Post Access Report (Publicly Accessible Report)

xWave - ABS NTQ Path to Certification - Prototype Validation Stage

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EXECUTIVE SUMMARY

CalWave has developed a submerged pressure differential type Wave Energy Converter (WEC) xWave. It is a single floating body taut moored to seafloor with mooring lines. The xWave WEC utilizes the body movements in any direction to produce power. Each mooring line is connected to a power take off unit and provides torque, due to the body movements, for power generation. The floating body can work semi-submerged or submerged using a control algorithm and designed torque limit.

The xWave WEC integrates novel designs of: 1) unique hull form that can operate submerged, and semi-submerged; 2) multiple independently controlled power take-off (PTO) units; 3) unique mooring system that links to the PTO; 4) advanced control systems; 5) Interfaces with applicable technologies.

The current xWave WEC system was developed through many research projects not limited but including

- FOA 1663 – CalWave xWave Pilot at Scripps, San Diego
- FOA 1837 – CalWave Holistic PTO and Control Co-Design
- FOA 2080 – CalWave Design for PacWave
- FOA 2415 – CalWave xWave at PacWave
- Feasibility stage and concept verification stage with ABS / CalWave xWave New Technology Qualification and Path to Certification under TEAMER

In this project ABS performed the NTQ review and third-party evaluation for the xWave WEC on prototype validation stage. The review was in accordance with Part 1D- ABS Rules for Alternative Arrangements, Novel Concepts and New Technologies, Appendix 2- Guidance on Qualifying New Technologies.

The NTQ review of the prototype validation includes, in general, the review of engineering design documentation, Risk assessment reports, manufacturing and quality assurance plan, and prototype test plans and test reports. It was noted that CalWave's xWave deployment was not planned within the timeframe of this project, and hence review of test plans and reports, as well as witness tests are not included in this project.

It is concluded that the new technologies utilized in the xWave WEC are capable of performing their intended functions defined in the System Requirements and Description Document (SRDD) document. Due to lack of prototype tests, ABS and CalWave agreed that the statement of maturity for the prototype certificate includes conditions and review comments.

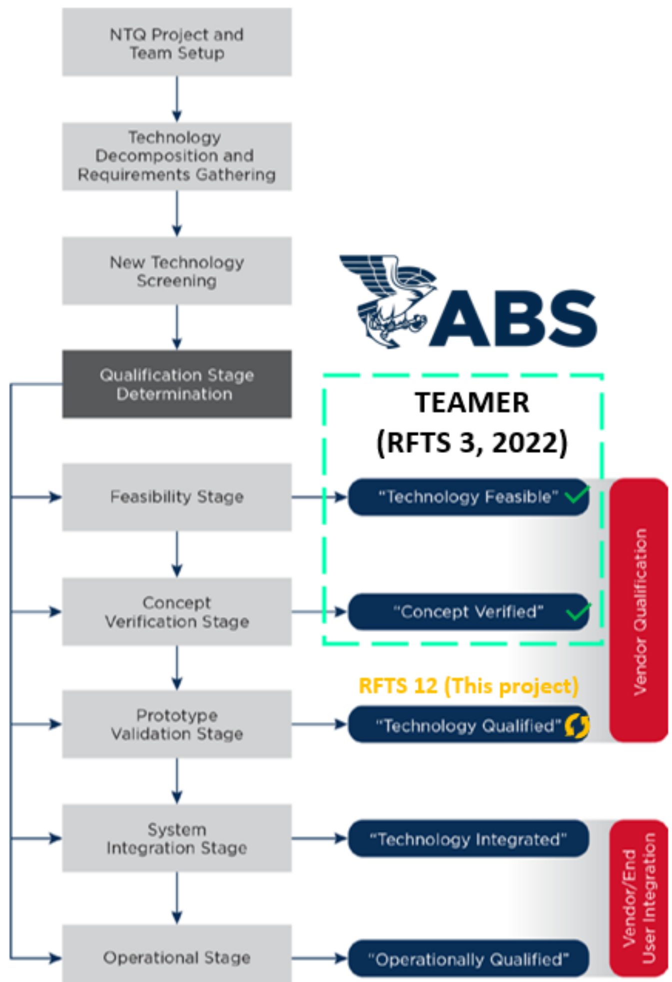
A critical aspect of achieving commercial feasibility for grid integrated technologies is formal certification. Achieving certification is a dedicated multi-year process that ultimately provides the confidence needed for wide scale insurability and bankability of commercial scale systems. This result of this project is a step forward toward that goal. The regulatory agencies can be confident that foreseeable hazards associated with the introduction of the proposed new technology have been systematically reviewed by a reputable third party.

