4	Submerged land-lease		Payments to the state or federal regulatory authorities for rights to operate marine energy converter project on publically owned seabed or lakebed.
2.1.2.2	4	Onshore land-lease		Payments to land owners for rights to operate transmission lines, onshore substation, or other facilities.
2.1.2.3	4	Transmission Charges/Rights		Any payments to Transmissions Systems Operators or Transmission Asset Owners for rights to transport generated power.
2.1.2.4	4	Federal Energy Regulatory Commission (FERC) Fees		Fees paid to Federal Energy Regulatory Commission (FERC) during operations.
2.1.3	3	Insurance	26552	Insurance policies held by project company or operations manager during operational period.
2.1.4	3	Operations, Management, and General Administration	35678	Activities necessary to forecast, dispatch, sell, and manage the production of power from the plant. Includes both on-site and off-site personnel, software, and equipment to coordinate high voltage equipment, switching, port activities, marine activities, weather forecasting.
2.1.4.1	4	Generation Planning and Integration		Efforts to forecast, sell, and dispatch power generated by the facility.
2.1.4.2	4	Operating Facilities		Co-located offices, parts store and quayside facility, helicopter facilities, etc.
2.1.4.3	4	Operating Equipment		Lease payments for operating equipment held by the project to support operations (e.g., cranes, fork trucks).
2.1.4.4	4	Sales, General, & Administrative		Includes financial reporting, public relations, procurement, parts and stock management, Health, Safety, and Environment (HS&E) management, training, subcontracts and general administration.
2.1.4.5	4	Marine Energy Converter Power Consumption		Charges for power drawn from the grid by the marine hydrokinetic project (e.g., marine energy converter, substation) during operation.
2.1.4.6	4	Weather Forecasting		Daily 96 hour forecast of metocean conditions used to plan maintenance visits and project power production.
2.1.4.7	4	Marine Management		Coordination of port equipment, vessels, and personnel to carry out maintenance and inspections of generation and transmission equipment.
2.1.4.8	4	Condition Monitoring		Monitoring of SCADA data from marine energy converter components to optimize performance and identify component faults.
2.1.4.9	4	Operating Margin		Any margin earned by an independent operations management company.
2.1.4.10	4	Professional Advisory Services		Legal support, external consultants, accounting, etc., during operation.
2.2	2	Maintenance	106338	Vessel, labor, and equipment costs of operations for the project.
2.2.1	3	Long Term Service Agreement		Annualized cost of a contract, generally between the owner and marine energy converter OEM or Third Party, to maintain the water power project at a guaranteed level of availability for a defined period, will likely replace scheduled and unscheduled maintenance categories below for duration of contract
2.2.2	3	Scheduled Maintenance	50056	Planned and routine activities to ensure that marine energy converters, substructures, and all related systems are operating correctly, at optimal efficiency, and to minimize unscheduled breakdowns/downtime, includes cost of vessels, labor, equipment, spare parts and consumables. Sometimes referred to as preventative maintenance.
2.2.2.1	4	Marine Energy Converter Scheduled Maintenance	43429	Planned maintenance activities for marine energy converter systems.
2.2.2.1.1	5	Structural Assembly Scheduled Maintenance	90	Planned maintenance activities to the structural assembly.
2.2.2.1.2	5	Power Conversion Chain (PCC) Scheduled Maintenance	43339	Planned maintenance activities to the power conversion chain.
2.2.2.2	4	Balance of System (BOS) Scheduled Maintenance	6627	Planned maintenance activities for balance of system.
2.2.2.2.1	5	Regular Cable Surveys	4454	Surveys of array and export cable routes to ensure coverage and determine cable burial depth.

2.2.2.2.2	5	Substructure & Foundation Inspections	1480	Inspections covering above water and under-water aspects of the substructure and foundation as well as the integrity of the cathodic protection system maintenance.
2.2.2.2.3	5	Electrical Transforming Equipment Inspection		Inspections of switchgears, transformers and back-up power supply.
2.2.2.2.4	5	Direct Current (DC) Convertor Inspection		Inspection of DC convertor equipment and filtering equipment.
2.2.2.2.5	5	Onshore Electric Infrastructure	693	Inspections of switchgear, transformers and any connections.
2.2.3	3	Unscheduled Maintenance	56282	Interventions and other activities to respond to random failures. Costs include equipment and vessels, labor, replacement parts, and consumables. Also known as corrective maintenance.
2.2.3.1	4	Marine Energy Converter Unscheduled Maintenance	45817	Unplanned maintenance activities for marine energy converter systems.
2.2.3.1.1	5	Structural Assembly Unscheduled Maintenance	731	Unplanned maintenance activities to the structural assembly.
2.2.3.1.2	5	Power Conversion Chain (PCC) Unscheduled Maintenance	45087	Unplanned maintenance activities to the power conversion chain.
2.2.3.2	4	Balance of System (BOS) Unscheduled Maintenance	2957	Unplanned maintenance activities for balance of system.
2.2.3.2.1	5	Substructure & Foundation Inspections	571	Inspections covering above water and under-water aspects of the substructure and foundation as well as the integrity of the cathodic protection system maintenance.
2.2.3.2.2	5	Electrical Transforming Equipment Inspection +Cable repair	1214	Inspections of switchgears, transformers and back-up power supply.
2.2.3.2.3	5	Direct Current (DC) Convertor Inspection		Inspection of DC convertor equipment and filtering equipment.
2.2.3.2.4	5	Onshore Electric Infrastructure	1173	Inspections of switchgear, transformers and any connections.
2.2.3.3	4	Unscheduled Maintenance Contingency	7508	Liquid financial instrument set up to respond to "known unknown" costs that arise during maintenance.

PLEASE SEND COMMENTS OR QUESTIONS about this CBS to:
National Renewable Energy Laboratory: Ben Maples (Ben.Maples@nrel.gov, 303-384-7137)

Appendix B – AEP Required information for RivGen 1.F

Below is a table of contents for the reporting requirements for AEP calculations per the DOE, Standardized Cost and Performance Reporting for Marine and Hydrokinetic Technologies, September 3, 2014, referred to as LCOE guidance throughout this document:

Guidance Requirement	Section
1. Device C_P Curve	A.1
2. Device Power Curve	
3. Itemized Losses between Device Mechanical Power and Power Capture Matrices	A.2
4. Description of Device Losses Estimation	
5. Array Loss Factor	NA- no array proposed
6. Description and Justification of Array Calculations	
7. Availability Losses	A.3
8. Description and Justification of Availability Loss Calculations	
9. TAEP	A.4
10. AEC and AEP at device and array scales	
11. (Optional) Additional Resource Location and Deployment Depth	N/A
12. (Optional) Additional Resource Velocity Distribution	A.5
13. (Optional) Additional Resource Array Scale	N/A
14. (Optional) Additional Resource Description and Justification	N/A

A.1 Device C_P and Power Curves

Historical data is used to derive the following curves.

