Test Plan

xWave New Technology Qualification and Path to Certification

Awardee: CalWave Power Technologies Inc.

Awardee point of contact: Dan Petcovic

Facility: American Bureau of Shipping

Facility point of contact: Shirlyn Zhang

Date: 10/31/2022

1 INTRODUCTION TO THE PROJECT

CalWave is developing a wave energy converter (WEC) called xWave, which operates fully submerged and is classified as a submerged pressure differential type. As ocean waves pass over the submerged wave buoy, a pressure differential is created, exciting the absorber in multiple degrees of freedom to oscillate in resonance with the ocean waves. Energy is efficiently extracted using multiple independently controllable power take-off (PTO) units. Based on CalWave's 2 body WEC technology tested in the US DOE's Wave Energy Prize, multiple improvements on absorber geometry and PTO controls have been achieved.

CalWave has developed advanced WEC control algorithms that can significantly enhance the device power absorption as well as safe operation during the past three years. The advanced controls have been developed using extensive numerical modeling in the frequency and time domain and implemented in controller at 3 separate wave tank tests (total of 6 weeks testing). In parallel with the core hydrodynamic and control development, CalWave has progressed on associated anchoring, mooring, umbilical cable, grid interconnection, and operations and maintenance development. This co-development is aligned with the holistic approach to system development.

A critical aspect of achieving commercial deployments for the xWave, or any new grid integrated technology, is the formal certification. Achieving certification for a new technology is a dedicated multi-year process that ultimately provides the confidence needed to allow for wide scale insurability and bankability of commercial scale systems. As CalWave progresses the xWave technology through iterative scaled deployments, integrating this development with a structured and formalized certification process will be foundational not only to CalWave's success, but also to the advancement of the marine energy industry by providing working reference cases of certified systems and growing confidence within the industry, leading to increased participation of utility operators and unlocking project financing opportunities.

ABS (the Facility) will provide New Technology Qualification (NTQ) support for the WEC designed by CalWave, based on the processes outlined in the ABS Guidance Notes on Qualifying New Technologies for the maritime industry. ABS will provide statements of maturity at each stage of the development, which will support the commercialization of the technology.

2 ROLES AND RESPONSIBILITIES OF PROJECT PARTICIPANTS

2.1 APPLICANT RESPONSIBILITIES AND TASKS PERFORMED

CalWave will provide design documentation, operational planning, and risk assessment for the patented xWave technology that will form the foundation of the New Technology Qualification process. At each stage of the review, CalWave will work in collaboration with ABS to incorporate feedback into revised product design, operational planning, and risk assessment documentation that is aligned with the prototype validation process. Additionally, CalWave will ensure iterative feedback obtained during the NTQ process will be fed into further development goals and planning to best align the xWave technology development with the ABS guided validation roadmap.

2.2 Network Facility Responsibilities and Tasks Performed

ABS will conduct New Technology Qualification of the proposed design and issue statements of maturity for each stage of the qualification process. The Statements of Maturity issued at each stage will demonstrate feasibility and maturity levels as evaluated by ABS based on its unique role in the industry. Typically, five sequential steps will be taken for the NTQ process, which progressively qualify the technology from the feasibility stage, concept verification, prototype validation, system integration through the operational stage (see Figure 1). The qualification activities within each stage revolve around risk assessments and engineering evaluations that build upon each other to determine if the new XWave system provides acceptable levels of performance and safety in line with established requirements and current marine industry practice. In this project we will focus on the feasibility and concept verification stages only based on the existing testing and numerical data. We will work with CalWave to continue with the NTQ process of prototype validation based on newly developed testing data in 2022. This is out of the scope of work in the current Teamer project.

While the NTQ process will be applied specifically to CalWave's WEC technology in this project, the disseminated results will benefit the broader community. The community will know that the XWave WEC technology has been subjected to an independent review and assessment of the maturity of the system with formal correspondence issued confirming the system's ability to perform intended functions in accordance with defined performance requirements. The marine renewable energy industry routinely develops new technologies with no service history in the proposed application or environment. There is often a period of time when the technology is still a concept design or a mockup of the future full-service device. During this time, it is difficult for the designers to judge if the technology is still worth future efforts or investment. ABS' NTQ could be especially valuable in walking the designer through the early stages and help improve the technology through various maturity levels.