INTRODUCTION TO THE PROJECT

A critical aspect of achieving commercial feasibility for grid integrated technologies is formal certification. Achieving certification is a dedicated multi-year process that ultimately provides the confidence needed for wide scale insurability and bankability of commercial scale systems.

As the xWave technology progresses towards larger deployments, integrating this development with a structured and formalized certification process is foundational not only to CalWave's success, but also to the advancement of the marine-energy industry by providing working references of certified systems and growing confidence within the industry unlocking project financing opportunities. Furthermore, the work with ABS allows us to align IEC TC 114 technical specification efforts on both sides and stage documentation for subsequent steps towards IEC certification as soon as ABS becomes an IEC-RE certification body (application pending).

Under RFTS 3, the American Bureau of Shipping (ABS) provided expert, independent review of CalWave's technology development and advancement of the xWave system on feasibility and concept verification stages. In this project CalWave will continue the New Technology Qualification (NTQ) process with ABS on prototype validation stage.



The ABS NTQ stage gate process towards a fully qualified technology is shown on the right-hand side. In the diagram it is shown what qualification stages CalWave and ABS conducted under the previous RFTS 3, with the next step in the qualification process being the Prototype Validation stage tackled under this round of TEAMER.

The planned work towards Prototype Validation will include review of engineering design documentation, operations/logistics plans, as well as risk management efforts.

Note that CalWave's xWave deployment at significant size is currently not planned to start within the timeframe of this projects/RFTS 12 period of performance and hence, it cannot be expected that ABS can deliver a full statement of maturity for the prototype certification stage under this TEAMER award round.

The intent of the review is to illustrate a Path to Certification, using the ABS NTQ process. Providing certification for marine energy systems is critical for unlocking project financing and insurability or commercial deployments.

1 Roles and Responsibilities of Project Participants

1.1 Applicant Responsibilities and Tasks Performed

CalWave will organize and stage all necessary engineering and risk management documents to ABS. Such documents will include: System engineering descriptions, calculations and design rationales; prototype test plans and WEC manufacturing plans, numerical simulation results, wave tank test data or similar. CalWave requested ABS to review the documentation by complying with IEC TS 114 technical specifications. The compatibility analysis on the translation of ABS NTQ to IECRE TQ will be conducted when ABS becomes a marine renewables IEC-RE certification body. As ABS is still in the IEC-RE application process, this is out of the current scope of work.

CalWave's tasks are summarized as following:

1. Prepare engineering design, test planning, prototype manufacturing planning, and risk management documentation.
2. Engage in workshops to discuss documents and content organized by ABS pending required discussions.
3. Provide and document feedback to ABS questions and review notes.

1.2 Network Facility Responsibilities and Tasks Performed

ABS is a not-for-profit marine classification, standards, and technology organization in the U.S. ABS has over 3,000 engineers, scientists, and marine surveyors with global expertise in supporting the design, installation, operation, and maintenance of all types of marine and offshore assets. ABS has a lot of research projects per year on hydrodynamic analysis and CFD application to ship and offshore topics (e.g., wave and current loads on marine structures/assets). ABS has extensive experience of general hydrodynamic and CFD software such as ANSYS, Orcaflex, OpenFOAM or STAR-CCM+. ABS has its in-house High-Performance Computing (HPC) hardware, including three clusters with a total of more than 1,000 cores. ABS HPC is managed daily by a professional IT team that supports the entire company.

ABS will continue to support CalWave via their 'New Technology Qualification' of the proposed design. Qualification activities at ABS will revolve around reviewing CalWave's risk assessments and engineering evaluations to determine if the xWave system provides acceptable levels of performance and safety in line with established requirements and current marine industry practice towards prototype certification.

In this project ABS will focus on the prototype validation stage as a subsequent step to the previous two stages concluded under one previous TEAMER project (RFTS3). The following tasks will be performed:

ABS's work will include all tasks relevant to guide CalWave through the iterative NQT review process towards a statement of maturity as shown in the schematic below:

