TPL ASSESSMENT GUIDE

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Contents

1 Overview

Technology Performance Level (TPL) assessment is intended to provide a comprehensive and holistic measure of a wave energy converter's (WEC) techno economic performance potential. The advantage of using TPL in conjunction with Technology Readiness Level (TRL) assessments in guiding technology development trajectories to successful outcomes in less time, at less overall cost, and with less encountered risk has been articulated in [1-3]. In partnership with industry and international collaborators, a TPL assessment methodology for grid-connected applications has been developed through the application of the systems engineering approach and based on the specific mission statement: "the wave energy plant will convert ocean wave energy to electricity and deliver it to the continental grid market in a competitive and acceptable manner across the lifecycle" [4,5]. Metrics under seven different categories have been developed, weighted based on their relative relevance, and combined to yield a composite score.

The methodology has been implemented in this tool. While the TPL assessments can be applied at all technology development stages and associated Technology Readiness Levels (TRLs), this tool is aimed at assessing early stage concepts. This tool uses a series of questions in seven distinct categories to guide the assessor in evaluating a WEC. Each question addresses a specific aspect that impacts the techno economic performance of a WEC. For each question, the reviewer must provide a score. Also, this tool is intended to evaluate a wide range of WEC archetypes whose techno-economic performance may be impacted differently by different evaluation criteria. It is possible that some of the criteria are not applicable to certain archetypes. In such cases, the assessor has the option to turn off an inapplicable criterion.

Table 1 TPL high level definitions [1]

TPL	Category Characteristics		TPL Characteristics
9	High	Technology is economically viable and competitive as a renewable energy source.	Competitive with other energy sources without any support mechanism
8			Competitive with other energy sources given sustainable (e.g. low feed-in tariff) support mechanism
7			Competitive with other renewable energy sources given favorable (e.g. high feed-in tariff) support mechanism
6	Medium	Technology features some characteristics for potential economic viability under distinctive market and operational conditions.	Majority of key performance characteristics and cost drivers satisfy potential economic viability under distinctive and favorable market and operational conditions.
5			To achieve economic viability under distinctive and favorable market and operational conditions, some key technology implementation improvements are required and regarded as possible.
4		Technological or conceptual improvements may be required.	To achieve economic viability under distinctive and favorable market and operational conditions, a number of key technology implementation and fundamental conceptual improvements are required and regarded as possible.
3	Low	Technology is not economically viable.	Minority of key performance characteristics and cost drivers do not satisfy potential economic viability and critical improvements are not regarded as possible within conceptual fundamentals.
2			Some key performance characteristics and cost drivers do not satisfy potential economic viability and critical improvements are not regarded as possible within conceptual fundamentals.
1			Majority of key performance characteristics and cost drivers do not satisfy and present a barrier to potential economic viability and critical improvements are not regarded as possible within conceptual fundamentals.

2 Use cases

The use cases are:

- Developers improving their design, to find fatal flaws early, to get feedback on current design, to identify areas of significant improvement which will yield the most value for the effort
- Reviewers assessing technologies in competitions
- Reviewers assessing proposals for making funding decisions
- Investor or project developer due diligence
- Landscaping the domain for formulating R&D strategy

3 Background information needed from developer

This section is a summary of the information that needs to be available in order to perform a TPL assessment. If the assessment is being done by the developer, then not much context will need to be provided and this list just provides some guidance on what information will need to be gathered. If the developer is providing this information to an outside party for their use in conducting an assessment, then it is important that the information provided have enough context and background that the assessor will understand it. A detailed description of the information required for assessment is given in the appendix.

3.1 General

This section should provide the assessor with a high-level overview of the technology, its working principles, dimensions, range of configurations for different operating and survival states, major components, and layout in a farm.

- Working principle
- Operating configuration
- Survival configuration
- Power take off
- Station keeping
- Array layout and balance of station (BOS)

3.2 Design

The design philosophy, design basis including all assumptions, environmental conditions, etc., standards and guidelines used, tools used, etc. should be discussed.

3.3 Manufacture, Assembly, Installation, and Maintenance

This section should provide assessors with an understanding of steps needed to take a converter concept from raw materials and components, to full operation and maintenance plans. This shall include the associated costs resulting from the evolution of raw materials and components, to full operational WEC with resulting maintenance schedule.

3.4 Performance

This section should provide the assessor with a quantitative measure of the ability of the WEC to capture and convert wave power.

