Report on the 4th Marine Energy Instrumentation and Data Workshop

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1 National Renewable Energy Laboratory
2 European Marine Energy Centre
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List of Acronyms

DAS	data acquisition system
DOE	U.S. Department of Energy
IEC	International Electrotechnical Commission
IECRE	IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications
ITTC	International Tank Testing Conference
ME	marine energy
MEC	marine energy converter
MHKiT	Marine and Hydrokinetic Toolkit
MODAQ	Modular Ocean Data Acquisition
NREL	National Renewable Energy Laboratory
PBE	Powering the Blue Economy™
PNNL	Pacific Northwest National Laboratory
PRIMRE	Portal and Repository for Information on Marine Renewable Energy
SME	subject matter expert
TC	Technical Committee
TRL	technology readiness level
TS	Technical Specification
WPTO	Water Power Technologies Office

Executive Summary

The 4th Marine Energy Instrumentation and Data workshop was held on March 16–17, 2022. This gathering brought together marine energy (ME) developers, researchers, and stakeholders to discuss the current state of ME technologies and the industry's instrument and data needs. The overall objective of the workshop was to identify gaps facing the ME industry for needed data collection, processing, and analysis. Shortcomings in the ability to collect data and conduct analysis with device performance, environmental, and ME resource data can lead to insufficient information for improving device designs and pursuing device certification. Therefore, the objectives of the workshop were to:

- Better understand the current state of ME instrumentation, measurement, and data
- Pinpoint needs and gaps in instrumentation, measurement, and data capabilities
- Identify how best practices and industry standards can be better understood and adopted.

The ME Instrumentation and Data workshop began with presentations that gave updates on projects that stemmed from the 2017 Marine Hydrokinetic Instrumentation workshop and short presentations from workshop participants. Following the opening session, three sequential sessions focused on specific aspects of the ME industry. Each targeted session began with an introductory presentation from a relevant subject matter expert.

The sessions focused on the following topics:

- Leveraging testing facilities and infrastructure to drive R&D and commercialization
- Measurement strategies and best practices
- Key measurement and data challenges for Powering the Blue Economy™ and environmental effects monitoring.

Participants were then placed into breakout rooms where a facilitator guided the conversation to answer questions related to the session topic. Google Jamboards (collaborative virtual whiteboards) were used to capture and organize ideas.

The workshop resulted in 23 identified gaps or needs that fell into five key themes:

1. Standardization of data collection practices, instruments, and data formats
2. Better access to lessons learned, best practices, and training
3. Determination of volume of data to collect
4. Development of new and improvement of existing instrumentation and sensors
5. System characterization and predictive sensing.

For each recommendation, the gap/need, impact of the gap/need, and possible solutions were identified. The findings in this report are meant to be informative for use by the government, industry, research community, and other relevant stakeholders to help advance ME testing and measurement. They do not represent the U.S. Department of Energy Water Power Technologies Office views or program objectives.

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1 Introduction

There have been several workshops focused on Marine Energy (ME) instrumentation and data needs, with the most recent occurring in 2017. The 2017 workshop resulted in numerous recommendations for development of new instrumentation and data tools to better meet the needs of the ME industry (Driscoll, Mauer, and Rieks 2018). These recommendations ranged from the development of standardized, open-source ME data processing tools and data acquisition systems to the establishment of new mechanical loads measurement techniques. Some of these recommendations led to projects funded by the U.S. Department of Energy (DOE) Water Power Technologies Office (WPTO), like the Marine and Hydrokinetic Toolkit (MHKiT), the Modular Ocean Data Acquisition system (MODAQ), and fiber-optic loads measurement research.

Because 5 years had elapsed since the last workshop, another workshop was held in March 2022. This gathering brought together ME developers, researchers, and stakeholders to discuss the current state of ME technologies and the industry's instrument and data needs.

1.1 Workshop Objectives

The overall objective of the workshop was to identify gaps and needs facing the ME industry for the purposes of data collection, processing, and analysis. Shortcomings in the ability to collect and conduct analysis with device performance, environmental, and ME resource data can lead to insufficient information for improving device designs and pursuing device certification. Therefore, the objectives of the workshop were to:

- Better understand the current state of ME instrumentation, measurement, and data
- Pinpoint gaps in instrumentation, measurement, and data capabilities
- Identify how best practices and standards can be better understood and adopted.