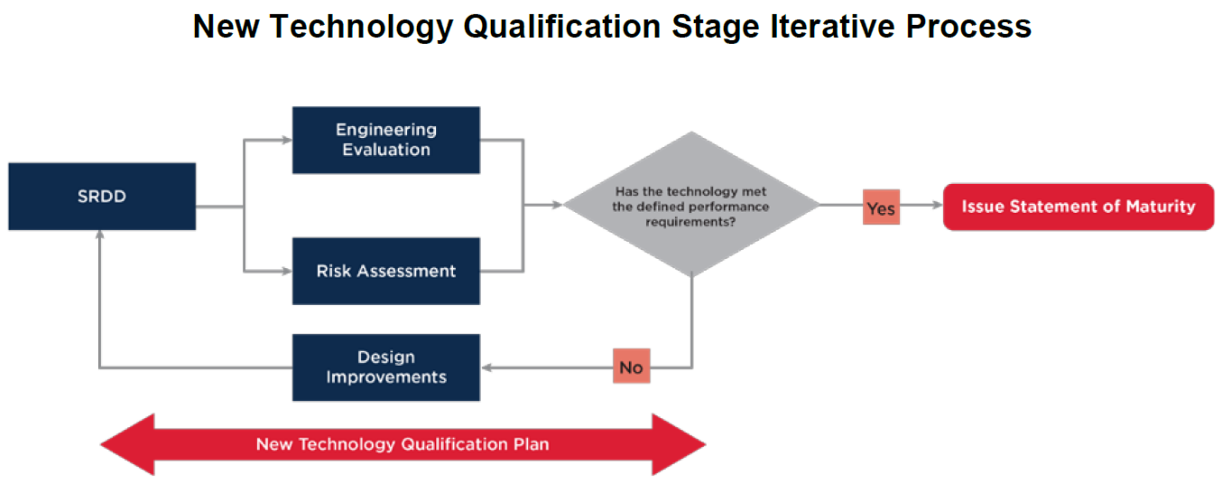


Figure 1: New Technology Qualification Stage Iterative Process flowchart.

2 Project Objectives

The project objective is to review CalWave's innovative design, validate and verify the performance and test results in accordance with defined performance requirements on the Prototype Validation stage. ABS (the Facility) will provide New Technology Qualification (NTQ) support based on the process outlined in the ABS's Rules for Alternative Arrangement, Novel Concepts, and New Technologies Part 1D. ABS might provide statements of maturity at Prototype Validation stage. However, CalWave's xWave deployment at significant size is currently not planned to start within the timeframe of this projects/RFTS 12 period of performance and hence, it cannot be expected that ABS can deliver a full statement of maturity for the prototype validation stage under this TEAMER award round. Nevertheless, it is the goal to proceed in the prototype validation stage of the NTQ as far as possible and to prepare CalWave and ABS for a rapid completion of the prototype validation stage once the xWave prototype is launched at PacWave. After completion of the project, ABS will deliver a post access report with a review letter with progress description towards prototype validation stage for the xWave technology.

Success in NTQ Prototype Validation stage is defined by meeting the requirements outlined in the ABS's Rules for Alternative Arrangement, Novel Concepts, and New Technologies Part 1D. We can assess success by the passage of individual requirements of the Prototype Validation stage process, such as the receipt and review of engineering designs, witness prototype testing, receipt and review of testing results, receipt and review of risk assessment document, as defined by a System Requirements and Description Document (SRDD), inspection test plan and detailed manufacturing plan. CalWave shall address ABS's comments and send them to ABS for review. ABS will issue a statement of maturity letter when all the review comments are fully addressed to ABS's satisfaction.

The following table lists metrics to measure the success of the NTQ process:

Table 1 Measures of the success of NTQ process

No	Items	Notes
1	Report completeness	CalWave will furnish a list of reports including design documentation, existing open water testing data, wave tank testing data, and, if timing allows, at scale PTO test rig data as part of the intake phase of the NTQ process. Completeness is evaluated as

		in the documentation being suitable to complete a documented number of sub-tasks defined under ABS NTQ process. E.g. a percentage of NTQ tasks completed will be estimated at the end of the NTQ process as a measure of CalWave intake material completeness.
2	Device technical maturity	CalWave has assessed its technical maturity using ABS questionnaire and it is determined that the NTQ stage is prototype validation stage. It is understandable that the technology may advance when the Teamer project starts. We will reassess the NTQ stage which will be agreed by both the applicant and the facility.
3	Technical risk	CalWave has completed and documented a thorough analysis of both the technical and operational risks that have potential to occur during the lifecycle of this project. Each documented risk has been assessed for probability, impact, risk cost appetite, and defined mitigation strategies. CalWave's experience in designing WEC reduces the risk profile of this Technology Concept. Minor modifications and upgrades during and after testing are anticipated and have been considered for in the cost analysis and the timeline projection accordingly. CalWave's Risk analysis and mitigation strategies will be provided as part of the submission of our full testing report.

Providing qualification for xWave marine energy device is critical for unlocking project financing and insurability or commercial deployments. Qualification/Certification of wave energy converter (WEC) technology to class/IEC standards is a trend for the final WEC commercialization. NTQ is the first step to advance innovative ideas from concept to reality. For the marine renewable industry, this project will serve as a demonstration for future developers to be familiar with the NTQ process, including new technology stages, documents needed for engineering review, engineering evaluation, risk assessment, and verification/validation process. Also, the developers could assess and estimate the maturity level for their own technology. The lessons learned from the review comments could help the future developer for a better WEC design.

