# Findings from the 3rd U.S. Instrumentation Workshop


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## I. Keywords

Marine Energy, Instrumentation, Testing, Data Analysis


## II. Overview

The 3rd Marine Hydrokinetic Instrumentation Workshop was held at Florida Atlantic University's Sea Tech Campus in Dania Beach, Florida, from February 28 to March 1, 2017. The workshop brought together over 37 experts in marine energy measurement, testing, and technology development to present and discuss the instrumentation and data-processing needs of the marine energy industry. The goals of the meeting were to:

- Better understand the state of instrumentation, measurement, and data-processing capabilities for testing, assessment, monitoring, and operation of marine energy converters (MECs)
- Identify gaps (problems, deficiencies, or lack of capabilities) in marine hydrokinetic (MHK) measurement and data-processing technology, assess the impact of those gaps, and prioritize the gaps for solutions
- Define pathways for developing solutions to the gaps
- Present progress made to address gaps identified at previous workshops.

This paper presents the findings of the workshop in MHK sensors, instrumentation and data processing.

The prior two workshops focused on all areas of measurement and modeling for both MHK and offshore wind with a goal of sharing state-of-the-art equipment and methods, field testing experiences, and lessons learned. Environmental monitoring was not in the scope at a prior workshop hosted by the Pacific Northwest National Laboratory (PNNL)—the Instrumentation for Monitoring Around Marine Renewable Energy Converters Workshop[1]. This third workshop instead focused on identifying measurement and data-processing needs, determining gaps in measurement capabilities, and defining solution pathways for those gaps, as relevant for laboratory and field testing and operation of MHK technologies. The workshop theme was:

*Instrumentation and data processing to advance marine hydrokinetic energy in the laboratory and in the field: How do we get the information we need?*

A pre-workshop survey was sent out in advance of the workshop to query participants and the wider community about the state-of-the-art, gaps, and research and development (R&D) challenges related to MHK measurement systems, instruments, and sensors.

The two-day workshop was comprised of a general half-day plenary session, focused breakout sessions with smaller groups, and reporting from each breakout session. This structure was chosen to facilitate in-depth discussions and exchanges of information that would not have been possible in a presentation to a large audience. The input from the breakout groups, the pre-workshop survey and in consultation with technical experts were compiled into 28 findings that are described in terms of gaps in existing technology, capabilities, and infrastructure. The findings also include descriptions of the benefits of closing the gaps and potential solutions to those gaps. The findings were grouped in four topic areas:

- Information dissemination and data processing
- Standards, guidelines, and recommended practices
- Enhanced measurement capabilities
- New measurement and testing capabilities.

Please note that the gaps, impacts of the gaps, benefits of closing the gaps, and solutions to the gaps contained within this extended abstract were synthesized from the preworkshop survey and input from workshop participants. The findings are intended to be informative and used by government bodies, industry and the research community to help advance MHK testing and measurement – they do not necessarily represent the U.S. Department of Energy (DOE) Water Power Technologies Office (WPTO) views or program objectives.

## III. Overview of Findings

This section provides an overview of the findings from each of the four topic areas with two detailed findings from the technical report– note that the selected finding presented in detail are not necessarily considered a priority by DOE, but they are presented so the reader understands the technical report content.

[1] http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23100.pdf.

**Information Dissemination and Data Processing** – the dissemination of knowledge and data processing codes that can help the testing community achieve higher data quality, select the correct sensors, leverage prior work to reduce costs and increase testing success. This topic area identified five recommendations:

- MHK Instrumentation Database: Increased Capabilities and Awareness
- Open-Source Data Reduction, Conditioning, and Processing Code
- Open-Source Code for Automated Data QA During Data Acquisition in the Field and Laboratory
- Open-Source Data Conversion Tools Based on Consensus File Formats
- Automated Analysis of Large Volumes of Data

***Example Finding: Open-Source Data Reduction, Conditioning, and Processing Code***

Programming and scripting languages such as MATLAB, Python, C, and R are commonly used in the MHK field for data reduction, conditioning, processing, manipulation, and visualization. The codes contain many built-in functions that allow users to develop powerful processing tools; however, they do not contain many of the functions that are needed by the MHK community (e.g., calculate wave energy flux based on the International Electrotechnical Commission (IEC)-accepted method, plot a wave rose, determine a wave power matrix or CEC power curve, calculate the significant wave height from a spectrum). Thus, significant effort is often dedicated to developing processing codes and tools to support the needs of individual projects—much of this effort is redundant because there is significant overlap in the needed functionality. These codes do not typically represent a competitive advantage, yet they typically remain in-house with limited sharing internally and externally. For example, the national laboratories have developed analysis codes to support work on the Wave Energy Prize, validation of Wave Energy Converter SIMulator (WEC-Sim), reference model testing, and controls development. These codes are not available to the community or even shared between DOE national laboratories. While there are several public open-source libraries with some of the needed functions (such as oceanographic tools), programmers can invest substantial time finding them and then verifying that the codes are correct and/or meet the desired need.