These objectives were achieved through discussions structured around priority questions posed during the workshop breakout groups:

- What are the key gaps in current instrumentation, data tools, and best practices?
- How can existing capabilities be improved and better leveraged?
- What are the roles of various organizations in the development of capabilities and tools?

1.2 Workshop Structure

The 2022 ME Instrumentation and Data Workshop was held virtually on March 16–17, 2022. The first day began with presentations giving updates on projects that stemmed from the 2017 Marine and Hydrokinetic Instrumentation workshop. These presentations included overviews of MHKiT, the ME Data Pipeline, MODAQ, Mini-DAQ, and loads-measurement research.

Workshop participants were given an opportunity to provide updates on their current projects, highlighting instrumentation or data needs that were unmet. The challenges that were highlighted included difficulty finding instruments capable of withstanding the harsh marine environment, lack of guidance on what and how much data to collect, and data management issues. These presentations helped to set the stage for an examination of the status of instrumentation and data capabilities across the ME industry and research community.

Following the opening session, three sessions focused on specific aspects of the ME industry. Each targeted session started with an introductory presentation from a relevant subject matter expert (SME). The SME introduced the topic and seeded the workshop participants with questions to ponder during the breakout session.

The sessions focused on the following topics:

- Leveraging testing facilities and infrastructure to drive R&D and commercialization
- Measurement strategies and best practices
- Key measurement and data challenges for Powering the Blue Economy™ (PBE) and environmental effects monitoring.

Participants were then placed into breakout rooms where a facilitator guided the conversation to answer questions related to the session topic. Google Jamboards (collaborative virtual whiteboards) were used to capture and organize ideas. The Jamboards allowed participants to write down ideas and answers to questions throughout the session.

1.3 Report Structure

The main body of this report is structured first around the high-level themes that were common across all or most breakout topics. The findings are then organized into the individual breakout group topics. The findings from each breakout session are tied to each of the high-level themes:

1. Standardization of data collection practices, instruments, and data formats
2. Better access to lessons learned, best practices, and training
3. Determination of volume of data to collect
4. Development of new and improvement of existing instrumentation and sensors
5. System characterization and predictive sensing.

Each finding is presented with the topic background and desired capability described first. Next, the gap in capability is described along with a discussion of the impact of the gap on advancing ME technologies. Lastly, the benefits of addressing the gap and possible solutions are detailed. Within this report, a gap is defined as an unmet need of the ME community.

2 Key Themes

The workshop was divided into several sessions that focused on specific aspects of marine energy technologies and testing. Five common themes emerged from the sessions, which highlight unmet needs related to instrumentation, data, and testing that are applicable to most aspects of marine energy development and testing. Specific examples of unmet needs/gaps within each key finding are highlighted in Section 3.

2.1 Standardization of Data Collection Practices, Instruments, and Data Formats

The topic of standards was a mainstay of discussion throughout the workshop. This included conversations around formal standards developed by international bodies, such as the International Electrotechnical Commission (IEC), as well as the development of best practices and recommendations for instrumentation, data channels or signal channel lists, data processing, and reporting.

Industry could benefit from best practice adoption of such aspects of ME technology development and testing. To the extent that is feasible, having recommended commonly used instrumentation, instrument configurations and operation guidelines, data processing, reporting, and assessment metrics would enable a level, apples-to-apples comparison and assessment of device performance. Having a common set of results would also facilitate a more straightforward capture of lessons learned that could help advance ME technologies and help funding agencies and investors understand the value of ME technologies.

Recommended best practices and instrumentation would also ease the burden of integrating sensors for technology developers, as they would have a verified, fit-for-purpose list of sensors and instruments from which to work when planning their design and test campaigns. Additionally, consistent measurements and best practices—including those for environmental monitoring—would aid in the certification and permitting processes, as relevant agencies would become familiar with data and results provided by technology developers and test centers.

Because of the variety of marine energy device archetypes, standards cannot always be one-size-fits-all. Flexibility within standards will be essential for easing the burden on the developers applying them. For instance, multiple options for collecting a required measurement could be included within these standards. Additionally, avenues for researchers and developers to provide feedback about what methods for applying standards do and do not work would help shape standards into usable, industry-accepted norms.