3 Test Facility, Equipment, Software, and Technical Expertise

The American Bureau of Shipping (ABS) serves as a hub of independent offshore and maritime knowledge and technical authority for both industry and government agencies, supporting owners and operators of maritime vessels and other assets with specialized expertise across an asset's full lifecycle. This includes activities with ship/offshore platform design, construction, acquisition, sustainment, and decommissioning. ABS R&D activities include internal programs and external projects (with government agencies, academia, professional/industry organizations, and industry). ABS provides a wide range of engineering analysis, modeling, and simulation support for the marine energy sector. This includes hydrodynamic modeling of wave and flow movements using computational fluid dynamics (CFD), turbine blade geometry optimization, optimal array layout, strength and fatigue analysis of marine energy structures, mooring analysis, estimation of extreme loading conditions during the site deployment, and verification of alignment/conformance to applicable engineering and other technical standards. ABS also provides independent verification/certification of marine energy systems under the ABS New Technology Qualification (NTQ) and Approval-In-Principle (AIP) processes. ABS has partnered with a number of private companies and academic institutions in supporting their development of marine energy technology.

Dr. Sue Wang, Dr Zhongfu Ge and Mr. Jude Tomdio from ABS will lead the NTQ process in this Teamer project. Dr Sue Wang is Manager at ABS Global Engineering. She holds a PhD degree in Ocean Engineering from the University of Hawaii. She has over twenty years of experience in the areas of hydrodynamic analysis, multi-body interaction, mooring and station keeping analysis, global performance analysis for renewable energy assets and floating units. She is the principal author of the ABS Guide for Position Mooring System. Dr. Wang is an active working group member on the API mooring standard and on an internal mooring standard harmonization project sponsored by the International Association of Oil & Gas Producers (IOGP).

Mr. Jude Tomdio is currently the Managing Principal Engineer for electrical and controls technologies. Mr. Tomdio has over 15 years of experience and his areas of expertise include electrical, instrumentation and control technologies, advanced power systems, AC and DC electrical networks, energy storage systems, renewable energy sources, risk assessment, electrical safety and hazardous area classification, classification review/verification, and qualification processes.

ABS' numerical simulation review work will be managed by Dr. Zhongfu Ge, Manager of Technology. Dr. Ge has been leading ABS' global CFD capabilities for more than seven years and has extensive experience in solving industrial problems using CFD as well as project management. Dr. Ge has successfully managed and completed other TEAMER Test Support projects as of January 2025.

ABS has its in-house High-Performance Computing (HPC) hardware, including three clusters with a total of more than 1,000 cores. ABS will use programs including Orcaflex and/or AQWA to check the mooring and global performance analysis. Our CFD team will use OpenFOAM (ABSFoam) or STAR-CCM+ to check the CFD analysis if any. ABS software of DLA/SFA that interfaces environmental load to Finite Element (such as the program Nastran or ABAQUS) analysis may be used for structural analysis if necessary.

4 Article Description

CalWave's xWave WEC is a wave energy converter (WEC) designed to harness the power of ocean waves for clean electricity generation. Unlike traditional WECs operating at the surface, the xWave operates fully submerged, utilizing pressure differentials created by passing waves. CalWave's xWave WEC technology is designed according to IEC/IEEE technical specifications and standards and to address the biggest challenges in ocean wave energy: Extreme loads in stormy seas, and consistent, reliable power output. The xWave consists of a single absorber body housing individually controlled PTO units that connect to taut mooring legs. The absorber oscillates fully submerged and is capable of true multi-DOF (Degree of Freedom) power absorption with significant efficiency increase.

This innovative design unlocks several advantages such as:

- Efficient Power Extraction: Multiple, independently controlled power take-off (PTO) units efficiently capture wave energy.
- Advanced Control Systems: CalWave has developed sophisticated control algorithms, developed and verified through extensive numerical modeling and wave tank testing, to

optimize power absorption and ensure safe operation throughout all design load cases, scenarios, and conditions.

- Durable Design: The xWave's single absorber body with controllable PTO units allows for superior maneuverability and adaptability to varying wave conditions.
- Holistic System Development: CalWave takes a comprehensive approach, considering anchoring, mooring, grid interconnection, and maintenance alongside the core xWave drivetrain and absorber technology.

Below images show the 1:5 scale x1 demonstration unit as it was deployed at San Diego, CA in 2021/2022 on the ocean surface (left) and operating submerged (right).

As part of the xWave product lines, CalWave has scaled up the proven and demonstrated xWave WEC design towards a multiple hundred kW rated WEC unit

The xWave electrical system can be viewed as three distinct but interdependent subsystems: the onboard electrical network, which handle wave-to-wave power flow and torque control on the electric machines; the cable connection to shore; and the onshore power conditioning.