- Power capture
- Conversion efficiency
- Availability factor

3.5 Cost

While it is still too early to perform a comprehensive LCOE determination, estimates should be provided to help the assessor determine the associated estimates of CapEx and OpEx costs.

3.6 Benefit to Society

Beyond the techno economic feasibility, development of the WEC and the farm for which it will be used, should have both tangible and intangible benefits to: (1) local communities; (2) the environment; and (3) society. This section requests information to help the assessor's understanding of the broader impacts of the WEC and its use in a wave energy farm.

3.7 Permitting, Environmental, and Conflict Issues

Information is needed to understand the potential for environmental, wildlife, and other user conflicts that can impact permitting and areas where the WEC can be used.

3.8 Safety

Safety of people and property is a priority in any commercial activity. Provide information on the dangers from the installation and operation of the WEC farm to the people working there and others who may also use the same area. Provide information on how those dangers will be mitigated. The answers in this section should provide the assessor with an understanding of the risks posed by the WEC throughout its lifecycle to:

- Personnel
- Equipment

4 Recommended best practices

It is recommended that the assessor provide a detailed comment for each question describing how the score was arrived at. A reference must be made to any document from which the necessary background information was collected. When there is insufficient background information, the attendant uncertainty in the score must be flagged by selecting a low confidence level.

The best practice is for two or more assessors to independently assess a technology and then meet to compare scores, discuss differences, and arrive at consensus. The assessment will have the most value after independent assessors meet to resolve significant disparities in scores. WEC developers wishing to have their technologies assessed by the laboratories must first do an assessment themselves and then provide the background information and their assessment to the laboratories.

Whenever possible while completing an assessment, the scoring should be based directly upon rigorously-cited pieces of developer provided information (see the Reference Model examples). If the necessary information is not provided exactly, causing the assessor to extrapolate, perform calculations, or make assumptions based upon the available data, all steps of this reasoning should be documented as scoring justification, along with any additional cited references. It is recommended that an assessor also consult the references included at the end of this document and the example Reference Model assessments to gain a useful context and point of comparison for scoring.

It is fully expected that not all questions can be answered with complete confidence and rigorous reasoning. Each score should also indicate an associated confidence level (high, medium, or low). A score based upon clearly documented and reasonable developer-provided information, or calculated therefrom in a straightforward manner would have a high confidence level. If the score is based upon reasonable extensions, minor assumptions, or slight extrapolations from developer provided data and scoring guidance, a medium confidence level should be selected, and all such extensions/assumptions/extrapolations should be documented. A score based upon gratuitous assumption from little information, or for which the information is dubious or has a high degree of associated uncertainty, would have a low confidence level. Again the reader is referred to the Reference Model assessments as illustrative examples.

5 Assessment examples

TPL assessments of Reference Models are given here as illustrative examples. They are based on the related studies and supporting documentation available in [6-8] and the Reference Model project site. Detailed assessments will be available online.