The NTQ Process will provide CalWave, its customers/partners, funding entities, and other interested parties (Government agency Technical Authorities, regulators, insurers, etc.) with a high degree of confidence that the resulting technology is mature and robust enough for the intended applications. Through Statements of Maturity issued at each stage in the qualification process, 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.

After completion of the project, we will deliver a post access report with two Statement of Maturity letters for new technology.

3 Project Objectives

The project objective is to review CalWave's innovative design, and to verify the new system will perform its functions in accordance with defined performance requirements on feasibility and concept verification stages. As an outcome of the process, Calwave intends to present results in a scholarly publication.

The design documentation being reviewed in the NTQ process includes the following critical components, tools, and analysis:

- xWave Design Basis & Regulatory Guidance
- System Modelling and Design Tools
- Absorber Body Design
- Power Take-Off Design
- Electrical System & Infrastructure
- Umbilical Design
- Mooring and Anchoring Design
- xWave Operational Design for PacWave (including Power Performance)
- Installation, Operation & Maintenance
- Risk Management & FMECA
- Outstanding Testing for Validation
- System requirements and description document (SRDD)

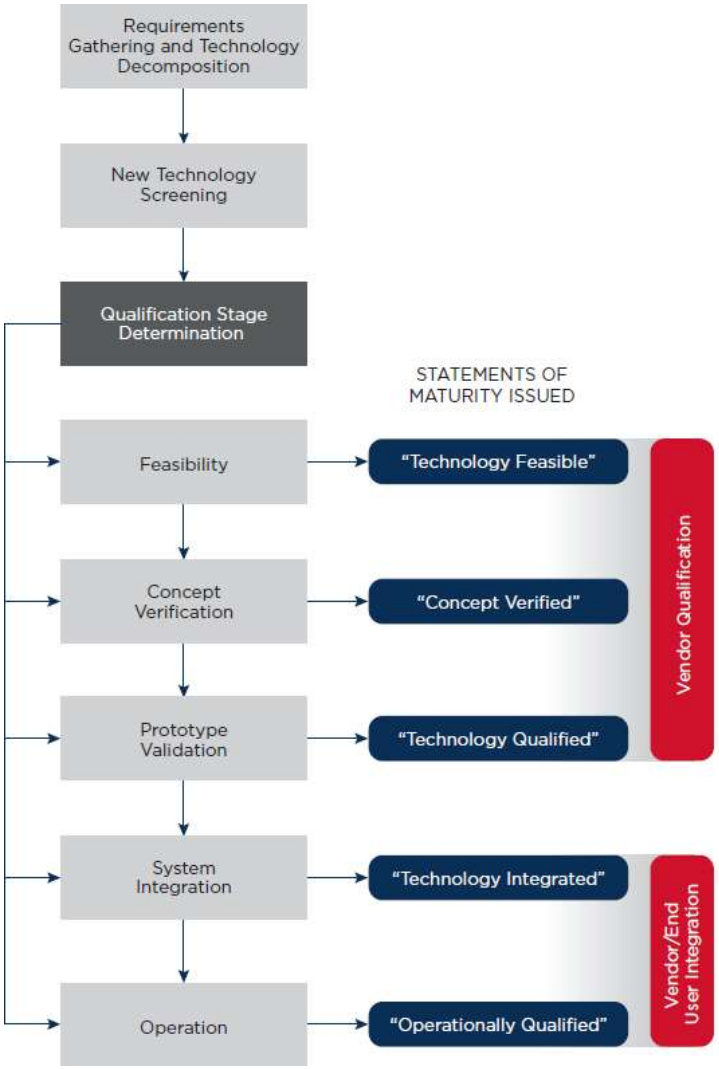

Figure 1. ABS New Technology Qualification Process

4 TEST FACILITY, EQUIPMENT, SOFTWARE, AND TECHNICAL EXPERTISE

ABS is a not-for-profit marine classification, standards, and technology organization head quartered in the United States of America. ABS has over 3,000 engineers, scientists, and marine surveyors with global expertise in the design, installation, operation, and maintenance of all types of marine and offshore assets. ABS provides a wide range of engineering analysis, modeling, and simulation support for the marine energy sector. The support includes hydrodynamic modeling of wave and flows movements, structural analysis of marine energy equipment, mooring analysis, system reliability, safety modeling and verification. ABS also provides third party independent verification/validation of marine energy systems under ABS' New Technology Qualification (NTQ) and Approval-In-Principle (AIP) processes. ABS is actively involved in the industry technical committee such as IEC renewable energy working group. ABS has

partnered with many private companies and academic institutions in supporting their development of marine energy technologies.