2.2 Better Access to Lessons Learned, Best Practices, and Training

Lessons learned and best practices are useful only if ME researchers, developers, and stakeholders have easy access to them and can effectively interpret and act upon their guidance. For this reason, since the 2017 instrumentation and data workshop, there have been efforts to enhance the accessibility and impact of lessons learned.

The Portal and Repository for Information on Marine Renewable Energy (PRIMRE) project, for example, initiated an effort to collect lessons learned from ME companies and to disseminate the findings on the OpenEI portal. The Telesto knowledge base, a feature of PRIMRE, offers guidance on conducting various types of ME tests and data management best practices and features a database of commonly used instruments and sensors.

Even though initiatives such as PRIMRE exist, the consensus from workshop participants was that lessons learned and best practices were not easily discoverable, indicating that these efforts need to be reworked and their existence made more broadly known. Training workshops on best practices and how best to leverage existing tools could benefit ME researchers and developers. Lessons learned also encompass aspects of ME device design and testing beyond instrumentation and data (i.e., technology design and project management). For the purposes of this report, lessons learned and best practices are focused on instrumentation and data.

2.3 Determination of the Volume of Data To Collect

The question "What volume of data is actually needed?" was posed in several forms during the workshop. Without a clear understanding of the volume of data required to characterize technology performance, understand environmental impacts from deployed devices, or meet certification or permitting requirements, researchers and developers may err on the side of data overcollection. For the purposes of this report, "volume" of data includes needed sensors and instruments, sample rates, and data collection duration.

Data overcollection can have detrimental impacts on the outcomes of a test because of the effects on equipment and timelines such as:

- Increased device weight from excess sensors and batteries
- Decreased test duration due to data storage constraints
- Sacrificed data channels in favor of high sample rates on other data channels
- Delayed/extended project timelines to collect additional—potentially unnecessary—data.

Determining the necessary types and amounts of data required to fully understand a system or environmental condition would save both time and money for developers, funding agencies, and certification/permitting bodies.

Enacting guidelines for necessary data collection would also help make standards and best practices easier to implement. Some of the IEC technical specifications stipulate high sample rates (up to 20 kHz) for a long period of time to meet the requirements for carrying out the test. Refining the guidance on when those high sample rates are required would ease the burden on developers and researchers to have hardware that can collect, store, and transmit large volumes of data. The IEC 62600 technical specifications are actively under development by Technical Committee (TC) 114. Feedback from researchers and developers using the technical specifications can help refine data requirements. Additionally, the purpose of the device test must be identified early to adequately determine the volume of data required. Guidelines for various types of tests can be developed to cover most common scenarios, but additional consideration must be given to ensure the data needs of all tests can be met.

Limiting data collection to only what is necessary would also render data collection on smaller ME devices and devices far from shore easier and more effective. Remote ME technologies will likely need to rely on satellite data connections for transmitting data to shore or the cloud. Satellite data rates are expensive, and bandwidth is often limited. This requires the majority of the data to be stored on the device and could lead to the necessity of onboard data processing as well. Adding significant data storage capabilities can take up valuable space on a small device. Collecting large quantities of data can also require more power, which can put a strain on smaller devices that produce little electricity.

2.4 Development of New and Improvement of Existing Instrumentation and Sensors

Throughout the workshop, there were several conversations focused on the need for both new instrumentation and a better understating of existing instruments. Researchers have experienced limitations of the existing hardware, particularly when attempting to deploy in challenging conditions where devices must be weatherproofed and marinized. Additionally, there are cases where the limitations of existing hardware are not known, leading to uncertainty for data collection initiatives. Solutions for these problems could include development of new instruments, integrating existing sensors to be operated in a novel way, studying performance of sensors and instruments for long-term deployment or under harsh conditions, and improving sensor or instrument weatherization.

2.5 System Characterization and Predictive Sensing

As the ME industry advances and more complicated testing of ME devices is carried out, the establishment of increasingly innovative techniques for characterizing system performance will be required. This characterization should run the gamut from in-lab test setups through full-sized ME device deployments in the field.

Standardized recommended techniques for assessing test setup characteristics would ensure consistent quality of results. Advanced sensors and data collection capabilities for in-ocean testing would enable advanced controls and prediction of maintenance cycles. Structural health monitoring could become an increasingly useful technique for determining maintenance needs as device deployments become longer in duration. Additionally, monitoring system performance and health in real time would enable more advanced control and modeling methods using techniques like machine learning and digital twins.