5.1 Reference Model 3 (point absorber)

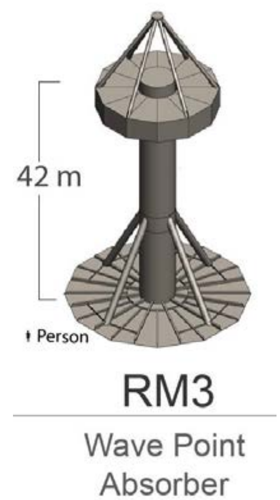

Table 2 TPL score sheet for Reference Model 3

Categories		Subcategories (threshold)		Sub-subcategories (threshold)	
C1 Cost of energy	5.9	C1.1 CAPEX	6.2	C1.1.1 Design (4)	5.3
				C1.1.2 Manufacturability (4)	7.3
				C1.1.3 Transportability (4)	8.0
				C1.1.4 Installability (4)	5.0
		C1.2 OPEX	6.5	C1.2.1 Reliability (4)	6.5
				C1.2.2 Maintainability (4)	6.5
		C1.3 Performance	5.0	C1.3.1 Energy capture (4)	4.0
				C1.3.2 Energy conversion (4)	6.3
		C1.4 Availability	6.7	C1.4.1 Availability (4)	6.7
C2 Investment opportunity	6.3	C2.1 Investment opportunity	6.3	C2.1.1 CAPEX uncertainty (4)	7.7
				C2.1.2 OPEX uncertainty (4)	6.7
				C2.1.3 Performance uncertainty (4)	5.0
				C2.1.4 Availability uncertainty (4)	6.7
C3 Grid operations	6.0	C3.1 Forecastable (3)	6.0		
C4 Beneficial to society	3.0	C4.1 Impact on local communities (3)	1.7		
		C4.2 Greenhouse gas (GHG) emission and pollution (4)	4.3		
C5 Permitting and certification	3.3	C5.1 Environmental impacts (7)	5.0		
		C5.2 Ecological impacts (7)	5.0		
		C5.3 Area use conflicts (7)	1.5		
C6 Safety and function	5.0	C6.1 Safety (7)	4.7		
		C6.2 Survivable	5.4	C6.2.1 Extreme loads (7)	3.5
				C6.2.2 Grid failure (7)	5.7
				C6.2.3 Collisions (7)	7.0
				C6.2.4 Temporary conditions (7)	5.0
				C6.2.5 Fatigue (7)	7.0
				C6.2.6 Configuration changes (7)	5.0
C7 Globally	5.5	C7.1 Deployment (4)	5.5		
TPL	**5.4**	**Number of subcategory thresholds breached**	**5**	**Number of sub-subcategory thresholds breached**	**4**

Flexibility in how the capabilities must be satisfied	
No flexibility-Any technical solution must satisfy this capability to be viable	
Some flexibility-A technical solution may not fully satisfy this capability but will trade off with another requirement to make the higher capability viable	
Medium flexibility-A technical solution may only partly satisfy this capability and still be viable	
High flexibility-A technical solution may not satisfy this capability and still be viable	

5.2 Reference Model 5 (surge flap)

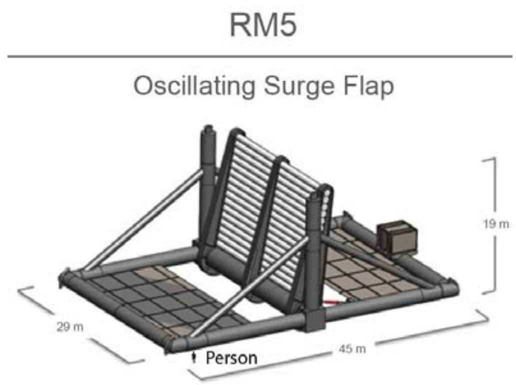

Table 3 TPL score sheet for Reference Model 5

Categories		Subcategories (threshold)		Sub-subcategories (threshold)	
C1 Cost of energy	4.9	C1.1 CAPEX	6.3	C1.1.1 Design (4)	5.2
				C1.1.2 Manufacturability (4)	7.0
				C1.1.3 Transportability (4)	8.0
				C1.1.4 Installability (4)	6.0
		C1.2 OPEX	4.7	C1.2.1 Reliability (4)	5.0
				C1.2.2 Maintainability (4)	4.0
		C1.3 Performance	4.7	C1.3.1 Energy capture (4)	3.7
				C1.3.2 Energy conversion (4)	6.0
		C1.4 Availability	4.3	C1.4.1 Availability (4)	4.3
C2 Investment opportunity	3.2	C2.1 Investment opportunity	3.2	C2.1.1 CAPEX uncertainty (4)	7.0
				C2.1.2 OPEX uncertainty (4)	5.0
				C2.1.3 Performance uncertainty (4)	1.0
				C2.1.4 Availability uncertainty (4)	5.0
C3 Grid operations	1.0	C3.1 Forecastable (3)	1.0		
C4 Beneficial to society	7.3	C4.1 Impact on local communities (3)	9.0		
		C4.2 Greenhouse gas (GHG) emission and pollution (4)	5.7		
C5 Permitting and certification	4.6	C5.1 Environmental impacts (7)	5.0		
		C5.2 Ecological impacts (7)	5.0		
		C5.3 Area use conflicts (7)	4.0		
C6 Safety and function	4.7	C6.1 Safety (7)	4.2		
		C6.2 Survivable	5.2	C6.2.1 Extreme loads (7)	6.5
				C6.2.2 Grid failure (7)	4.3
				C6.2.3 Collisions (7)	3.5
				C6.2.4 Temporary conditions (7)	5.0
				C6.2.5 Fatigue (7)	5.0
				C6.2.6 Configuration changes (7)	8.0
C7 Globally	4.5	C7.1 Deployment (4)	4.5		
TPL	**4.1**	**Number of subcategory thresholds breached**	**5**	**Number of sub-subcategory thresholds breached**	**7**