Dr. Xi-Ying Zhang and Mr. Jude Tomdio from ABS will lead the NTQ process in this Teamer project. Dr. Xi-Ying Zhang is Principal Engineer at ABS Corporate Technology Department, Houston, Texas. She has 15 years of experience in the offshore industry and is specialized in offshore structures and geotechnics, mooring and anchor systems. Currently she is the technical lead for marine energy projects at ABS. She has participated in the development and revision of industrial codes of practice and ABS Rules/Guides/Guidance Notes for marine and offshore applications.

Mr. Jude Tomdio is currently Principal Engineer for the machinery, propulsion, 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.

5 Test or Analysis Article Description

CalWave is developing a wave energy converter (WEC) called xWave, which operates fully submerged and is classified as a submerged pressure differential type. As ocean waves pass over the submerged wave buoy, a pressure differential is created, exciting the absorber in multiple degrees of freedom to oscillate in resonance with the ocean waves. Energy is efficiently extracted using multiple independently controllable power take-off (PTO) units.

CalWave's *xWave* WEC technology is designed according to IEC/IEEE 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. Below images show the currently deployed scale model WEC as deployed on the ocean surface (left) and operating submerged (right). The xWave architecture enables critical and redundant load management approaches via:

1. PTO detuning,
2. variable submergence depth, and
3. proven unique geometry-changing control mechanisms.

CalWave has developed advanced WEC control algorithms that can significantly enhance the device power absorption as well as safe operation during the past three years. The advanced controls have been developed using extensive numerical modeling in the frequency and time domain and implemented in controller both in multiple iterations of wave tank testing and PTO bench testing. CalWave's xWave technology can be operated in a variety of resources due to its large bandwidth enabled by Holistic Controls and is entirely scalable in its approach. Primarily mid-term application at intermediate scales is targeted as utility scale grid operators, community choice electricity authorities (CCA's) and coastal communities.

CalWave intends to initially focus our development where we can have the most impact: island communities, which make up 11% of the world's population (730 million). Over 90% of power on islands is generated through imported fossil fuels, which creates a huge burden on developing economies and the environment. By offsetting these communities' reliance on costly, heavily polluting diesel generation, we can make significant gains towards reducing global greenhouse gas (GHG) emissions and bringing equity to all. The 18.7 million people living in the Pacific Islands and New Zealand have an estimated combined electricity consumption of over 46 GWh/yr.

Similarly, Alaska, Hawaii, and Puerto Rico consume 45 GWh/yr of electricity which can be provided by wave power technology. These entry-level markets are not only the most commercially attainable due to the high cost of imported energy, but they are also most impacted by the effects of climate change.

6 Work Plan

6.1 NTQ Description

In this application, ABS will review the following documents and issue statements of maturity regarding the technology developed by Calwave:

- Wave tank and bench test data in FOA-1663,

- Larger scale PTO development and bench testing in FOA-1837, and
- Calwave design report for PacWave in FOA-2080.

Using them as a baseline for establishing a formal path to certification, Calwave will continue its future design development after completion of these FOAs.

For this specific project, ABS will perform the following activities:

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. The decomposed system should be reviewed to identify which of those items are considered new technology. Once the system is decomposed into subsystems/components, the system requirements can be 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 initial plan should be developed based on the findings in the screening process. The plan is updated at each subsequent stage based on the findings from the previous stage and discussions between Calwave and ABS.