Implementation of an online MHK data-processing code repository specific to marine energy with version control and search capabilities organized by function and language will be useful to help the MHK community. This would help the community to discover existing code that allows quicker and more consistent data processing—and perhaps establish common processing practices. Code should be divided up into specific functions that perform a single task, thus allowing users to pick functions they need without having to wade through large codes to cut out the needed capabilities. For specific cases, such as IEC analysis (e.g. a power curve) a complete code would be needed to make sure that the inputs and setting are correct and provides IEC compliant results – this will reduce variability and develop analysis capabilities based on a consistent interpretation and application of the standards. The DOE national laboratories developed a suite of tools, such as crunch, mcrunch or GPP which were widely used within the wind industry and became commonly accepted analysis tools.

Codes/functions should all be well commented and use a standardized input/output model. In the repository, users would be able to search for and download functions to meet their needs, modify the code, and, if enhancements are added, upload the enhanced versions. Moderators should review code changes and release those that meet quality and performance requirements. This site should also contain a collection of pointers to other sites that have useful processing codes and tools to avoid duplication on the site.

Gaps:

Code-sharing sites for processing and analysing data-sharing sites exist in other fields (e.g., oceanography) and are widely used within those fields to help the community to more quickly process data. Currently, the Marine and Hydrokinetic Data Repository (MHKDR, https://www.nrel.gov/water/mhk-instrumentation-sensor-database.html) is the only site known to exist in the MHK community to share measurement information, and it does not have the functional capabilities needed to support code sharing (e.g., version control, searching, uploading/downloading). Open-source code-sharing capabilities have been developed for WEC-Sim, but no online community tool is known to exist with sufficient functionality for sharing data processing and analysis code specific to marine energy.

Impact of Gaps:

- Higher costs and increased project duration because significant funding and time are invested in developing custom data-processing codes
- Divergent analysis and conclusions, non-conformity to accepted practices and standards, reduced credibility of findings, and lower investor confidence are some results of using custom codes developed on a project-by-project basis
- Higher probability of errors in code, resulting in errors—possible design flaws and failures.

Benefits of Closing the Gaps:

- Public open-source data-processing tools will help the MHK community produce credible results using consistent and vetted processing tools and techniques. Some benefits include:
- Lower cost and quicker data processing because needed code functions can be quickly found and integrated into a larger processing tool; because code developed by individual projects would be shared and leveraged by others
- High-quality figures and graphics that conform to commonly accepted layouts because plotting code would be available to, and enhanced by, the user community
- Lower probability of errors (higher confidence in the results) because code would be traceable to sources where code has been vetted by industry experts and other users

- Reduced redundancy as one set of code is used instead of everyone developing and validating their individual piece of code
- Increased confidence in the correctness of the test results by other stakeholders like banks and insurance companies because analysis is done using validated code

Solutions:

- Many online open-source code portals exist for oceanography and other fields but none that completely meet the needs for MHK data processing. Existing DOE code portals can be leveraged (i.e., WEC-Sim, https://wec-sim.github.io/WEC-Sim/) to share code for the MHK community, but they currently have insufficient functionality to meet the MHK data processing needs. The recommended solution steps are:
- Develop guidelines for code interfaces (if it does not exist) and for data reduction, conditioning, processing, manipulation, and visualization—consensus and vetted functions
- Develop a general DOE code-sharing portal (this could be done by leveraging an existing portal like the WEC-Sim portal), augment an aligned website such as the MHK Instrumentation Database (https://www.nrel.gov/water/mhk-instrumentation-sensor-database.html) or develop a separate portal framework
- Linking existing MHK resources including code portals through the MHK community of practice
- Encourage sharing of analysis software, perhaps through the U.S. International Energy Agency – Ocean Energy Systems (IEA OES) or other national/international programs—specifically, engage DOE national laboratories to upload their code, which should include specific functions (e.g., a function to calculate the wave energy flux using the method given in IEC 62600 - 100) and complete project codes
- Implement a database to share data-processing code on OpenEI and/or use DOE Code (https://www.osti.gov/doecode/)
- Identify and support code curators to establish initial content
- Develop guidelines for processing MHK data based on accepted practices and standards.

**Standards, Guidelines, and Recommended Practices** – experience-based consensus methods and practices that enable a degree of conformity in testing and in collection, processing and visualization of data.