The xWave system utilizes a Holistic Control approach that reaches beyond common PTO control and utilizes a variable submergence depth control approach as an effective means to increase performance and survivability of the xWave system.

In the Holistic Control framework, the ocean wave energy input via loads into the primary wave-structure energy capture step is no longer considered to be solely defined by the wave state characteristics and based on a single absorber design but instead is treated as an operational variable. This unique approach maximizes energy flux, achieving consistent and high utilization of the device's capacity over a large range of wave states, while efficiently protecting the device from extreme waves. CalWave's xWave technology is hence highly adaptable to different resources.

The device characteristic impedance, or in a parametric modeling language, the frequency dependent device added mass and radiation damping, becomes an xWave operational parameter to vary in a limited range: Rather than being constant for a given bandwidth (as it is the case for surface piercing devices without submergence depth control features) the effective device impedance is to an extent controllable via the device's holistic control features, namely the submergence depth. This feature enables to hydrodynamically tune the device impedance towards favorable operating points for approximation of impedance matching and furthermore controls the wave excitation of the device.

CalWave adopted and altered a system breakdown structure from the Navy's Ship Work Breakdown Structure (SWBS) system. This general work breakdown structure is publicly available and in the following the highest level WEC categories are listed with an indication, if a specific category, respectively sub-system of the xWave WEC is relevant to the NTQ

This general system breakdown structure (SBS) has not fundamentally changed from SBS's used during the previous NTQ stages: The system is generally still considered to be of the exact same architecture and working principle. However, the complexity of the subsystems and component count has increased, which inherently comes along with upscaling the size and power rating of a WEC (e.g. electrical system protection components, mechanical drivetrain seal redundancy count and similar).

5 Work Plan

5.1 NTQ Description and Work Schedule

New Technology Requirements Gathering and Technology Screening

The NTQ follows a system engineering approach to qualifying new technology. The qualification process starts with a top-down system decomposition, wherein the system is divided into subsystems, which are further broken down into components. Due to system updates from the initial xWave system demonstrated at San Diego in 2021/2022 to the updates system to be tested at PacWave, part of the prototype validation will be an update on the system decomposition.

The decomposed system will be reviewed to identify which of those items are considered new technology. Once the system is decomposed into subsystems/components, the system requirements will be updated and mapped to each item. A system requirements and description document (SRDD) will be developed by CalWave for the new technology and submitted to ABS for review. It will be maintained throughout the NTQ process. This document defines and sets the baseline requirements for the new technology. As the design matures through development and as more knowledge is gained through qualification, these requirements may be subject to change.

New Technology Qualification Plan

The NTQ Plan defines a roadmap for progressing the new technology through the appropriate qualification stages. The objective of the plan is to provide a summary of qualification activities that need to be performed at each stage in order to demonstrate the ability of the new technology to meet the requirements specified in the SRDD. The plan is now updated at the Prototype Validation stage based on the findings from the previous stages and discussions between CalWave and ABS:

Stage 3 – "Technology Qualified" via Prototype Validation Stage: Work Breakdown

The third stage of the NTQ process is the Prototype Validation Stage which is targeted under this TEAMER RFTS. The main objective in this stage is to validate with a prototype what was verified in the Concept Verification Stage. The qualification planning includes the following activities split into an "Engineering Evaluation" part and a "Risk Assessment" part which are both part of the work plan and listed in the following. Note that not all activities can be expected to be completed to the full extent as CalWave's PacWave deployment as well as the large parts of the prototype fabrication lie outside of the RFTS 12 targeted period of performance. These items are labeled with "Partially" and more distinction is included in each of the sections:

Engineering Evaluation

a) Engineering Design Review correlate with Task 1 – 5 in the Gantt Chart shown in Figure 2: The engineering design documentation will be prepared and packaged by CalWave for review by ABS. The documentation will confirm that the overall system, down to the lowest component level, has satisfied all system requirements and that performance requirements a of the xWave technology is finalized and measurable. In addition, the requirements for system integration, installation, commissioning, operation, maintainability, and decommissioning will be reviewed by ABS.

b) Prototype Testing: ABS will evaluate to what degree existing open water (x1 demonstration unit deployed at San Diego) testing data, wave tank testing data, and at scale PTO test rig data can be used to validate prototype testing. Typically, prototype testing under this stage is intended to prove that the interactions between the systems, subsystems, and components under relevant loading and environmental operating conditions can perform reliably as intended. With CalWave's at scale PTO test rig, all of the expected loading conditions can already be assessed without a deployed machine in the ocean. However, it is likely that a review of all systems interacting with each other is only possible once the actual PacWave device is deployed which is not planned to occur under this RFTS.
c) Manufacturing: A preliminary xWave manufacturing plan will be finalized and shared with ABS that includes the manufacturing methods and processes, the facilities, the production schedule, and quality assurance requirements. Note that actual manufacturing planning for the PacWave device will occur towards the end of the RFTS12 and hence, this item cannot be expected to be completed entirely.
d) ABS Survey: A potentials ABS survey for wave tank testing as well as PTO testing will be planned. Typically, the ABS survey in the prototype validation stage also includes the survey of the fabrication facilities. However, as fabrication of the PacWave WEC lies outside of the RFTS 12 period of performance, the surveys will be limited to a potential wave tank test (Not funded under this project) and a survey of CalWave's test and integration facilities.