3 Session-Specific Findings

As mentioned in Section 1.2, the workshop was organized into three sessions focused on areas of ME research and development and testing. Each session opened with a presentation from relevant SMEs to prepare the participants for the breakout discussions. The SMEs presented background information on the topic and provided some measurement and data needs related to the topic area (based on their experience) to seed discussion.

Following the presentations, workshop attendees were placed in breakout rooms where a facilitator guided the discussion. Google Jamboards were prepopulated with questions to structure the conversations. Participants had the choice of speaking about their ideas or placing notes in the Jamboard to respond to questions. The Jamboards and notes were kept after the workshop to preserve the discussion and ideas.

Each session-specific finding outlined in the following subsections features an overview of the identified gap, which provides some context for the gap and how it relates to ME. Each finding is tied back to the key themes. Each gap is then summarized with impacts of the gap and possible next steps.

3.1 Topic 1: Leveraging WPTO Investments To Drive R&D and Commercialization

At the heart of ME technology testing, data collection, and data processing are the facilities where such activities are carried out. WPTO has made significant investments into these innovative facilities, which are outfitted with cutting-edge equipment and expertise central to advancing the development of ME technologies.

The first breakout sessions were focused on identifying the unique instrumentation and data needs associated with various types of testing facilities, encompassing university research institutions, national labs, and open-water facilities.

These facilities are represented throughout the life cycle of technology R&D, from low technology readiness level (TRL), small-scale devices to mid-TRL component, subsystem, and system testing to higher-TRL, large-scale testing. Each phase of testing has unique needs in terms of infrastructure, instrumentation, and data processing.

3.1.1 Early TRL and Scaled Testing

3.1.1.1 Recommended protocols for data integration between data collected on test articles and facility data acquisition systems

The ability to synchronize multiple data streams is a crucial aspect of all forms of testing. This synchronization is essential for correlating system response to environmental conditions, wave/tidal resource, or other test article responses. For tank and basin testing, synchronization with tank or basin control data is an additional need. Having a uniform data collection point—as well as time synchronization—improves the quality, ease, and timeline for data analysis. Decisions can be made about device operation and subsequent tests as data come in through the use of one centralized data acquisition system (DAS) with automated data analysis. Monitoring these data together provides researchers and developers greater insight into device and tank performance, allowing for system modifications, which can allow for feedback into the testing process through real-time learning about the test results. Testing timelines can also be shortened when data can be viewed and analyzed in near real time.

The standardization of communication protocols, sensors, and instrumentation for tank tests could ease the challenges of data integration. Publishing such standards would aid developers during the design and build of their prototype, as they would have a baseline for what to include to enable successful data collection.

Key Theme: Standardization of Data Collection Practices, Instruments, and Data Formats

Gaps: There is a lack of standard tank testing communication protocols, recommended list of tank testing instruments, and guidelines for conducting tank tests.

Impact of Gaps: Additional burden falls on both developers and tank testing facilities to implement different data collection setups. Increased time and effort are required to integrate a test device with facility DAS.

Next Steps To Close the Gaps:

- Develop a recommended list of sensors and instruments to be used for tank testing.
- Facilitate collaboration between wave tank facilities to identify uniform communication protocols and/or data formats for integrating test devices with facility DASs.

3.1.1.2 Well-characterized methodologies for handling data communication both with and without cables

On a small-scale device, such as those tested in wave tanks, wires can have a significant impact on the dynamic performance and therefore on the tank testing results.

Sensors and cables add weight, stiffness, and drag to the device undergoing tests. Cables connecting the device to DASs outside the tank can add an extra mooring point that would otherwise not exist during an open-water deployment. Every effort is made to add slack to the data acquisition cables and route them above the water to avoid interfering with the wave field; however, impacts on the device performance are ultimately unavoidable due to the added weight and tension required to hold a device in a particular position. Oftentimes, teams are unable to perform a characterization of the device performance in the water without the sensors and cable attached, which renders characterizing the cable impact difficult.

While technology for wireless transmission of data exists, it has not been fully characterized or implemented for either in-water testing or tank testing. Existing solutions are often pricey—as well as large in size—which is not suitable for tank testing. Typical solutions that use acoustics or light as the data carrier are often geared toward short-distance transmission at high bandwidth or long distances with low bandwidth. WPTO is currently researching alternative solutions for ME applications through national laboratory and university research.