Power Curve Overview

The power curve was generated by using the peak efficiency established from stable operation of the Rivgen 1.F Power System in the Kvichak River in July 2015. The power curve represents power output at the point of grid interconnection and includes all onboard efficiency losses, from turbine C_P, mechanical losses in the driveline, generator efficiency, control system energy loss, and power transmission and conversion energy losses.

These losses have been backed out and itemized in the below sections, manufacturer information used to derive generator, power conversion and transmission losses and mechanical loss estimated based on best available data.

C_P vs. TSR

The following curve represents a measured curve of C_P vs. TSR as derived by resesarchers from The University of Washington following RivGen 1.F deomonstration in Igiugig, Alaska in 2015, it is compared to data from RivGen 1.0 demonstration in Igiugig, Alaska in 2014. This is from "2015 Preliminary Results from UW DOE Controls Project (email dated Sep. 30th 2015 from Dom Furbush)."

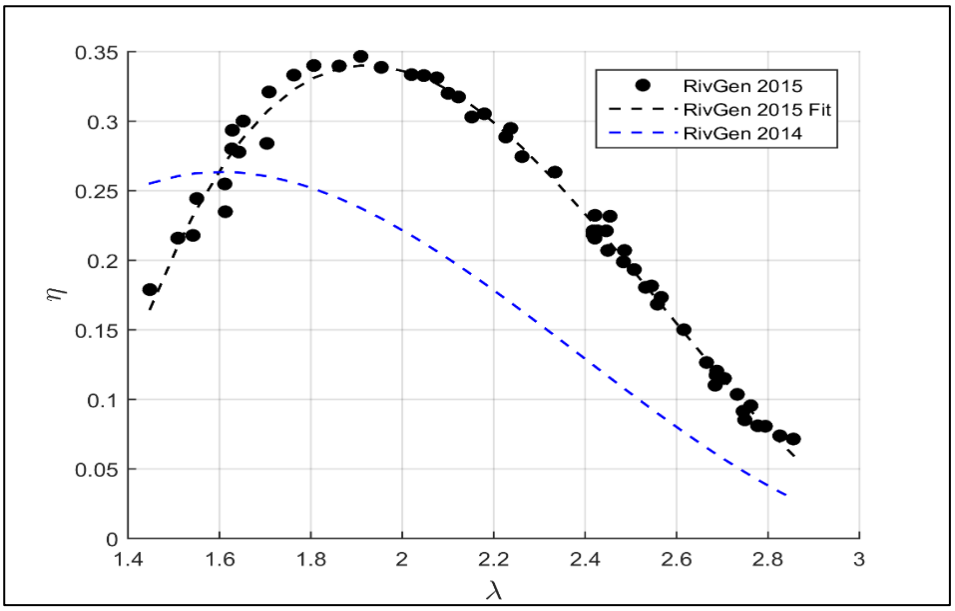

Figure 5. RivGen 1.f (black, 2015) and rivgen 1.0 (dotted blue, 2014) cp curves as caluclated from field data by UW researchers

Based on this data the following Power curve was developed (FIGURE 6) :

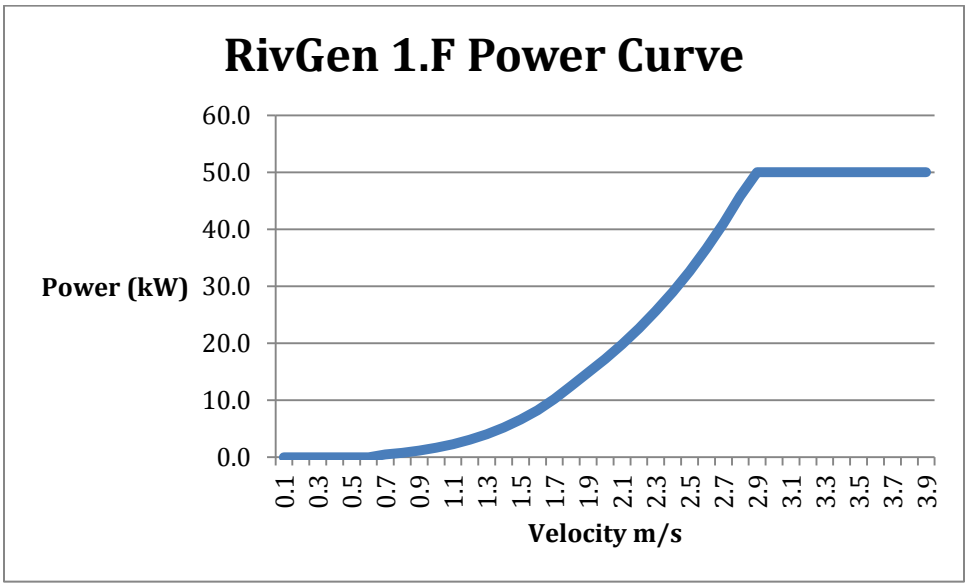

Figure 6. RIVGen 1.F Power curve

Table 6. Data for RivGen 1.f power curve

POWER CURVE				
Hydrokinetic Energy		Power Curve Calculations (power limited operation)		
Vel. Bin	Power in Water [kW]	no limit power [kW]	cut-in limited power [kW]	**power limited [kW]**
0.1	0.01	0.0	0.0	**0.0**
0.2	0.05	0.0	0.0	**0.0**
0.3	0.16	0.0	0.0	**0.0**
0.4	0.38	0.0	0.0	**0.0**
0.5	0.74	0.1	0.0	**0.0**
0.6	1.27	0.3	0.0	**0.0**
0.7	2.02	0.5	0.5	**0.5**
0.8	3.01	0.8	0.8	**0.8**
0.9	4.29	1.2	1.2	**1.2**
1.0	5.88	1.6	1.6	**1.6**
1.1	7.83	2.3	2.3	**2.3**
1.2	10.17	3.1	3.1	**3.1**
1.3	12.93	4.0	4.0	**4.0**
1.4	16.14	5.2	5.2	**5.2**
1.5	19.86	6.6	6.6	**6.6**