As a minimum the following information should be included in the documents provided by TSR.

Engineering design

- Description of system, sub-systems and all basic components
- Function requirements for the system
- Design standards appliable to the system and all basic components
- Provide related drawings and datasheet of the systems and all basic components.
- Design assessment through analysis. It includes analysis methodology, analysis conditions and analysis results. The analysis conditions should reflect operating conditions.

Test planning

- Design assessment through engineering scale model or prototype tests. The document should include description of engineering scale models or prototypes, testing facilities, test conditions, data acquisition and testing results.

Prototype manufacturing planning

- Outline of fabrication procedures.

Risk Assessment
The following design level risk assessments are planned in the second half of the project and align with task # 5 – 7 in the Gantt Chart shown in Figure 2. The activities will verify all technical risks and documents prepared by CalWave will be reviewed by ABS:
a) Final design risk assessment (e.g., design FMECA) and Final process risk assessment (e.g., process FMECA or HAZOP) will be prepared for ABS review by CalWave

b) Update all previous risk assessments as needed based on updated final design level documentation: specifically risk review from the previous risk assessment via ABS under the Concept Verification and Feasibility stage will be acknowledged and integrated by CalWave and discussed with ABS.

c) Final hazard register review based on the final design with all action items closed out after discussions and workshops conclude as part of Task #7

List of ABS/Industry Standards for Review

1) IEC TS 62600-2 Marine Energy – Wave, tidal and other water current converters – Part 2: Design requirements for marine energy systems
2) IEC TS 62600-10:2021 Marine energy - Wave, tidal and other water current converters - Part 10: Assessment of mooring system for marine energy converters (MECs)
3) IEC TS 62600-4:2020 Marine energy - Wave, tidal and other water current converters - Part 4: Specification for establishing qualification of new technology
4) IEC TS 62600-100:2012 Marine energy - Wave, tidal and other water current converters - Part 100: Electricity producing wave energy converters - Power performance assessment
5) ABS Guidance Notes on Qualifying New Technologies
6) ABS Guide for Position Mooring Systems
7) ABS Requirements for Additive Manufacturing

Gantt Chart/Work Schedule

The following Gantt Chart structures the order of tasks and expected durations described above.

		M1				M2				M3				M4				M5				M6			
#	Tasks	WK1	WK2	WK3	WK4	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12	WK13	WK14	WK15	WK16	WK17	WK18	WK19	WK20	WK21	WK22	WK23	WK24
1	Collect design reports/industry standards	■	■																						
2	Calwave to develop system requirements and description documents (SRDD)			■	■																				
3	ABS/Calwave to Develop NTQ plan					■	■																		
4	ABS to review design reports and give comments for Stage 3 "Prototype Validation Stage"							■	■	■	■	■	■												
5	Calwave to address comments													■	■										
6	ABS to review risk assessment report															■	■								
7	Calwave to address comments																	■	■						
8	ABS to issue statement of maturity letter or review letter with concluded steps towards statement of maturity																			■	■				
9	Post Access Report																					■	■		
10	Post Access Questionnaire and data submission																							■	■

Figure 2: Gantt Chart / Work Schedule

5.2 Safety

The mission of ABS is to serve the public interest as well as the needs of our clients by promoting the security of life and property and preserving the natural environment. ABS is committed to excellence in environmental, health and safety management. ABS promotes a safe and healthy environment for staff and visitors, through programs and practices designed to protect people and the environment.

The ABS staff will follow all relevant safety procedures and protocols outlined at ABS Health, Safety, Quality, Environmental (HSQE) SharePoint:

https://eagle.sharepoint.com/sites/Intra/hsqe/SitePages/Home.aspx (internal access only).

The majority of the proposed work will be performed on the computer, the safety or health risks for the project will be minimal. For potential inspection work during which ABS surveyor will visit and observe experimental testing (e.g. wave tank testing) or manufacturing/testing/integration facilities, it will be ensured that all facility safety guidelines and protocols are strictly followed to ensure safety to all staff involved in such audits.