Flexibility in how the capabilities must be satisfied	
No flexibility-Any technical solution must satisfy this capability to be viable	
Some flexibility-A technical solution may not fully satisfy this capability but will trade off with another requirement to make the higher capability viable	
Medium flexibility-A technical solution may only partly satisfy this capability and still be viable	
High flexibility-A technical solution may not satisfy this capability and still be viable	

5.3 Reference Model 6 (oscillating water column)

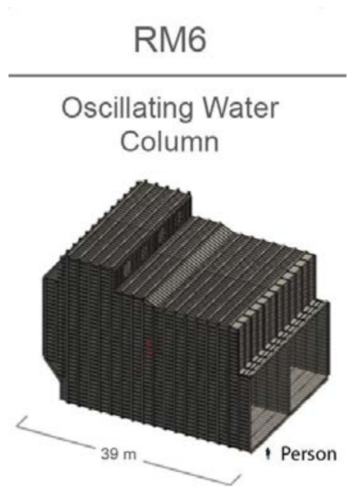

Table 4 TPL score sheet for Reference Model 6

Categories		Subcategories (threshold)		Sub-subcategories (threshold)	
C1 Cost of energy	6.4	C1.1 CAPEX	6.5	C1.1.1 Design (4)	5.8
				C1.1.2 Manufacturability (4)	7.5
				C1.1.3 Transportability (4)	8.0
				C1.1.4 Installability (4)	5.4
		C1.2 OPEX	7.6	C1.2.1 Reliability (4)	8.0
				C1.2.2 Maintainability (4)	6.5
		C1.3 Performance	5.5	C1.3.1 Energy capture (4)	5.8
				C1.3.2 Energy conversion (4)	5.3
		C1.4 Availability	7.0	C1.4.1 Availability (4)	7.0
C2 Investment opportunity	5.6	C2.1 Investment opportunity		C2.1.1 CAPEX uncertainty (4)	8.7
				C2.1.2 OPEX uncertainty (4)	7.0
				C2.1.3 Performance uncertainty (4)	3.0
				C2.1.4 Availability uncertainty (4)	7.0
C3 Grid operations	3.0	C3.1 Forecastable (3)	3.0		
C4 Beneficial to society	7.2	C4.1 Impact on local communities (3)	8.0		
		C4.2 Greenhouse gas (GHG) emission and pollution (4)	6.3		
C5 Permitting and certification	5.8	C5.1 Environmental impacts (7)	8.0		
		C5.2 Ecological impacts (7)	5.0		
		C5.3 Area use conflicts (7)	5.0		
C6 Safety and function	5.3	C6.1 Safety (7)	4.3		
		C6.2 Survivable	6.4	C6.2.1 Extreme loads (7)	4.0
				C6.2.2 Grid failure (7)	3.7
				C6.2.3 Collisions (7)	7.5
				C6.2.4 Temporary conditions (7)	9.0
				C6.2.5 Fatigue (7)	8.0
				C6.2.6 Configuration changes (7)	9.0
C7 Globally	6.4	C7.1 Deployment (4)	6.4		
TPL	**5.8**	**Number of subcategory thresholds breached**	**3**	**Number of sub-subcategory thresholds breached**	**3**

Flexibility in how the capabilities must be satisfied	
No flexibility-Any technical solution must satisfy this capability to be viable	
Some flexibility-A technical solution may not fully satisfy this capability but will trade off with another requirement to make the higher capability viable	
Medium flexibility-A technical solution may only partly satisfy this capability and still be viable	
High flexibility-A technical solution may not satisfy this capability and still be viable	

6 Details of calculation

The details of the TPL calculation are shown below. The categories, subcategories and sub-subcategories are as shown on the score sheets in Section 5.

$$TPL = 0.7 \times (C1 \times C2 \times C7)^{1/3}$$
$$+0.1 \times (C3 \times C4)^{1/2}$$
$$+0.2 \times (C5 \times C6)^{1/2}$$

The category scores are:

$$C1 = \left[\frac{1}{\frac{0.7}{C1.1} + \frac{0.3}{C1.2}} \times C1.3 \times C1.4\right]^{1/3}$$

$$C2 = C2.1$$

$$C3 = C3.1$$

$$C4 = 0.5 \times C4.1 + 0.5 \times C4.2$$

$$C5 = (C5.1 \times C5.2 \times C5.3)^{1/3}$$

$$C6 = (C6.1 \times C6.2)^{1/2}$$

$$C7 = C7.1$$

And the subcategory scores are:

$C1.1 = 0.365 \times C1.1.1 + 0.365 \times C1.1.2 + 0.09 \times C1.1.3 + 0.18 \times C1.1.4$

$C1.2 = 0.7 \times C1.2.1 + 0.3 \times C1.2.2$

$C1.3 = (C1.3.1 \times C1.3.2)^{1/2}$

$C1.4 = C1.4.1$

$C2.1 = [(0.7 \times C2.1.1 + 0.3 \times C2.1.2) \times C2.1.3 \times C2.1.4]^{1/3}$

$C6.2 = (C6.2.1 \times C6.2.2 \times C6.2.3 \times C6.2.4 \times C6.2.5 \times C6.2.6)^{1/6}$

Other subcategory scores and all sub-subcategory scores are calculated as the arithmetic mean of their question scores.

7 References

TPL

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Appendix

Technical Submission Request

Technical Submission Request

Target TRL: Low

This technical submission request (TSR) is a guide for Wave Energy Converter (WEC) developers that details the information required to perform a Technology Performance Level (TPL) of a concept at a low Technology Readiness Level. This TSR is divided into several sections and each section provides a list of information that will help the assessor to understand the technology and develop appropriate scores for the TPL evaluation. Please assume the assessor is not familiar with the technology and provide as thorough a response as possible. Where detailed information is not yet developed, provide reasonable estimates and state the basis of the estimate. Also, the bulleted list in each section is a recommended set of information to include, so feel free to include additional information as needed to help the assessor. DOE has published several guidance documents that may be helpful:

1) Marine and Hydrokinetic Technology Development Risk Management Framework
2) Levelized Cost of Energy Analysis of Marine and Hydrokinetic Reference Models
3) Systems Engineering Applied to the Development of a Wave Energy Farm

1. General information

This section provides the assessor with a high-level overview of the technology, its working principles, dimensions, range of configurations for different operating and survival states, major components, and layout in a farm. These play a significant role in the TPL assessment, so please provide sufficient but concise answers.

1.1. Working Principle and WEC Configuration

Provide a description of the overall working principle of the WEC. This should include a narrative, illustrations and engineering drawings of the method(s)/physics that the WEC uses to capture and convert wave energy to transportable power (e.g. electricity, hydraulics, etc.). Include descriptions of all embodiments/configurations used during power generation. This section should include:

- A description of the working principle for power capture. This must describe the physics in sufficient detail for an assessor to understand and determine the feasibility of the capture method.
- A description of the physical configuration for power capture – if a device has multiple distinct configurations or can adjust its form/configuration based on operational, resource, site or environmental conditions, please detail each configuration and how the WEC morphs into these configurations.
- Engineering drawings with principle dimensions of the WEC and its major components, identification of the water line, identification of predominate orientation to the waves, etc.
- A table that includes displaced volume, total mass, mass and material of major components, mass of ballast for each configuration, frontal area, wetted areas, etc.
- An overview of the control system, including an overview of the control principles, a description of the sensors needed to measure the environment and to provide feedback on the state of the WEC, etc.

1.2. WEC Survival Configuration

Provide a description of the survival strategy. This should include a narrative, illustrations and engineering drawings of the method(s) used to minimize hazard to navigation, reduce/avoid storm loads, avoid sinking in hull breach events, etc. This section should include:

- A description of the threshold (operation cutoff) conditions, characterized by the extreme sea states (Hs, Tp) and their recurrence interval, that necessitate transitioning to a survival state. Refer to IEC/TS 62600-2: Marine energy – Wave, tidal and other water current converters – Part 2: Design requirements for marine energy systems. Edition 1.0, 2016-08.
- A description each different physical configuration used in the survival strategy – if a device has multiple distinct configurations or it can adjust its form/configuration based on conditions, please detail each configuration and/or how the WEC adjusts to storm conditions.
- Engineering drawings with relevant dimensions.
- A risk assessment of failure modes that will result in severe device damage and/or loss with mitigation measures

1.3. WEC Power Take Off Configuration

Provide a description of the Power Take Off. This should include a narrative, illustrations and engineering drawings of all conversion steps within the WEC. This section should include:

- A description of the PTO with sufficient detail to understand all conversion and storage steps between the absorbing element and power transmission leaving the WEC.
- Engineering drawings (Assembly and exploded) of the PTO showing all major components with dimensions.