1.6	24.10	8.3	8.3	**8.3**
1.7	28.91	10.2	10.2	**10.2**
1.8	34.31	12.5	12.5	**12.5**
1.9	40.35	14.8	14.8	**14.8**
2.0	47.07	17.2	17.2	**17.2**
2.1	54.49	19.8	19.8	**19.8**
2.2	62.65	22.6	22.6	**22.6**
2.3	71.58	25.6	25.6	**25.6**
2.4	81.33	28.9	28.9	**28.9**
2.5	91.93	32.6	32.6	**32.6**
2.6	103.41	36.6	36.6	**36.6**
2.7	115.80	41.0	41.0	**41.0**
2.8	129.15	45.8	45.8	**45.8**
2.9	143.49	50.9	50.9	**50.0**
3.0	158.85	56.3	56.3	**50.0**
3.1	175.28	62.1	62.1	**50.0**
3.2	192.79	68.3	68.3	**50.0**
3.3	211.44	74.9	74.9	**50.0**
3.4	231.25	82.0	82.0	**50.0**
3.5	252.26	89.4	89.4	**50.0**
3.6	274.50	97.3	97.3	**50.0**
3.7	298.02	105.6	105.6	**50.0**
3.8	322.84	114.4	114.4	**50.0**
3.9	349.00	123.7	123.7	**50.0**
4.0	376.54	133.4	133.4	**50.0**

A.2. Itemized Losses & Device Losses Description

Control System Losses

Based on work conducted by UW under ORPC's DOE Advanced Controls Project, estimated controls system losses are less than 1%, estaimated at 99% efficiency

Electrical Losses

The Electrical losses include losses due to generator efficiency, transmission efficiency, and power conversion efficiency. These are detailed below.

Generator

The generator efficiency is based on a linear fit of test data from the generator manufacturer, CPI.

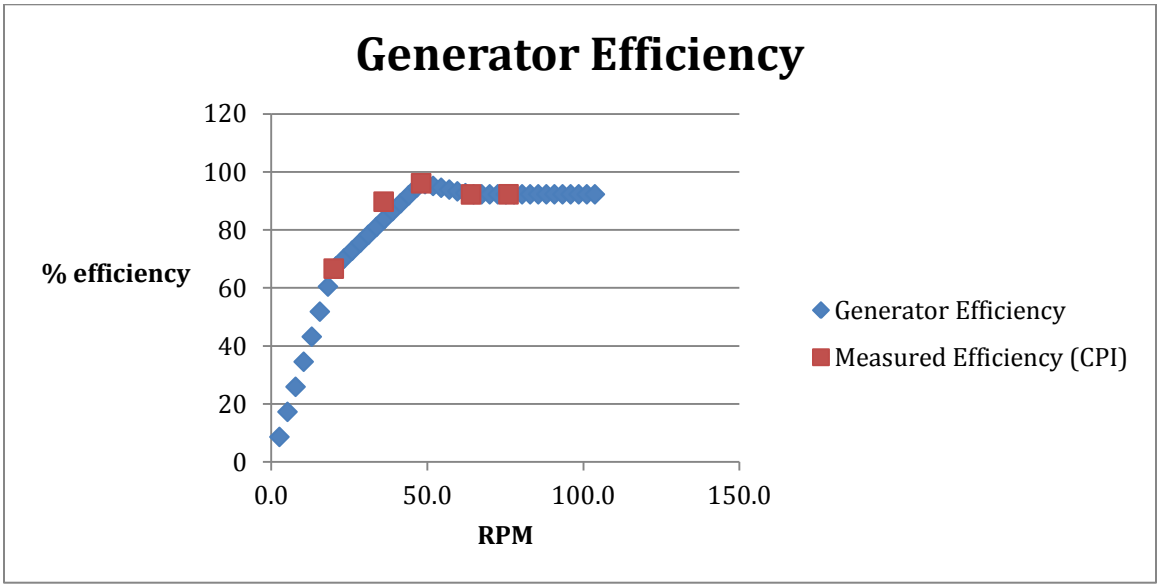

Figure 7. RivGen generator efficiency

Power Transmission and conversion efficiency

Table 7. Transmission and power conversion losses

Transmission Eff. %	96.0%
Inverter Eff. %	97.5%
VFD Eff. %	98.0%
Transformer and parasitic losses Eff %	97.5%
Total Converter Efficiency %	**93.2%**

Mechanical Losses

Mechanical losses occur to inefficiencies in the driveline system, primarily from bearing assemblies but also from mechanical couplings, especially where flexure in the supporting chassis and foundation are not efficiently handled by these components.

Testing on bearing sleeve material was performed as part of a prior funded project by the DOE project, DE-EE0003631, Abrasion Testing of Critical Components of Hydrokinetic Devices -- Final Technical Report, December 6, 2014. Results determined in flume testing indicated a maximum coefficient of friction, $f = 0.16$. This value corresponded to separate tribological testing funded by ORPC, from CSM Instruments report, T- 11- 252 – Tribological Analysis of Bulk Polymer, October 19, 2011, which found a maximum coefficient of friction, $f = 0.14$.

However, these values are used as a lower estimate, and do not correlate with some CFD modeling and the streamtube analysis used in other loss estimates.
Mechanical losses can be derived from the used of streamtube modeling in the estimation of energy loss %. The scale factor, mu, can be interpreted as an overall estimation of drag as an effective mechanical driveline loss coefficient. Given the historical accuracy of the streamtube model in predicting C_P and the lack of other accurate measures of driveline losses at this time, this value is used as an estimate of overall mechanical losses, with mu = 0.345. Comparing fitted peak $C_{P,max}$ to the idealized peak $C_{P,max}$ provided a mechanical loss of 25.9%.

A.3 – Availability Losses and Justification

Availability was calculated from historical operational data at Cobscook Bay, with additional assumptions as outlined below:

$$Availability = \frac{Operable\ Time}{Operable\ Time + Down\ Time}$$

Where,

$$Operable\ Time = Service\ Life - Down\ Time$$

1. *Service Life,* for the purposes of calculation is normalized to one year, with *Availability* calculations taking into account maintenance assumptions as described below. For this estimate of RivGen® Availability, these assumptions were constructed so as not to change by year. Therefore, for estimating baseline AEP over multiple years, *Availability* scales linearly by year up to a maximum of 20 years.