- Unified Testing Practices, Sensing Technology, Measurement Methodology, Data Collection, and Data Processing
- AIS Standards for MEC On-Station and Off-Station/Private Aids to Navigation Standard
- Methods and Guidelines for Near the Air-Water Interface Turbulence Measurement

***Example Finding: Unified Testing Practices, Sensing Technology, Measurement Methodology, Data Collection, and Data Processing***

The MHK industry is still nascent, and accepted practices for field and laboratory measurements and data processing and analysis either do not exist or are at very early stages of development. At low TRLs, the IEC is developing laboratory and small-scale field testing standards for wave and current technologies. While these are not yet available, methods and techniques can be adopted from aligned fields such as naval architecture and aeronautics. At higher TRLs, IEC TC114 technical specifications can be used, but many are still under development (such as mechanical loads) or have not started development. Many companies may also forego purchasing standards at their early stages of development to reduce costs or because they are unaware of their applicability. As a result, field and laboratory measurements and data-processing and analysis methods are chosen on a case-by-case/project-by-project basis and not on consensus standards and guidelines. Additionally, many sensors/instruments may be chosen for different reasons that include cost, availability, perceived importance, lack of knowledge, or because the limitations of sensors are unknown. As well, measurement and signal-conditioning specifications (e.g., sample rates, sensor locations, data filtering, and sensor response/sensitivity) can also be chosen on a project-specific basis. Decisions on what data to measure, the measurement specifications, and processing and analysis methods are often based on current needs, experience from prior projects, forecast needs, and cost. Thus, similar projects with similar technologies and testing goals can use significantly different sensors/instruments and data in terms of quantities being measured. Because of the project-specific nature of measurements and data, the broader applicability of the data can be limited and cross-technology/cross-testing comparisons are difficult. Without foreknowledge of data needed to support later design iterations, measurements and analysis may only be chosen to support testing and evaluation of current technology; data may be insufficient to support future design activities.

It would be useful for the industry to have TRL-specific public guidance documents and standards that clearly define the types of measurements, types of sensors/instruments, where to make measurements, minimum measurement specifications by the type of test, how to conduct the test to produce correct and sufficient data, and how to process the results so they are credible and comparable. Such documents and standards would be intended to serve as information resources to help guide technical experts in instrumentation and data processing and should not be considered substitutes to domain expertise and experience.

Gaps:

Unlike other industries, the MHK industry has not converged to a set of accepted sensors, instruments, or group of sensors and instruments for specific measurement categories and tests for the various TRL levels. At low TRLs, no guidelines or standards exist that provide measurement and analysis specifications for this early-stage pre-certification testing in the laboratory for loads, performance, and motion; through IEC TC114, there is an effort to provide a solution. Also, because the cost and limited accessibility of the IEC publications under development, the community is not familiar with the content in the standards and/or is not applying the requirements of the standards for pre-commercial higher TRL testing.

Impact of Gaps:

- Sub-optimal data collection—limited data and poor-quality data, as well as data gaps (insufficient data to support evaluation and future development)
- Lack of common sensor/instrument used for specific measurements; lack of measurements in necessary locations (e.g., might miss critical strain measurements); and lack of common measurement specifications, which leads to limited data consistency between projects
- Lack of understanding between test/tank facility operators, developers, and other stakeholders.

Benefits of Closing the Gaps:

- Unified testing practices, sensing technology, measurement methodology, data collection, and data processing can lead to:
- Higher-quality and sufficient data that can support device evaluation, future design, and permitting because the methods and requirements are based on hands-on experiences and developed for the type of test and TRL—ultimately improved understanding and performance of MECs
- More straightforward development of common tools and processing techniques because common and agreed-to measurements, processing techniques, and testing practices exist
- Selection of the best or most suitable sensors/instruments for the test and desired measurement
- Common data quality, data formats, processing tools, and metrics that allow straightforward cross-technology comparison
- Feedback to help advance standards and guidelines and a better understanding of requirements for field and laboratory test projects.

Solutions:

- Develop common and agreed-to measurements, processing techniques, and testing practices; as part of this effort, continue to develop TC114 standards and testing guidelines that define different types of test and measurement by TRL/scale
- Ensure test facilities adopt common testing practices
- Ensure government-sponsored projects adhere to, as it makes sense and is practical, consensus testing standards and guidelines
- Develop procedures to calibrate and qualify instruments and sensors to meet agreed-upon requirements; then develop a list of accepted/qualified sensors/instruments for different tests
- Support research to determine the best placement of sensors that will minimize the number of measurements and fully capture all necessary information
- Review existing literature (including wind energy related standard in the IEC 61400 series, floating structures, oil & gas, and other fields) to leverage existing efforts on conformity in measurement, processing, and data visualization
- Encourage and/or incentivize greater involvement by the MHK community in standards and guidelines development.