Key Theme: Standardization of Data Collection Practices, Instruments, and Data Formats

Gaps: There is a lack of standard protocols for assessing sensor cable impacts on tank tests. No standard technology for wireless data transfer and communication has been adopted.

Impact of Gaps: Compromised tank test results can occur from wire impacts. Greater uncertainty can exist in scaling up for larger tests.

Next Steps To Close the Gaps:

- Continue research into wireless data transfer technologies.
- Develop standard protocols for characterizing impact of wires and sensors on tank test results.
- Budget time during tank testing for characterization of device response without cables.

3.1.1.3 Standard tank testing protocols and procedures

Tank testing and data collection can be streamlined through the development of standard testing protocols. Having well-documented and broadly adopted procedures would remove much of the burden of creating and communicating expectations and test plans for tank testing from both the device developers and the test centers. Well-laid-out requirements and expectations for roles and responsibilities during the preparation, execution, and decommissioning of a tank test could streamline the process.

Additionally, system calibrations should be conducted both prior to and after tank testing. System calibrations typically occur out of the water, where the weight and ballast of the system can be recorded. During the course of testing, instruments are often added, and the device is frequently modified. This renders the calibration that took place prior to the test invalid for later tests.

The IEC and the International Tank Testing Conference (ITTC) are working to develop tank testing standards and recommendations. These documents will provide baseline processes and procedures to follow for tank and flume testing.

Key Theme: Standardization of Data Collection Practices, Instruments, and Data Formats

Gaps: Consistent and broadly accepted tank testing protocols are not widely adopted. Guidelines for individual facilities are often lacking or are not always used.

Impact of Gaps: Impacts include increased time and expense developing test protocols and working with developers to train on how tank testing is conducted; inconsistent data sets and results when system calibrations and checks are not consistently applied; difficulty in comparing test results; and decreased value of data collected, as analysis and interpretation cannot be standardized.

Next Steps To Close the Gaps:

- Encourage wave tank facilities to collaborate to develop consistent guides for tank testing, ranging from test planning and implementation to closeout.
- Gather support for adopting and implementing IEC and ITTC standards and best practices recommendations.

- Standardize calibration procedures both before and after tank testing.
- Budget time and funding for multiple device calibrations.

3.1.2 Mid-TRL Component and System Testing

3.1.2.1 Methods for characterizing test setup prior to test article integration

The results from a test are only as reliable as the test equipment used to complete it. With novel setups for testing the unique components, subsystems, and systems used in ME technologies currently under development, it is increasingly necessary to create and adopt consistent practices for characterizing the performance of the test equipment. These novel test setups often consist of components not specifically developed for ME applications, meaning that specification sheets on the equipment either do not exist or are not relevant to ME testing.

Past techniques include employing a reference model device for characterizing the operation of equipment and developing digital twins or real-time hybrid simulations of the test stand, which Sandia National Laboratories (Sandia) created for the SWEPT lab characterization (Coe et al. 2022). A real-time hybrid simulation is a modeled representation of the physical hardware that is run simultaneously with the actual hardware. Data are fed between the model and the physical system to improve performance on both systems and enable controls changes.

Both techniques have their advantages. Using a reference test setup gives the equipment operators an opportunity to work out safety and logistical considerations prior to a research device integration. A digital twin model allows for a better understanding of the range of operation without risking damage to physical hardware.

Key Themes: Standardization of Data Collection Practices, Instruments, and Data Formats; System Characterization and Predictive Sensing

Gaps: No standard practice exists for characterizing test setups prior to test article integration. Various procedures exist at different facilities that may not always meet the unique needs of ME testing.

Impact of Gaps: Test results may be compromised by uncertainties or errors introduced by the test setup. These compromised or invalid results may lead to greater uncertainty in later-TRL designs and increased risk of failure when advancing to open-water testing**.**

Next Steps To Close the Gaps:

- Bring together laboratory test engineers to discuss techniques used at respective facilities—organizations such as International WaTERS[1] and the IECRE[2] can help facilitate these conversations.
- Develop guidance documents prescribing methods for test setup characterization.

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[1] International Wave and Tidal Energy Research Sites (WaTERS) is a network of global ME test centers.
[2] IECRE is the IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications.