2. *Down Time, was* based on estimated downtime due to planned maintenance, unplanned maintenance, delays due to retrieval system failures and downtime dut to grid outages

    a. *Planned maintenance* is **42 days** annually, this is based on the fact that the RivGen 1.F was assumed to be out of the water for 6 weeks to avoid lake ice out and smolt outmigration from May 1 – June 15 each year.
    b. Unplanned maintenance, based on experience operating the 1.F system is was estimated that 3 unplanned maintenance events per year would consume 8 days a piece for a total of **24 days** of unplanned downtime
    c. *Retrieval system failures* based on experience with the 1.F system was estimated at **14 days**
    d. *Grid outages* are estimated as a cumulative total of **5 days**
    e. Given the magnitude of unplanned downtime above, the assumption is that over the full service life all major repairs can be covered each year without needing to add time for further maintenance.
    f. *Down Time = Planned downtime + Unplanned downtime + Retrieval system failures +Grid outages*

        = 42 + 24 + 14 + 5 days
        = 85 days

3. *Operable Time*, is demonstrated availability during full production without interruptions, which was 98% during operation in 2015.
    - Operable Time = (365 – *Down Time*) * 98% = 274 days

4. *Availability* is calculated then:

$$Availability = \frac{274}{365} = 76\%$$

A.4 – TAEP, AEC and AEP

Table A.5-1 shows the calculated values for the reference resource site. TAEP is calculated from applying the Power Curve to the Site Velocity Distributions, AEC modifies TAEP by Availability, and AEP modifies AEC by applying all transmission and conversion losses.

Table A.5-1. TAEP, AEC and AEP Calculations for Reference Resource Sites

	Kvichak River
Transmission Eff. %	96.0%
Inverter Eff. %	97.5%
VFD Eff. %	
Transformer, parasitc loss %	97.5%
Total Conversion %	93.2%
# RivGens	1
TAEP [MWh]	276.6
AEC [MWh]	211.1
AEP [MWh]	188.8

Availability was calculated at 76% for the above.

A.5 Additional Resource Velocity Distribution

The resource data used for the LCOE calculations are based on data from the Kvichak River at Igiugig, Alaska. This data came from two sources

1. Data collected by Terrasond Ltd in 2011[1].
2. USGS data from a streamgague maintained at the site from 1967-1986 (USGS 15300500 Kivicahk R at Igiugig AK).

The data from Terrasond included 4 expeditions to the project site. Initial expeditions established geodetic control references as well as correlation of these references and river stages with a historical streamgauge maintained by the USGS from 1967-1986 (USGS 15300500 Kivicahk R at Igiugig AK).

[1] Kvichak River Risec Project Resource Reconnaissance and Physical Characterization 2011

Subsequent expeditions included ADCP transects that were correlated to specific discharge levels. ORPC utilized the transect that was most closely associated with the RivGen deployment location (**Error! Reference source not found.**) to establish the river velocity experienced by the RivGen turbine at that discharge level (548 m^3/s). Daily Mean discharge levels averaged over 11 years (10/1/1975 to 9/30 1986) were calculated based on historical USGS data (FIGURE 9). Using an approximate linear fit relating discharge to velocity ORPC estimated the daily average water volicty at the resource at the site over the course of the year (FIGURE 10). This data was then binned into .1 m/s intervals to establish a velocity distribution at the project site (FIGURE 11).

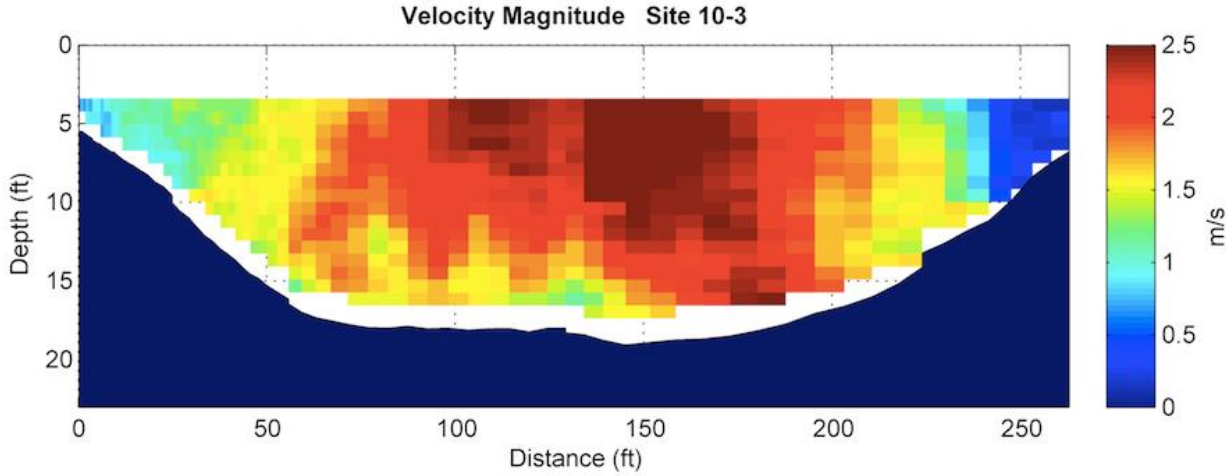

Figure 8. Data from terrasond expedition 4 taekn october 11-14 2016 at site 10 transect 3, closest to the RivGen 1.f deployment site. note discharge was at 548 m^3/s when transect was taken

Gauge Station	ice out	ice in	Avoided Cost of Power	Retail Cost of Power	Avg Load in Oper Period kwh	Max Load in Oper Period kwh	Transect Location
Kvichak River at Igiugig USGS 15300500	**1-Jun**	**15-May**	0.72	0.8	70	95	site 10- 3