Stage 1 – "Technology Feasible"
ABS will perform a high-level review of:

1. Design basis, functional specification, and technical specification of the Xwave system.
2. System and function architecture details, such as functional flow block diagram if any.
3. Design details such as basic engineering drawings and engineering principles associated with further development.
4. Software tool- review of validation test data (as requested), and test results
5. Design analysis methodology and any available preliminary results, e.g. hydrodynamic analysis, device dynamics and kinematics modeling, PTO modeling, electrical system modeling and umbilical modeling.
6. Details regarding physical and functional interface requirements (mechanical, electrical, software, etc.).
7. Applicable design references, codes, standards and guidelines, and technical justification for any proposed deviations.
8. Risk assessment study developed by Calwave

Stage 2 – "Concept Verified"

The second stage of the NTQ process is the Concept Verification Stage. This is accomplished by performing more detailed engineering studies and physical model testing. ABS will:

1. Review documents that describe the concept verification design requirements.
2. Review design documents that include but not limited to the configuration, drawings, analytical models, etc.
3. Review preliminary manufacturing plan, initial test plan and test results.
4. Review testing in PacWave and PacIsland. Verify if the XWave system at a conceptual level satisfies the specified functional and performance requirements. The performance requirements are to be established by Calwave and should be detailed enough that the technology can be evaluated against the expected performance criteria.
5. Review updated risk assessments from the feasibility stage and preliminary design risk assessment (e.g., FMECA) report.

6.2 Test and Analysis Matrix and Schedule

The budget hours for this project are 160 hours. We will complete all the tasks in 8 weeks' time. We present a test plan as follows with the proposed schedule.

	Month 1				Month 2			
Tasks	Week 1	2	3	4	5	6	7	8
Calwave - Collect design reports/industry standards								
Calwave - Develop system requirements and description document (SRDD)								
ABS/Calwave to Develop NTQ plan								
ABS to review reports and give comments for Stage 1 "Technology Feasible"								
Calwave to address comments for Stage 1								

ABS to review reports and give comments for Stage 2 "Concept Verified"								
Calwave to address comments for Stage 2								
ABS to develop post access report with letters of maturity								
ABS to Post Access Questionnaire								

6.3 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).

In early 2020, ABS became increasingly concerned with enforcing sanitization in the office space to protect employees from COVID-19. Since March 2020 ABS employees have been working from home. There is a dedicated team from ABS making every effort to proactively monitor the situation and ensure a safe working environment for all ABS employees. Since all proposed work will be performed on the computer, the safety or health risks for the project will be minimal.

6.4 CONTINGENCY PLANS

ABS will have two additional engineers who are qualified to support the proposed project during the project time. The manpower will be more than sufficient to carry out the project to completion.

6.5 DATA MANAGEMENT, PROCESSING, AND ANALYSIS

6.5.1 Data Management

During the project, ABS will provide a secure data management environment for collaborative work among project team members. Our team 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. This OneDrive app lets us view and share OneDrive files and documents with all team members.

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

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.

Type of Data	Access to Data
Calwave Design Reports	This data will only be used within the project team. No outside access will be provided.
A system requirements and description document (SRDD) which defines and sets the baseline requirements for the new technology	SRDD will be included in the Final Post Access report and be publicly available.
New Technology Qualification Plan which defines a roadmap for progressing the new technology through the appropriate qualification stages	NTQ plan will be included in the Final Post Access report and be publicly available.
Review comments from ABS for Stage 1 “Technology Feasible” and Stage 2 “Concept Verified”	Review comments will be included in the Final Post Access report and be publicly available.
Responses to comments from CalWave for Stage 1 “Technology Feasible” and Stage 2 “Concept Verified”	Responses to comments will be included in the Final Post Access report and be publicly available.
Post Access Report	The final post-access report will be submitted to MHK-DR and be publicly available.

6.5.2 Data Processing

The acquired data has been analyzed by Calwave to guarantee that it is in a correct form. In addition, the testing results have been compared with the numerical predictions to make sure that the data collected

are desired data. 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.