1.4. WEC Station Keeping Configuration

Provide a description of the station keeping system (mooring, foundation, etc.) This should include a narrative, illustrations and engineering drawings of the method(s) used to hold the WEC geostationary. This section needs to include:

- A description of the station keeping system. The description should detail how the station keeping system works, why it was chosen, how it transfers loads, how it impacts the WECs dynamics, etc. Also, please describe how the station keeping system will scale/change with depth.
- Engineering drawings of the station keeping system that detail items such as mooring dimensions, anchor locations, foundation depths (penetration into substrate), etc. Please dimension the watch circle, if applicable.
- A table of station keeping component properties, such as material types, dimensions (length, diameter), etc.
- A list of the acceptable bottom types/sub-straight and any bathymetric constraints (depth, bottom slopes, etc.) on the station keeping systems.

1.5. Array Layout and Balance-of-Station (BOS) configuration

Provide an overview and description of the expected wave energy farm layout for a farm in the order of 50 to 100 MW. This section should include:

- A description and drawing of a typical wave farm layout. The drawing should include WEC spacing, relative mooring placement, transmission lines/pipes, substations, and should identify the predominant wave propagation direction, and the orientation of devices within farm, etc.

- Please provide a table of all major components of the BOS and indicate how many WECs each component will service

2. Manufacture, Assembly, Installation, and Maintenance

The TPL evaluation also factors in the manufacture, assembly, installation, and maintenance for the WEC to determine the overall feasibility, efficiency and limitations in each of these areas. The answers in this section should provide the assessor with an understanding of steps, efforts, resources, equipment and infrastructure needed to take the device from raw materials and components through to operation and maintenance.

2.1. Manufacturing

Provide an overview of the manufacturing of the WEC. This should be sufficient detail to allow the assessor to understand the major steps, supplies and facilities needed to manufacture the WEC to a state where it is ready to ship to the mobilization/assembly point. This section should include:

- A table of the major components which comprise the WEC, identifying
    - whether the component is specifically/custom fabricated for the WEC or is a commercial of the shelf (COTS) item purchased through an established supply chain,
    - the primary material types used for the component – please identify if any scarce, rare, limited availability materials or exotic materials or materials that may have price volatility such as Neodymium are used.
    - if custom fabricated (component is not available through supply chain), if so, please list
        - the type of facilities and equipment that are required
        - expected duration of manufacturing of the component, including lead time of the materials and part.
        - the type of manufacturing processes needed and whether those manufacturing process can be automated
        - any specialized manufacturing skills, such as welding titanium, required for production, beyond common manufacturing skills,
        - identify any parts that will be difficult to manufacture such as metal plate that needs to be bent to complex (not developable surfaces) shapes or parts with complex or high tolerance machining required

2.2. Assembly

Provide an overview of the assembly process of the WEC prior to deployment. This section should include:

- A description of the key stages and activities, including time lines, of the assembly process. Please indicate what type of equipment and types of skilled labor needed to support each stage of assembly. Identify critical operations that cannot be reversed in case conditions or circumstances warrant.

- A list of major components that would likely be fabricated away from the assembly location, along with the modes of transportation needed to move the WEC components to the assembly area and any transportation issues such as over size or weight loads (provide dimensions and weight)
- A list of the harbor or shore facility constraints, such as assembly area size and water depth.

2.3. Installation

Provide an overview of the how the WEC will be installed. This section should include:

- A description of the key stages and activities, including time lines, of the installation process, from preparation for tow to when the WEC is delivering power to the grid. Please include a description of the configuration of the WEC at each stage of the installation. Please highlight when configuration/orientation changes occur, such as ballasting from a horizontal tow orientation to a vertical operation orientation, and whether those changes involve any risky or hazardous activities. Please include drawings that help the assessor visualize the key stages.
- A description of the number, type and size of the vessels needed at each stage of the install. Also, please include any specialty equipment, such as ROVs, needed for installation.
- An estimation of class of seas condition and continuous duration of weather windows required in each key stage of the installation process including tow out.
- A list of the harbor or shore facility constraints, such as assembly area size and water depth.
- Please identify any special skilled labor and dangerous operations, such as divers, underwater welding, etc.