00060, Discharge, cubic feet per second,												
Day of month	**Mean of daily mean values for each day for 10 - 11 years of record in, cfs (Calculation Period 1975-10-01 -> 1986-09-30)** **Period-of-record for statistical calculation restricted by user**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	17,200	15,400	13,600	12,600	11,500	12,900	17,400	23,100	27,200	26,700	24,100	20,600
2	17,100	15,400	13,600	12,500	11,500	13,000	17,800	23,400	27,000	27,000	23,700	20,200
3	17,100	15,300	13,600	12,600	11,500	13,100	17,900	23,500	26,900	26,600	23,700	20,200
4	16,800	15,200	13,700	12,500	11,400	13,200	18,000	23,800	26,900	26,600	23,600	20,100
5	16,800	15,200	13,700	12,400	11,500	13,300	18,100	24,000	27,000	26,300	23,600	19,900
6	16,700	15,100	13,700	12,400	11,500	13,600	18,300	24,100	26,900	26,500	23,500	20,000
7	16,700	15,100	13,500	12,300	11,400	13,700	18,500	24,300	27,000	26,400	23,500	19,800
8	16,600	15,000	13,500	12,300	11,500	13,900	18,600	24,400	26,800	26,300	23,300	20,300
9	16,500	14,900	13,500	12,200	11,500	13,900	18,800	24,700	26,900	26,200	23,500	19,800
10	16,500	14,900	13,600	12,200	11,500	14,000	19,100	24,800	26,900	26,300	23,300	19,500
11	16,300	14,700	13,500	12,200	11,500	14,200	19,400	25,100	26,900	26,200	23,100	19,300
12	16,200	14,600	13,500	12,200	11,600	14,200	19,600	25,400	27,300	26,100	22,700	19,100
13	16,200	14,600	13,400	12,100	11,600	14,500	19,700	25,500	27,100	26,200	22,400	19,000
14	16,200	14,500	13,400	12,100	11,500	14,600	20,000	25,700	26,900	26,500	22,300	18,900
15	16,300	14,500	13,400	12,000	11,700	14,800	20,200	25,700	27,000	26,300	22,000	18,900
16	16,200	14,300	13,200	12,000	11,700	15,100	20,300	26,000	27,100	26,500	21,800	18,800
17	16,100	14,200	13,200	12,000	11,800	15,100	20,300	26,400	27,500	25,900	21,700	18,900
18	16,100	14,100	13,200	11,900	11,700	15,200	20,500	26,400	27,600	25,600	21,800	18,800
19	16,100	14,100	13,200	12,000	11,700	15,300	20,900	26,700	27,100	25,500	21,700	18,500
20	16,100	14,000	13,100	11,800	11,800	15,400	21,000	26,800	27,400	25,700	21,600	18,400
21	16,000	13,800	13,100	11,800	11,900	15,700	21,400	26,800	27,500	26,100	21,600	18,300
22	16,000	13,800	13,100	11,700	11,900	15,800	21,500	26,900	27,800	25,700	21,100	18,200
23	15,900	13,800	13,100	11,700	12,200	15,900	21,700	27,100	27,600	25,600	20,900	18,000
24	15,900	13,800	13,100	11,700	12,100	16,100	21,700	27,400	27,500	25,100	20,800	18,000
25	15,900	13,800	13,000	11,700	12,100	16,100	21,800	27,400	27,700	25,100	20,600	18,100
26	15,800	13,700	12,900	11,700	12,200	16,400	22,100	27,200	27,900	24,800	20,900	18,100
27	15,700	13,700	12,900	11,700	12,300	16,700	22,300	27,300	27,500	24,600	20,700	17,800
28	15,600	13,800	12,800	11,700	12,500	16,800	22,500	27,200	27,200	24,400	20,800	17,900
29	15,600	13,000	12,700	11,600	12,600	17,100	22,700	27,300	27,400	24,500	20,800	17,800
30	15,600		12,600	11,500	12,700	17,200	23,000	27,300	26,900	24,500	20,800	17,600
31	15,500		12,700		12,700		23,000	27,300		24,600		17,500

Velocity& Interpol.	Discharge	Water& Depth&m)
2.5	548	5

00060, Discharge, cubic meterst per second,												
Day of month	Mean of daily mean values for each day for 8 - 9 years of record in, cfs (Calculation Period 2000-10-01 -> 2010-09-30) Period-of-record for statistical calculation restricted by user											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	487.3	436.3	385.3	356.9	325.8	365.4	492.9	654.4	770.5	756.4	682.7	583.6
	484.4	436.3	385.3	354.1	325.8	368.3	504.2	662.9	764.9	764.9	671.4	572.2
	484.4	433.4	385.3	356.9	325.8	371.1	507.1	665.7	762.0	753.5	671.4	572.2
	475.9	430.6	388.1	354.1	322.9	373.9	509.9	674.2	762.0	753.5	668.6	569.4
	475.9	430.6	388.1	351.3	325.8	376.8	512.7	679.9	764.9	745.0	668.6	563.7
	473.1	427.8	388.1	351.3	325.8	385.3	518.4	682.7	762.0	750.7	665.7	566.6
	473.1	427.8	382.4	348.4	322.9	388.1	524.1	688.4	764.9	747.9	665.7	560.9
	470.3	424.9	382.4	348.4	325.8	393.8	526.9	691.2	759.2	745.0	660.1	575.1
	467.4	422.1	382.4	345.6	325.8	393.8	532.6	699.7	762.0	742.2	665.7	560.9
	467.4	422.1	385.3	345.6	325.8	396.6	541.1	702.5	762.0	745.0	660.1	552.4
	461.8	416.4	382.4	345.6	325.8	402.3	549.6	711.0	762.0	742.2	654.4	546.7
	458.9	413.6	382.4	345.6	328.6	402.3	555.2	719.5	773.4	739.4	643.1	541.1
	458.9	413.6	379.6	342.8	328.6	410.8	558.1	722.4	767.7	742.2	634.6	538.2
	458.9	410.8	379.6	342.8	325.8	413.6	566.6	728.0	762.0	750.7	631.7	535.4
	461.8	410.8	379.6	339.9	331.4	419.3	572.2	728.0	764.9	745.0	623.2	535.4
	458.9	405.1	373.9	339.9	331.4	427.8	575.1	736.5	767.7	750.7	617.6	532.6
	456.1	402.3	373.9	339.9	334.3	427.8	575.1	747.9	779.0	733.7	614.7	535.4
	456.1	399.4	373.9	337.1	331.4	430.6	580.7	747.9	781.9	725.2	617.6	532.6
	456.1	399.4	373.9	339.9	331.4	433.4	592.1	756.4	767.7	722.4	614.7	524.1
	456.1	396.6	371.1	334.3	334.3	436.3	594.9	759.2	776.2	728.0	611.9	521.2
	453.3	390.9	371.1	334.3	337.1	444.8	606.2	759.2	779.0	739.4	611.9	518.4
	453.3	390.9	371.1	331.4	337.1	447.6	609.1	762.0	787.5	728.0	597.7	515.6
	450.4	390.9	371.1	331.4	345.6	450.4	614.7	767.7	781.9	725.2	592.1	509.9
	450.4	390.9	371.1	331.4	342.8	456.1	614.7	776.2	779.0	711.0	589.2	509.9
	450.4	390.9	368.3	331.4	342.8	456.1	617.6	776.2	784.7	711.0	583.6	512.7
	447.6	388.1	365.4	331.4	345.6	464.6	626.1	770.5	790.4	702.5	592.1	512.7
	444.8	388.1	365.4	331.4	348.4	473.1	631.7	773.4	779.0	696.9	586.4	504.2
	441.9	390.9	362.6	331.4	354.1	475.9	637.4	770.5	770.5	691.2	589.2	507.1
	441.9	368.3	359.8	328.6	356.9	484.4	643.1	773.4	776.2	694.1	589.2	504.2
	441.9	0.0	356.9	325.8	359.8	487.3	651.6	773.4	762.0	694.1	589.2	498.6
	439.1	0.0	359.8	0.0	359.8	0.0	651.6	773.4	0.0	696.9	0.0	495.8