6.5.3 Data Analysis

Data provided to ABS for review includes multiple years of analytical and numerical modeling by different approaches:

- Frequency domain analytical modeling with two-port PTO modeling approach for PTO co-design (MATLAB); results led to current device sizing and PTO design characteristics.
- Higher-order dynamics modeling (up to 2nd-order dynamics) using python - PyDY multibody dynamics toolbox for assessment of parametric resonance conditions.
- WECsim time domain analysis (nonlinear BEM hydrodynamics, implementation of transfer functions from previous wave tank tests to represent experimentally derived hydrodynamics) used for irregular wave resource performance assessment, nonlinear controller tuning (approximation of causal impedance matching), failure mode assessment (e.g., PTO tether failure)
- Star-CCM+ modeling for viscous effects (as a function of the Reynolds and the KC number) and for 50-year return wave survival cases; staged failure modes.
- OrcaFlex umbilical and mooring modeling for design of umbilical connection point and floater configuration.

7 PROJECT OUTCOMES (REQUIRED FOR POST ACCESS REPORT ONLY)

7.1 RESULTS

Technical comments were created against the results and adjudicated sufficient to justify the issuance the below included Statements of Maturity.

7.2 Lesson Learned and Test Plan Deviation

There are several lessons learned in this review process, a summarized listing is outlined below.

1. We can improve and over communicate time management, submittal items scheduling, comments response time and general review period schedule with Calwave.
2. Improve on documentation submittal schedule and schedule time of invoice payment

7.3 Path to Certification

As shown in Figure 1, a five-stage process is followed that aligns with the typical product development phases of a new technology:

1. Feasibility Stage
2. Concept Verification Stage
3. Prototype Validation Stage
4. System Integration Stage
5. Operational Stage

ABS completed the New Technology Qualification process of the first two stages. The third stage of the NTQ process is the Prototype Validation Stage. The main objective in this stage is to validate with a prototype what was verified in the Concept Verification Stage. The following qualification activities along with future activities for the System Integration Stage should be highlighted in the New Technology Qualification Plan (NTQP) and submitted to ABS for review:

Engineering Evaluation

i) Systems Requirements and Description Document (SRDD)

- Review engineering documents that describe the component requirements and the interaction between components, subsystems, and the overall system if applicable.
- Detailed design documents including detailed drawings, product specifications, process and instrument details, detailed calculations, etc.
- Prototype test plans, test data (as requested), and test results summarized in a report.
- Additional qualification testing, data, and results identified in the design risk assessment (e.g., FMECA).

ii) Inspection Test Plan (ITP)

iii) Detailed manufacturing plan.

Risk Assessment

i) The final updated risk assessment reports from the Concept Verification Stage (as applicable).

ii) The final design risk assessment (e.g., FMECA) report.

iii) The process risk assessment (e.g., process FMECA) report (as applicable).

iv) The final system Reliability Availability and Maintainability (RAM) analysis report (as applicable).

v) Final hazard register with all action items closed out.

ABS Survey

Survey during the manufacturing process and prototype testing may be required. The local ABS

Survey office should be contacted ahead of time to arrange for any witness testing. Refer to Section 5/ 3.1.4 of ABS Guidance Notes on Qualifying New Technologies for additional information.

8 CONCLUSIONS AND RECOMMENDATIONS

The submitted document reviewed were aligned with ABS Guidance Notes for Qualifying New technologies and provided the technical comments are addressed satisfactorily, the appropriate statement of maturity levels will be issued.

Currently, two (2) maturity levels have been reached and the statements are being issued:

1. Feasibility Stage
2. Concept Verification Stage

9 REFERENCES

The listed references from ABS Guidance Notes on Qualifying New Technologies were used in the review.

[1] ABS Guidance Notes on Qualifying New Technologies

[2] ABS Guide for Position Mooring Systems

[3] ABS Guidance Notes on Safehull Finite Element Analysis of Hull Structures

10 ACKNOWLEDGEMENTS

ABS gratefully acknowledges the financial support of TEAMER's Technical Support program (Round 3).