5.3 Contingency Plans

ABS will have two additional engineers identified who are qualified to support the proposed project during the project time. The available staff at ABS will be more than sufficient to carry out the project to completion. CalWave will have a backup point of contact identified in case the primary point of contact is not available.

The technology certification work builds upon work and technology development efforts CalWave executes under WPTO FOA awards. Such awards come along with their own, separate description of deliverables and output quality (e.g. engineering reports, risk management templates). Given these WPTO requirements and checks on deliverables and content, it is unlikely that TSR input documentation will be fundamentally insufficient for the technology qualification work proposed in this TEAMER award.

There is a project manager assigned from ABS to oversee the whole project, including setting up the kickoff meeting/monthly progress update meeting/closeout meeting, monitoring the project progress, milestone and budget in a timely manner. The PM will open an account in ABS Freedom system to which TSR can upload the reports and download ABS review comments. Normally there is a four-week turnaround time for ABS to review the report and TSR to address the comments respectively. If TSR is temporarily not responsive and/or items received are not sufficient to meet input requirement(s), ABS PM will coordinate with TSR to set up a meeting for further discussion and get an agreement on the input requirements and timeline.

All the Engineering reports and risk assessment report in Section 6.1 as a minimum should be submitted to ABS for review. Generally, any discrepancies between expected/required comprehensiveness and actual CalWave input documentation, ABS will flag and point out the missing or required additional content. Three iterations of the process will be allowed for CalWave to fully address the comments. If no action is taken by CalWave to quickly provide missing content, the lack of information will be explicitly pointed out in the ABS status statement towards a prototype certification as a deliverable of this TEAMER award.

5.4 Data Management, Processing, and Analysis

5.4.1 Data Management

During the project, ABS will provide a secure data management environment for collaborative work among project team members. ABS will store and maintain the data in the Microsoft (MS) Teams environment with integrated MS Office applications. Microsoft OneDrive will be used to keep data and files backed up, protected, synced, and accessible on all our devices. OneDrive app lets users view and share OneDrive files and documents with all team members involved.

The ABS IT department maintains appropriate cybersecurity controls consistent with the U.S. Government Risk Management Framework for cybersecurity and other IT-security requirements. ABS will be glad to provide additional information on these controls if requested/needed.

The following table summarizes the management plan for specific project data. The final post-access report and all the relevant data (both meta and raw) to support the output figures, tables, and graphs presented in the Final Post Access report in connection with the implementation of the Project Documents will be submitted to MHK-DR and be publicly available.

Table 1. Data Management Plan

Type of Data	Access to Data
A system requirements and description document (SRDD) which defines and sets the baseline requirements for the new technology	SRDD will be embedded in the Final Post Access report which will be uploaded to MHK-DR as protected data.
ABS review comments	Comments will be included in the Final Post Access report which will be uploaded to MHK-DR as protected data.
Progress description towards 'Prototype Validation' stage	The review letter with progress description will be documented in the Post Access Report which will be uploaded to MHK-DR as protected data.
Post Access Report	The final post-access report will be submitted to MHK-DR as protected data.

5.4.2 Data Processing and Analysis

Any acquired testing data has been analyzed by CalWave under best practices as well as IEC technical specification (TS) 62600-103 ('Guidelines for the early-stage development of wave energy converters') to guarantee that appropriate data processing took place and information is processed in a correct form. Data obtained from ABS in the form of comments on documentation will be reviewed in detail and compared with existing analysis, with an identified action or response for each comment. No specific file formats or software other than typical office software is expected to be required for the proposed work.

6 PROJECT OUTCOMES

6.1 RESULTS

6.1.1 Initial Determination of Qualification Stage

xWave WEC technology has gone through feasibility and concept verification NTQ stages. The xWave 1 WEC was deployed off the coast of San Diego. CalWave has been working on the improvement of xWave WEC with knowledge gained from xWave 1. For the prototype validation stage NTQ, ABS and CalWave have worked on the check list as shown in Table 2.

It was noted that CalWave's xWave WEC deployment was not planned within the timeframe of this project, and hence related test plans and test reports are not included in this project. The prototype stage qualification review is limited, and additional work will be necessary for a full prototype validation stage qualification of xWave WEC. The review scope within this project and review comments are included in Section 7.1.2.

6.1.2 ABS Review Comments

The technical review was carried out in accordance with the following core standards

- ABS Rules for Alternative Arrangements, Novel Concepts and New Technologies, Part 1D
- IEC TS 62600-4 Marine energy – Wave, tidal and other water current converters –Part 4: Specification for establishing qualification of new technology

The key documents for review are the System Requirements and Description document (SRDD) and risk assessment. SRDD includes the goals, functions and performance requirements, design details and appliable standards. The SRDD is not necessary to be a single document. It can be a package of documents. For xWave WEC, there are nine packages of documents submitted to ABS.