Figure 9 USGS data from Kvichak River site, daily mean averge discharge from 10/1/1975 to 9/30 1986

operation dates: **8-Jun** **1-May**

Discharge data (USGS), represents the mean of daily mean values from May-Sept.,(Calculation period 1999-10-01 ->2

Date	Discharge (m^3/s)	Velocity at project site(m/s)	Power/m2(kW/m2)
1/1	487	2.4235	7.1173
1/2	484	2.4210	7.0948
1/3	484	2.4210	7.0948
1/4	476	2.4133	7.0278
1/5	476	2.4133	7.0278
1/6	473	2.4108	7.0055
1/7	473	2.4108	7.0055
1/8	470	2.4082	6.9833
1/9	467	2.4057	6.9612
1/10	467	2.4057	6.9612
1/11	462	2.4006	6.9170
1/12	459	2.3980	6.8950
1/13	459	2.3980	6.8950
1/14	459	2.3980	6.8950
1/15	462	2.4006	6.9170
1/16	459	2.3980	6.8950
1/17	456	2.3955	6.8730
1/18	456	2.3955	6.8730
1/19	456	2.3955	6.8730
1/20	456	2.3955	6.8730
1/21	453	2.3929	6.8511
1/22	453	2.3929	6.8511
1/23	450	2.3904	6.8292
1/24	450	2.3904	6.8292
1/25	450	2.3904	6.8292
1/26	448	2.3878	6.8074
1/27	445	2.3853	6.7856
1/28	442	2.3827	6.7639
1/29	442	2.3827	6.7639
1/30	442	2.3827	6.7639
1/31	439	2.3802	6.7422
2/1	436	2.3776	6.7206
2/2	436	2.3776	6.7206
2/3	433	2.3751	6.6990
2/4	431	2.3725	6.6774
2/5	431	2.3725	6.6774
2/6	428	2.3700	6.6559
2/7	428	2.3700	6.6559
2/8	425	2.3674	6.6344
2/9	422	2.3649	6.6130
2/10	422	2.3649	6.6130
2/11	416	2.3598	6.5704
2/12	414	2.3572	6.5491
2/13	414	2.3572	6.5491
2/14	411	2.3547	6.5279
2/15	411	2.3547	6.5279
2/16	405	2.3496	6.4855
2/17	402	2.3470	6.4644
2/18	399	2.3445	6.4434
2/19	399	2.3445	6.4434
2/20	397	2.3419	6.4224

2/21	391	2.3368	6.3805
2/22	391	2.3368	6.3805
2/23	391	2.3368	6.3805
2/24	391	2.3368	6.3805
2/25	391	2.3368	6.3805
2/26	388	2.3343	6.3597
2/27	388	2.3343	6.3597
2/28	391	2.3368	6.3805
3/1	385	2.3317	6.3389
3/2	385	2.3317	6.3389
3/3	385	2.3317	6.3389
3/4	388	2.3343	6.3597
3/5	388	2.3343	6.3597
3/6	388	2.3343	6.3597
3/7	382	2.3292	6.3181
3/8	382	2.3292	6.3181
3/9	382	2.3292	6.3181
3/10	385	2.3317	6.3389
3/11	382	2.3292	6.3181
3/12	382	2.3292	6.3181
3/13	380	2.3266	6.2974
3/14	380	2.3266	6.2974
3/15	380	2.3266	6.2974
3/16	374	2.3215	6.2561
3/17	374	2.3215	6.2561
3/18	374	2.3215	6.2561
3/19	374	2.3215	6.2561
3/20	371	2.3190	6.2355
3/21	371	2.3190	6.2355
3/22	371	2.3190	6.2355
3/23	371	2.3190	6.2355
3/24	371	2.3190	6.2355
3/25	368	2.3164	6.2149
3/26	365	2.3139	6.1944
3/27	365	2.3139	6.1944
3/28	363	2.3113	6.1740
3/29	360	2.3088	6.1536
3/30	357	2.3062	6.1332
3/31	360	2.3088	6.1536
4/1	357	2.3062	6.1332
4/2	354	2.3037	6.1129
4/3	357	2.3062	6.1332
4/4	354	2.3037	6.1129
4/5	351	2.3011	6.0926
4/6	351	2.3011	6.0926
4/7	348	2.2986	6.0724
4/8	348	2.2986	6.0724
4/9	346	2.2960	6.0522
4/10	346	2.2960	6.0522
4/11	346	2.2960	6.0522
4/12	346	2.2960	6.0522
4/13	343	2.2935	6.0321
4/14	343	2.2935	6.0321
4/15	340	2.2909	6.0120
4/16	340	2.2909	6.0120
4/17	340	2.2909	6.0120
4/18	337	2.2884	5.9919
4/19	340	2.2909	6.0120

4/20	334	2.2858	5.9719
4/21	334	2.2858	5.9719
4/22	331	2.2833	5.9519
4/23	331	2.2833	5.9519
4/24	331	2.2833	5.9519
4/25	331	2.2833	5.9519
4/26	331	2.2833	5.9519
4/27	331	2.2833	5.9519
4/28	331	2.2833	5.9519
4/29	329	2.2808	5.9320
4/30	326	2.2782	5.9122
5/1	326	2.2782	5.9122
5/2	326	2.2782	5.9122
5/3	326	2.2782	5.9122
5/4	323	2.2757	5.8923
5/5	326	2.2782	5.9122
5/6	326	2.2782	5.9122
5/7	323	2.2757	5.8923
5/8	326	2.2782	5.9122
5/9	326	2.2782	5.9122
5/10	326	2.2782	5.9122
5/11	326	2.2782	5.9122
5/12	329	2.2808	5.9320
5/13	329	2.2808	5.9320
5/14	326	2.2782	5.9122
5/15	331	2.2833	5.9519
5/16	331	2.2833	5.9519
5/17	334	2.2858	5.9719
5/18	331	2.2833	5.9519
5/19	331	2.2833	5.9519
5/20	334	2.2858	5.9719
5/21	337	2.2884	5.9919
5/22	337	2.2884	5.9919
5/23	346	2.2960	6.0522
5/24	343	2.2935	6.0321
5/25	343	2.2935	6.0321
5/26	346	2.2960	6.0522
5/27	348	2.2986	6.0724
5/28	354	2.3037	6.1129
5/29	357	2.3062	6.1332
5/30	360	2.3088	6.1536
5/31	360	2.3088	6.1536
6/1	365	2.3139	6.1944
6/2	368	2.3164	6.2149
6/3	371	2.3190	6.2355
6/4	374	2.3215	6.2561
6/5	377	2.3241	6.2767
6/6	385	2.3317	6.3389
6/7	388	2.3343	6.3597
6/8	394	2.3394	6.4015
6/9	394	2.3394	6.4015
6/10	397	2.3419	6.4224
6/11	402	2.3470	6.4644
6/12	402	2.3470	6.4644
6/13	411	2.3547	6.5279
6/14	414	2.3572	6.5491
6/15	419	2.3623	6.5917
6/16	428	2.3700	6.6559