11 APPENDIX

The following Statement of Maturity letters are included with this report:

1. ABS Statement of Maturity letter: Feasibility Stage

   

   Statement Of Maturity - Feasibility

2. ABS Statement of Maturity letter: Concept Verification Stage

   

   Statement Of Maturity - Concept

STATEMENT OF MATURITY

Client Name: Calwave Power Technology
Certificate Number: T2313430
Date Issued: November 1, 2022

TECHNOLOGY FEASIBLE

This is to certify that

XWAVE WAVE ENERGY CONVERTER TECHNOLOGY

has been reviewed in accordance with the ABS *Guidance Notes on Qualifying New Technologies* [1]. The proposed technology concept is considered feasible with respect to its intended functions in accordance with the defined performance requirements as outlined in the Preliminary Design Report, Deliverable. The technology may proceed to the ***Concept Verification Stage***.

Description and Application:

CalWave is developing a wave energy converter (WEC) called xWave, which operates fully submerged and is classified as a submerged pressure differential type. As ocean waves pass over the submerged wave buoy, a pressure differential is created, exciting the absorber in multiple degrees of freedom to oscillate in resonance with the ocean waves. Energy is efficiently extracted using multiple independently controllable power take-off (PTO) units. Based on CalWave's 2 body WEC technology tested in the US DOE's Wave Energy Prize, multiple improvements on absorber geometry and PTO controls have been achieved.

Boundaries: N/A

Scope of Review:

1. Design basis, functional specification, and technical specification of the Xwave system.
2. System and function architecture details, such as functional flow block diagram if any.
3. Design details such as basic engineering drawings and engineering principles associated with further development.
4. Software tool- review of validation test data (as requested), and test results
5. Design analysis methodology and any available preliminary results, e.g. hydrodynamic analysis, device dynamics and kinematics modeling, PTO modeling, electrical system modeling and umbilical modeling.
6. Details regarding physical and functional interface requirements (mechanical, electrical, software, etc.).
7. Applicable design references, codes, standards and guidelines, and technical justification for any proposed deviations.
8. Risk assessment study developed by Calwave

Comments/Notes: Refer to ABS review response letter dated 1 November 2022.

Reference Documents:
[1] ABS *Guidance Notes on Qualifying New Technologies*

ABS shall in no event be held liable for any identified/unidentified hazardous scenarios or qualification activities associated with this technology.

Approved By: Jin Wang

Jin Wang
Director, ABS Corporate Technology

STATEMENT OF MATURITY

Client Name: Calwave Power Technology
Certificate Number: T2313430
Date Issued: November 1, 2022

CONCEPT VERIFIED

This is to certify that

XWAVE WAVE ENERGY CONVERTER TECHNOLOGY

has been reviewed in accordance with the ABS *Guidance Notes on Qualifying New Technologies* [1]. The proposed technology concept is verified as being capable of performing its intended functions in accordance with the defined performance requirements as outlined in the Preliminary Design Report, Deliverable. The technology may proceed to the ***Prototype Validation Stage***.

Description and Application:

CalWave is developing a wave energy converter (WEC) called xWave, which operates fully submerged and is classified as a submerged pressure differential type. As ocean waves pass over the submerged wave buoy, a pressure differential is created, exciting the absorber in multiple degrees of freedom to oscillate in resonance with the ocean waves. Energy is efficiently extracted using multiple independently controllable power take-off (PTO) units. Based on CalWave's 2 body WEC technology tested in the US DOE's Wave Energy Prize, multiple improvements on absorber geometry and PTO controls have been achieved.

Boundaries: Additional requirements in ABS review response letter dated 1 November 2022 applies.

Scope of Review:

1. Review documents that describe the concept verification design requirements.
2. Review design documents that include but not limited to the configuration, drawings, analytical models, etc.
3. Review preliminary manufacturing plan, initial test plan and test results.
4. Review testing in PacWave and PacIsland. Verify if the XWave system at a conceptual level satisfies the specified functional and performance requirements. The performance requirements are to be established by Calwave and should be detailed enough that the technology can be evaluated against the expected performance criteria.
5. Review updated risk assessments from the feasibility stage and preliminary design risk assessment (e.g., FMECA) report.

Comments/Notes: Refer to ABS review response letter dated 1 November 2022.

Reference Documents:
[1] ABS *Guidance Notes on Qualifying New Technologies*

ABS shall in no event be held liable for any identified/unidentified hazardous scenarios or qualification activities associated with this technology.

Approved By: Jin Wang

Jin Wang
Director, ABS Corporate Technology