**Enhanced Measurement Capabilities** – additional or enhanced measurement capabilities that build upon or customize existing sensors, instruments, and DAS hardware to meet the needs of MHK testing

- Affordable Mechanical and Power Take Off Load Sensors for Very Small-Scale Laboratory Testing
- Affordable Mechanical and PTO Load Sensors for Larger-Scale Field Testing
- Wireless Time Sync of Underwater Instruments and Underwater Communication Between Measurement Array Elements
- Standardized Time Sync of Cabled Instruments
- Mooring Line Load Cell with Robust Communications
- Measurement in a High Electromagnetic Environment
- Short-Term Wave Height Forecast at Device
- Measuring Ocean Wave Elevations at the Device
- Increased Data from Existing Instruments
- Use Existing Sensors to Monitor Machine Health During Testing
- Micro DAS
- High-Speed Underwater Communication for Tank Testing
- High-Accuracy 6DOF Measurements (On Device)

**New Measurement and Testing Capabilities** – new technologies, methods, knowledge, and capabilities that meet the measurement and data needs of the MHK Community

- Black Box to Record Data for a WEC Device (Health Indicators)
- Underwater Pressure Grid for Tank Testing
- Generic Control DAS, Sensor, Signal Conditioning, and Data QA Package
- Help Implement Control Systems
- Increase Availability and Accessibility of Instrumentation
- Design Grade Metocean Studies and Tools for the Determination of Site-Specific Metocean Parameters for the West Coast, Hawaii, and Alaska
- Wave Energy Prospecting Tools

## IV. Thematic Areas

While 28 primary findings were identified, the following four themes emerged as common between many of the findings.

### Limited Knowledge Transfer

Over the last decade, the MHK industry has seen extensive testing activities in the laboratory and in the field. These tests have generated a wealth of experience, knowhow, and tools, yet much of this knowledge is not disseminated or is hard to find. As a result, duplicate efforts occur to develop software tools and many mistakes are repeated. While there is extensive literature within the field, it can be difficult to mine papers and reports to compile the lessons learned. There is a need for central information repositories where information and tools are globally discoverable. Through dissemination of knowledge, the MHK industry can avoid repeating mistakes, minimizing duplicate efforts, and leveraging the experience of others to help accelerate technology development and reduce costs while not compromising intellectual property.

### High Cost of Measurement

The MHK industry is pre-commercial and has very limited budgets for testing. Unfortunately, marine grade instruments can be expensive and strain tight test budgets. Often, a tradeoff is made between the breadth and duration of a test and the number and quality of measurements. Testing is the opportunity for device developers to get information needed to understand, characterize, and advance their technology. Thus, reducing measurements can lead to incomplete data sets and reduced learning, which can have compounding impacts on technology development. By adopting mechanisms to increase instrument availability, sharing instrument costs between projects, increasing the measurement capabilities of existing instruments, adapting instruments for MHK application, sharing knowledge of instrument use, and standardizing measurements, measurement costs can be reduced.

### Better Measurement Capabilities at Low TRLs

The TPL demonstrates that MECs can achieve rapid advancement for the lowest cost at low TRL levels (TRLs 1–3). Testing at these early stages is critical to validate numerical models and provide data on concept performance and loads. However, the measurement capabilities for smaller-scale models (1:10 and smaller) typically used at low TRLs is inadequate. The weight of sensors and DASs and the stiffness of wires connecting the device under test to external equipment can affect the device motion and performance. In addition, sensors are limited or do not exist for measuring loads at small scales. For technologies to advance at smaller TRLs, new measurement technologies are needed to ensure accurate and affordable measurements.

### Open-Source Tools for Unified Data Processing and Analysis

Processing and analysis of data collected during testing is the final step needed to turn the data into useful information. Most efforts in this area are performed on a project-by-project basis where custom code is developed using unique processing and visualization methods. This can lead to many factors that impact the credibility of test results, including inconsistent interpretation of data and errors in processing and calculations. Duplicate efforts between projects can unnecessarily increase project cost and duration. By encouraging sharing of vetted data reduction, processing, QA, and visualizations code and by adopting standard methods, the MHK industry would be able to accelerate the analysis and increase the credibility of test results

## V. Conclusions

This workshop identified 28 gaps related to measurement and data-processing for MRE testing; and for each gap, defined the impacts, benefits of closing the gaps and potential solution pathways. By solving these gaps, testing costs and timelines can be reduced and knowledge gained will accelerate technology development timelines and lower risk. The final workshop report can be found at:

https://www.nrel.gov/docs/fy18osti/70591.pdf

The findings in the report are intended to be informative and used by the MHK community to understand the impacts of the gaps. The hope is that with this understanding, solutions will be found through focused R&D by government bodies, industry and the research community.

## VI. Acknowledgments

The authors gratefully acknowledge the financial support from the U.S. Department of Energy's Water Power Technologies Office, which enabled us to organize, conduct, and report on the outcomes of this workshop. We also thank all the invited speakers and participants. Their insights and willingness to share their experiences about developing marine energy technologies helped make the workshop a success.

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC under contract No., DE-AC36-08GO28308.