6/17	428	2.3700	6.6559
6/18	431	2.3725	6.6774
6/19	433	2.3751	6.6990
6/20	436	2.3776	6.7206
6/21	445	2.3853	6.7856
6/22	448	2.3878	6.8074
6/23	450	2.3904	6.8292
6/24	456	2.3955	6.8730
6/25	456	2.3955	6.8730
6/26	465	2.4031	6.9391
6/27	473	2.4108	7.0055
6/28	476	2.4133	7.0278
6/29	484	2.4210	7.0948
6/30	487	2.4235	7.1173
7/1	493	2.4286	7.1623
7/2	504	2.4388	7.2529
7/3	507	2.4414	7.2757
7/4	510	2.4439	7.2985
7/5	513	2.4465	7.3214
7/6	518	2.4516	7.3672
7/7	524	2.4567	7.4133
7/8	527	2.4592	7.4364
7/9	533	2.4643	7.4828
7/10	541	2.4720	7.5526
7/11	550	2.4796	7.6230
7/12	555	2.4847	7.6701
7/13	558	2.4873	7.6937
7/14	567	2.4949	7.7649
7/15	572	2.5000	7.8126
7/16	575	2.5026	7.8366
7/17	575	2.5026	7.8366
7/18	581	2.5077	7.8846
7/19	592	2.5179	7.9811
7/20	595	2.5204	8.0054
7/21	606	2.5306	8.1030
7/22	609	2.5332	8.1275
7/23	615	2.5383	8.1767
7/24	615	2.5383	8.1767
7/25	618	2.5408	8.2013
7/26	626	2.5485	8.2756
7/27	632	2.5536	8.3254
7/28	637	2.5587	8.3754
7/29	643	2.5638	8.4256
7/30	652	2.5714	8.5012
7/31	652	2.5714	8.5012
8/1	654	2.5740	8.5265
8/2	663	2.5816	8.6027
8/3	666	2.5842	8.6283
8/4	674	2.5918	8.7051
8/5	680	2.5969	8.7566
8/6	683	2.5994	8.7824
8/7	688	2.6045	8.8342
8/8	691	2.6071	8.8602
8/9	700	2.6147	8.9384
8/10	703	2.6173	8.9645
8/11	711	2.6249	9.0434
8/12	720	2.6326	9.1226
8/13	722	2.6351	9.1492

8/14	728	2.6402	9.2024
8/15	728	2.6402	9.2024
8/16	737	2.6479	9.2826
8/17	748	2.6581	9.3903
8/18	748	2.6581	9.3903
8/19	756	2.6657	9.4716
8/20	759	2.6683	9.4988
8/21	759	2.6683	9.4988
8/22	762	2.6708	9.5260
8/23	768	2.6759	9.5807
8/24	776	2.6836	9.6631
8/25	776	2.6836	9.6631
8/26	771	2.6785	9.6081
8/27	773	2.6810	9.6356
8/28	771	2.6785	9.6081
8/29	773	2.6810	9.6356
8/30	773	2.6810	9.6356
8/31	773	2.6810	9.6356
9/1	771	2.6785	9.6081
9/2	765	2.6734	9.5533
9/3	762	2.6708	9.5260
9/4	762	2.6708	9.5260
9/5	765	2.6734	9.5533
9/6	762	2.6708	9.5260
9/7	765	2.6734	9.5533
9/8	759	2.6683	9.4988
9/9	762	2.6708	9.5260
9/10	762	2.6708	9.5260
9/11	762	2.6708	9.5260
9/12	773	2.6810	9.6356
9/13	768	2.6759	9.5807
9/14	762	2.6708	9.5260
9/15	765	2.6734	9.5533
9/16	768	2.6759	9.5807
9/17	779	2.6861	9.6906
9/18	782	2.6887	9.7183
9/19	768	2.6759	9.5807
9/20	776	2.6836	9.6631
9/21	779	2.6861	9.6906
9/22	788	2.6938	9.7737
9/23	782	2.6887	9.7183
9/24	779	2.6861	9.6906
9/25	785	2.6912	9.7459
9/26	790	2.6963	9.8014
9/27	779	2.6861	9.6906
9/28	771	2.6785	9.6081
9/29	776	2.6836	9.6631
9/30	762	2.6708	9.5260
10/1	756	2.6657	9.4716
10/2	765	2.6734	9.5533
10/3	754	2.6632	9.4444
10/4	754	2.6632	9.4444
10/5	745	2.6555	9.3633
10/6	751	2.6606	9.4173
10/7	748	2.6581	9.3903
10/8	745	2.6555	9.3633
10/9	742	2.6530	9.3363
10/10	745	2.6555	9.3633

10/11	742	2.6530	9.3363
10/12	739	2.6504	9.3094
10/13	742	2.6530	9.3363
10/14	751	2.6606	9.4173
10/15	745	2.6555	9.3633
10/16	751	2.6606	9.4173
10/17	734	2.6453	9.2558
10/18	725	2.6377	9.1758
10/19	722	2.6351	9.1492
10/20	728	2.6402	9.2024
10/21	739	2.6504	9.3094
10/22	728	2.6402	9.2024
10/23	725	2.6377	9.1758
10/24	711	2.6249	9.0434
10/25	711	2.6249	9.0434
10/26	703	2.6173	8.9645
10/27	697	2.6122	8.9122
10/28	691	2.6071	8.8602
10/29	694	2.6096	8.8862
10/30	694	2.6096	8.8862
10/31	697	2.6122	8.9122
11/1	683	2.5994	8.7824
11/2	671	2.5892	8.6794
11/3	671	2.5892	8.6794
11/4	669	2.5867	8.6538
11/5	669	2.5867	8.6538
11/6	666	2.5842	8.6283
11/7	666	2.5842	8.6283
11/8	660	2.5791	8.5773
11/9	666	2.5842	8.6283
11/10	660	2.5791	8.5773
11/11	654	2.5740	8.5265
11/12	643	2.5638	8.4256
11/13	635	2.5561	8.3504
11/14	632	2.5536	8.3254
11/15	623	2.5459	8.2508
11/16	618	2.5408	8.2013
11/17	615	2.5383	8.1767
11/18	618	2.5408	8.2013
11/19	615	2.5383	8.1767
11/20	612	2.5357	8.1521
11/21	612	2.5357	8.1521
11/22	598	2.5230	8.0297
11/23	592	2.5179	7.9811
11/24	589	2.5153	7.9569
11/25	584	2.5102	7.9086
11/26	592	2.5179	7.9811
11/27	586	2.5128	7.9328
11/28	589	2.5153	7.9569
11/29	589	2.5153	7.9569
11/30	589	2.5153	7.9569
12/1	584	2.5102	7.9086
12/2	572	2.5000	7.8126
12/3	572	2.5000	7.8126
12/4	569	2.4975	7.7888
12/5	564	2.4924	7.7411
12/6	567	2.4949	7.7649
12/7	561	2.4898	7.7174