2.4. Maintenance

Provide an overview of how the WEC will be maintained. This section should include:

- A list of all maintenance activities that are expected to be carried out on the WEC and its station keeping systems over the lifetime of the WEC. Include repair activities for random failures that are not expected for all WECs during their lifetime. For example, if one failure of the alternator is expected for every 30 years of operational experience some alternators will fail before the 20year design life of a fleet of 100 WECs. Please include descriptions of how the activities will be performed, the equipment needed to support those activities, the activity duration and the limiting sea state for the activity. For sea state, please use the Beaufort scale.
- In the event of an unexpected failure, what are the operational and maintenance responses? Is the device accessible? Is the device maintained in position of towed to shore? Where and how are subsystems and large components replaced?
- Describe the process for towing the WEC into the harbor for repairs that cannot be done at sea. Please include details such as how the WEC is released from the station keeping system, any configuration changes, and how the WEC is reconnected to the station keeping system.

- A description of the inspections, the interval between inspections and the equipment used for inspection. Also, if a health monitoring system is planned, please describe what conditions it will monitor.

3. WEC Performance

WEC performance is a critical element in the TPL evaluation to determine the capture and conversion efficiencies. The answers in this section should provide the assessor with a quantitative measure of ability of the WEC to capture and convert wave power.

3.1. Power Capture

Please provide a quantitative measure of the WECs power absorption. Please provide the following in your response:

- An estimate of the primary power absorption of the WEC. This is the power absorbed by the primary absorbing element before any additional conversion steps. Ideally, please provide the estimate of power absorption in the form of a power matrix as defined in IEC TS 62600-100:2012, Edition 1.0 (2012-08-30), Marine energy - Wave, tidal and other water current converters - Part 100: Electricity producing wave energy converters - Power performance assessment.
- An estimate of the power absorption for:
    - a minimum of two irregular sea states
    - sites with a resource of 15 kW/m and 30 kW/m incident power.
- An estimate of the capture width and capture width ratio – please explain how these are calculated.
- If the WEC power absorption is not omni-directional (directionally sensitive), please provide a power estimate for waves coming from 0, 30, 60 and 90 degree directions.
- Describe how the primary power estimate was determined and provide sufficient detail to allow the reviewer to determine the fidelity of the estimate.
- Describe the impacts of tidal height, tidal current, wind and other environmental conditions on the primary power absorption.
- Describe any other items of the system that could decrease energy production

3.2. Conversion Efficiency

Please provide a quantitative measure of the WEC's power conversion efficiency at each stage in the PTO, from the primary absorbing element to the creation of the transportable power leaving the WEC, such as electricity. Please provide the following in your response:

- A table identifying the distinct conversion and storage steps, the efficiency of each step (1-%loss), the rated power of the conversion, and the ratio of peak load/power to average load/power based on a time series response of the device for at least the 15 kW/m and 30 kW/m resource
- The annual average of consumed power in ancillary systems
- An estimate of the rated power of the WEC – this should be the maximum sustained power that the WEC will output at the design wave conditions. Please provide the significant wave height, peak period and wave energy flux of the design wave field.

3.3. Availability

Availability expresses on an average annual basis the portion of the time the WEC is operational and able to produce power. Time lost due to planned and unplanned maintenance and other outages, such as grid availability, should be considered as time when the WEC is unavailable. Please provide the following in your response:

- The target availability of the WEC
- A table that includes annual average time, over the life of the projects, for 1) planned maintenance, 2) unplanned maintenance, 3) forced outages (grid/utility), and 4) suspended operations (whale migration, etc.).
- A description of any redundancy in the subsystem
- A fault tree analysis of the major systems

4. Design

Provide an overview of the design assumptions, methods and tools used to determine the current WEC design. Please include sufficient detail so the assessor understands the fidelity of the engineering and all assumptions used. Please provide the following in your response:

- A discussion of the design philosophy, standards and guidelines used, and tools used
- The design basis, including all assumptions, environmental conditions, etc. Refer to IEC/TS 62600-2: Marine energy – Wave, tidal and other water current converters – Part 2: Design requirements for marine energy systems. Edition 1.0, 2016-08.

5. Cost Information

While it is still too early to perform a comprehensive LCOE determination, please provide estimates of the following cost information to help the assessor determine the CapEx and OpEx costs.