ABS performed the review of submitted documents, and the review comments have been communicated with CalWave. The review correspondences are included in Table 3. ABS review is based on following conditions.

1. This review of the documentation, submitted by CalWave Inc., is for Prototype Stage review and evaluation of the xWave wave energy converter, to verify and validate that the technology developed is capable of performing its intended functions in accordance with the defined performance requirements as outlined in System Requirements and Description Document (SRDD).
2. This prototype review focused on its novel designs of sub-systems of 1) unique hull form that can operate submerged, semi-submerged; 2) multiple independently controlled power take-off (PTO) units; 3) unique mooring system that links to the PTO; 4) advanced control systems; 5) Interfaces with applicable technologies.
3. This review was done under the TEAMER Testing Plan RFTS12 project. Systems testing interacting with each other could not be carried out in project RFTS12 and was not included in the review, which may need to be carried out before moving to the next stage for xWave WEC integration.

4. Detailed reviews of all the components of existing technology are not included. Only their related technical specification datasheets are reviewed.
5. Structure strength and fatigue results are taken from the reports provided by CalWave. Independent structure analysis was not included in this review, which may be required for this innovative hull form.
6. It is noted that our review at this time in no way precludes any future amendments and comments which may be deemed necessary by the review of detailed engineering design for this technology.
7. It is noted that ABS shall in no event be held liable for any identified/unidentified hazardous scenarios or qualification activities associated with this technology.

6.1.3 Lesson Learned

ABS and CalWave had scheduled monthly meetings to discuss findings and the next steps, which work well for both ABS and CalWave. CalWave has gained knowledge and has better understanding of ABS's requirements on prototype validation stage NTQ and new technologies screening. ABS has gained more experience working with a WEC designer on the application of ABS Rules.

The test plan was carried out as planned in its scope, while the project schedule was extended. The limiting scope on the prototype stage NTQ was noticed in the test plan proposal and was well communicated with CalWave. CalWave provided nine packages of documents that are associated with different systems. The development schedules for those systems were stretched beyond the test plan schedule, hence resulting in the project extension. The xWave WEC is a complex system, management of changes, prioritizing workloads, and having back up plans are very important for a complex project.

CalWave has gained a great understanding of what qualification measures are required for the xWave system. ABS guidance regarding document content, preparation, and change tracking allowed CalWave to greatly increase the quality and workflow of qualification activities.

Careful version tracking of documents and FMECA documents and line-items is utterly important for large qualification activities.

Additionally, while not a new learning rather than a confirmation of expectations was, that prototype qualification activities take time to conduct in a thorough and appropriate fashion. Due to the nature of increased fidelity in review of documents, but furthermore actual prototype fabrication and ultimately deployment, developers need to anticipate that clearing the prototype qualification stage is a lengthy process that involves company resources and hence is utterly important to embrace early on in the technology development.

7 Conclusions and Recommendations

xWave WEC is a submerged pressure differential type Wave Energy Converter (WEC). It is a single floating body device taut moored to the sea floor and generates power from motions of the floating body. xWave WEC integrates novel designs of: 1) unique hull form that can operate submerged, and semi-submerged; 2) multiple independently controlled power take-off (PTO) units; 3) unique mooring system that links to the PTO; 4) advanced control systems; 5) Interfaces with applicable technologies.

The xWave WEC systems of novel designs have been reviewed in accordance with Part 1D- ABS Rules for Alternative Arrangements, Novel Concepts and New Technologies, Appendix 2- Guidance on Qualifying New Technologies [1]. The systems are verified as being capable of performing its intended functions in accordance with the defined performance requirements as outlined in System Requirements and Description Document (SRDD). This review was done under the TEAMER Testing Plan RFTS12 project. Systems testing interacting with each other could not be carried out in project RFTS12 and were not included in the review, which may need to be carried out before moving to the next stage for xWave WEC integration.

The statement of maturity certificate in the prototype validation stage is a critical aspect of achieving commercial feasibility for grid integrated technologies representing formal certification. Achieving certification is a dedicated multi-year process that ultimately provides the confidence needed for wide scale insurability and bankability of commercial scale systems. The result of this project is a step forward toward that goal. The regulatory agencies can be confident that foreseeable hazards associated with the introduction of the proposed new technology have been systematically reviewed by a reputable third party.

8 References

[1] ABS Rules for Alternative Arrangements, Novel Concepts and New Technologies, Part 1D.
[2] IEC TS 62600-4 Marine energy – Wave, tidal and other water current converters –Part 4: Specification for establishing qualification of new technology
[3] IEC TS 62600-2: Marine energy systems – Design requirements
[4] IEC TS 62600-10: Assessment of mooring system for marine energy converters

9 Acknowledgements

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