12/8	575	2.5026	7.8366
12/9	561	2.4898	7.7174
12/10	552	2.4822	7.6465
12/11	547	2.4771	7.5995
12/12	541	2.4720	7.5526
12/13	538	2.4694	7.5293
12/14	535	2.4669	7.5060
12/15	535	2.4669	7.5060
12/16	533	2.4643	7.4828
12/17	535	2.4669	7.5060
12/18	533	2.4643	7.4828
12/19	524	2.4567	7.4133
12/20	521	2.4541	7.3902
12/21	518	2.4516	7.3672
12/22	516	2.4490	7.3443
12/23	510	2.4439	7.2985
12/24	510	2.4439	7.2985
12/25	513	2.4465	7.3214
12/26	513	2.4465	7.3214
12/27	504	2.4388	7.2529
12/28	507	2.4414	7.2757
12/29	504	2.4388	7.2529
12/30	499	2.4337	7.2075
12/31	496	2.4312	7.1849

Figure 10. Derivation of velocity from discharge and available power from velocity

Kvichak River site selected for AEP calculations		
Vel. Bin	**Power in Water [kW]**	**Igiugig**
0.1	0.01	0.00%
0.2	0.05	0.00%
0.3	0.16	0.00%
0.4	0.38	0.00%
0.5	0.74	0.00%
0.6	1.27	0.00%
0.7	2.02	0.00%
0.8	3.01	0.00%
0.9	4.29	0.00%
1	5.88	0.00%
1.1	7.83	0.00%
1.2	10.17	0.00%
1.3	12.93	0.00%
1.4	16.14	0.00%
1.5	19.86	0.00%
1.6	24.10	0.00%
1.7	28.91	0.00%
1.8	34.31	0.00%
1.9	40.35	0.00%
2	47.07	0.00%
2.1	54.49	0.00%
2.2	62.65	0.00%
2.3	71.58	32.10%
2.4	81.33	21.60%
2.5	91.93	15.89%
2.6	103.41	13.40%
2.7	115.80	17.00%
2.8	129.15	0.00%
2.9	143.49	0.00%
3	158.85	0.00%
3.1	175.28	0.00%
3.2	192.79	0.00%
3.3	211.44	0.00%
3.4	231.25	0.00%
3.5	252.26	0.00%
3.6	274.50	0.00%
3.7	298.02	0.00%
3.8	322.84	0.00%
3.9	349.00	0.00%
4	376.54	0.00%

4.1	405.50	0.00%
4.2	435.90	0.00%
4.3	467.78	0.00%
4.4	501.18	0.00%
4.5	536.13	0.00%
4.6	572.68	0.00%
4.7	610.84	0.00%
4.8	650.67	0.00%
4.9	692.19	0.00%
5	735.44	0.00%
5.1	780.45	0.00%
ANNUALIZED AVAILABLE POWER:		88.70
average velocity		2.46135

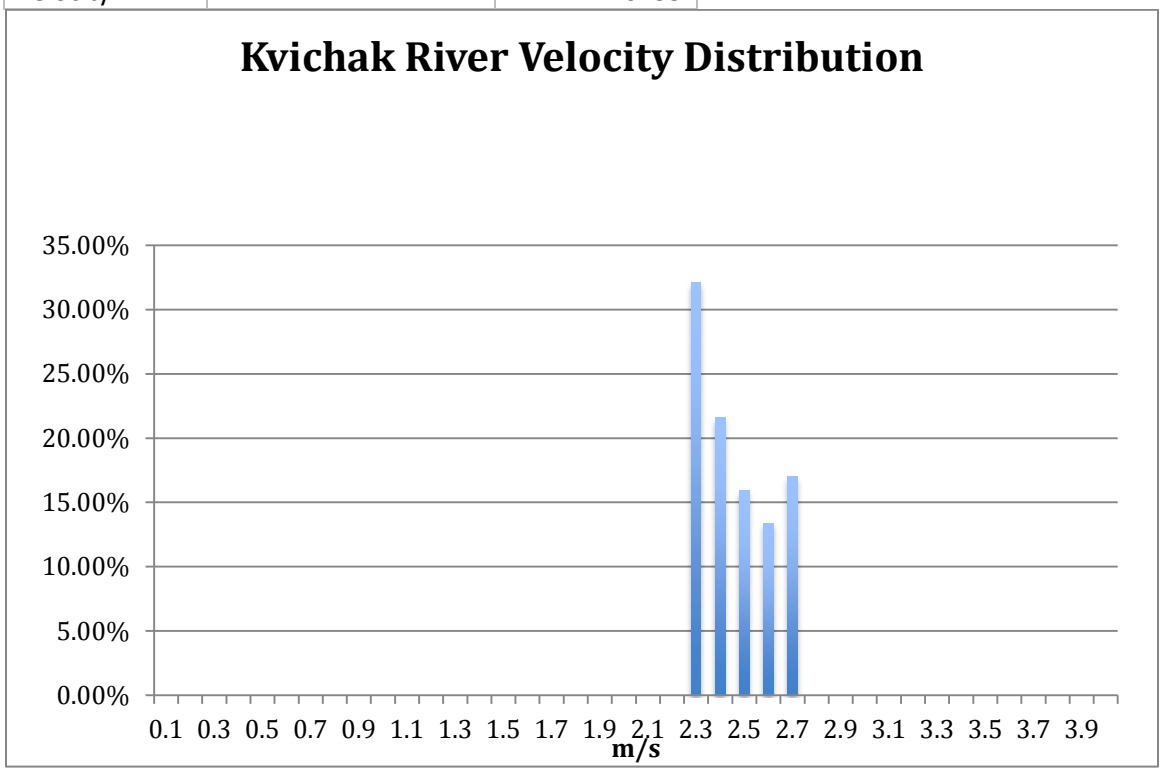

Figure 11. Binned velocity distribution at Kvichak River site