5.1. CapEx

Please provide a quantitative measure of the capital cost (material, manufacturing, transportation, installation, etc.) of the WEC broken down by each component, if a large uncertainty exists, please provide a range of cost that captures the uncertainty. In your response please provide the following:

- A narrative on how the capital costs were determined, including all major assumptions.
- A list with all major components of the WEC, including the station keeping system and the balance of station, in a table that breaks out the purchase costs for parts and materials, net manufacturing costs, transportation costs to assembly area, etc. for each component, along with the total CapEx for that component. Do not include overhead and profit here just burdened manufacturing labor and materials
- A list of the total WEC costs that breaks out the net component costs (from prior bullet), assembly costs, and all other expenditures prior to deployment and installation. Use this to calculate the cost per GW of the WEC manufactured and assembled (or partly assembled) ready to tow out
- A list of project costs that includes planning, engineering, permitting, overhead, and profit including amortized product development costs per WEC.

- A list of installation costs that includes, permitting site preparation such as anchor installation, divers/ROVs, tow and ancillary vessels, cranes, etc. Please factor in costs of weather standby.

5.2. OpEx

Please provide a quantitative measure of the operation and maintenance costs of the WEC broken down by each significant operation and maintenance activity. In your response please provide the following:

- A narrative of the maintenance activities and how they were determined
- For each of the tasks included in the maintenance activities list in section 2.4, please include the total cost of the expected activity each year, including 1) Labor on task, waiting, and traveling to site, 2) cost of support vessel time working and standby, 3) major replacement components and 4) consumable materials and parts such as Oil, lights, electronics parts, etc. For tasks that occur at intervals greater than a year, please provide the equivalent average annual cost.
- Based on an estimated mean time between failures, what is the expected unplanned maintenance items that may occur over the life of a WEC for a sample size of 100 MW of WECs. For each of the items, list the equivalent annual average maintenance cost per WEC when the costs are distributed over the number of WECs needed to yield the 100 MW. Please provide a basis for your estimates.

6. Benefit Society

Beyond the techno-economic feasibility, development of the WEC and the farm for which it will be used should have tangible and intangible benefits to local communities, the environment and society. This section requests information to help the assessor understanding the broader impacts of the WEC and its use in a farm. In your response please provide the following:

- An estimate the number of jobs (full time equivalent) per GW of produced WEC for 1) manufacturing the WEC, 2) construction and installation for assembly and installation of WECs for a farm, and 3) operations and maintenance of a farm of WECs. Please separately identify the permanent and temporary FTEs
- An estimate of the energy payback period (how long will it take to produce the same amount of energy) for manufacture, transport and installation of the WEC, station keeping system, and the balance of station.
- A description of the parts of the WEC components that can and cannot be recycled.
- An estimate of the carbon reduction for the life of the WEC over conventional combined cycle natural gas and coal power generation (average value 0.7 kg/kWh) per kWh of energy produced.

7. Permitting, Environmental, and Conflict Issues

Provide the assessor with information needed to understand the potential for environmental, wildlife, and other user conflicts that can impact permitting and areas where the WEC can be used. In your response please provide the following:

- A description of any issues that can impact the environment, fora and fauna at a location where the WEC is deployed. Please include any noise, entanglement, discharge/leaching, scour, pinch, blunt force impact, chain drag/scar, etc. Consider if the WEC has any toxic chemicals or paints used and if they have a chance for release into the water.
- A description of how the WEC may restrict other users.

8. Wave Energy Safety

Safety of people and property are a priority in any commercial activity. The answers in this section should provide the assessor with an understanding personnel and property safety through the lifecycle of the WEC.

8.1. Personnel

This section addresses the safety of all humans involved in the lifecycle of the WEC. In your response please provide the following:

- A description of the safety philosophy of the company and how that is incorporated into the WEC.
- Describe all risks to human health and safety during all life cycle stages of the wave energy farm from manufacture, construction, deployment, operation & maintenance, recovery, and disposal stage. How will these risks be mitigated? This should also include all risks such as diving, working in enclosed spaces, heavy lift operations, etc.
- Describe all human health and safety risks to other area users and how these risks will be mitigated.

8.2. Equipment

The section addresses the potential of the WEC to cause damage to the property such as to the ocean space, to other vessels, and to itself. In your response please provide the following:

- Describe all risks to the WEC during deployment, operation and recovery. How will these risks be mitigated? Example mitigation methods include multi-hulls, multi-chambers, health monitoring, reserve buoyancy, end-stop impact limiters, backup power systems, etc.
- Describe all risks from the WEC to other area equipment and property, such as collisions with vessels, entanglement with fishing equipment, damage to underwater infrastructure such as pipelines and cables, and damage to the grid. Example mitigation measures include lighting, compliant moorings, etc.