- Require the development of a report on test setup characterization prior to test initiation to be shared with all relevant stakeholders.

3.1.2.2 Sensors and capabilities to test power electronics and characterize PTO efficiency

Creation and integration of ME technologies with various loads and grids remains a significant challenge for ME developers. ME technologies have unique generation characteristics that generally differ from other conventional and renewable energy generation. Requirements imposed by local utilities add an additional layer of complexity to the development and testing of power electronics integrated with ME devices. The ability to characterize the performance of these marine-energy-powered devices is crucial to their further advancement.

Additionally, characterization and monitoring of power electronics performance under high humidity and other harsh marine conditions is needed. The performance of power electronics under harsh marine conditions is still an unknown and needs to be fully understood to optimize power electronics design and implementation with ME technologies.

Key Themes: Standardization of Data Collection Practices, Instruments, and Data Formats; Development of New and Improvement of Existing Instrumentation and Sensors; System Characterization and Predictive Sensing

Gaps: Standard test setups and sensors for monitoring internal components in power electronics are not readily available for ME technology testing.

Impact of Gaps: ME technologies are being tested without fully characterizing and monitoring the power electronics, leading to an increased risk of failure. It is difficult to capture lessons learned from testing without adequate data, which leads to delayed progress toward successfully commercialized technologies.

Next Steps To Close the Gaps:

- Develop test and sensor capabilities for power electronics.
- Develop standard power take-off and power electronics characterization methodologies.

3.1.3 Late-TRL and Open-Water Testing

3.1.3.1 Standardized load measurement techniques

Mechanical loads measurement is essential for validating structural models, improving structural design, and determining fatigue and maintenance cycles. The IEC TS 62600-3: Measurement of Mechanical Loads (IEC 2020) outlines required and recommended measurements and how to process the resulting data. However, the TS's guidance on techniques for sensor placement is vague, especially for wave energy devices. Because wave energy converters are developed using a variety of archetypes and operating principles, the TS must use vague requirements for measurements on the prime mover, but actual sensor placement techniques are not included. There are several types of strain gauges that are typically used for collecting mechanical loads data, each with unique capabilities. Furthermore, there are numerous methodologies for placing these gauges, which include different numbers of individual sensors, adhesive types, and sensor locations. Widely accessible guidance on measurement and installation methods is still lacking within the ME community.

In addition to a lack of detailed standards, collecting strain measurements in water is challenging. These challenges are often amplified when the path between the strain measurement and DAS is far or in a difficult-to-wire location, i.e., on a rotating frame. As a result, to date, in-field mechanical loads measurements have been sparce. Sandia and the National Renewable Energy Laboratory (NREL) have conducted load measurement campaigns on both scaled and full-sized wave energy converters and tidal energy converters, but little consensus has been achieved in standard processes or sensor choices.

Key Theme: Standardization of Data Collection Practices, Instruments, and Data Formats

Gaps: Various strain measurement sensors and techniques exist, but no standard techniques have been identified for meeting ME measurement needs. Additionally, for wave energy, little guidance exists for how or where to collect measurements.

Impact of Gaps: Very few mechanical load measurement campaigns have occurred, leading to a lack of model validation, design improvement, or understanding of maintenance cycles. Significant time and planning are required to conduct loads measurements due to the current lack of standardized procedures.

Next Steps To Close the Gaps:

- Prioritize the collection of mechanical loads measurements during ocean deployments to increase expertise in mechanical loads measurements and assessment.
- Collect lessons learned from deployments and develop best practices guides through initiatives like PRIMRE and the MRE Risk Framework.
- Provide feedback from mechanical loads measurement campaigns to the IEC TC 114 for integration of best practices into standards.

3.1.3.2 Debris avoidance and detection

Debris—such as logs and ice—can pose major hazards to ME technologies, particularly river energy converters. Debris can get caught in rotating and moving parts, leading to decreased device performance or the halting of operations altogether. Larger debris can damage or break device components or subsystems. The ability to detect and avoid these damaging collisions would be beneficial to the survivability of ME technologies. Methods for preventing collisions could follow a variety of approaches, including collecting debris upstream, redirecting debris, or maneuvering the marine energy converter (MEC) away from hazards.

Key Theme: Development of New and Improvement of Existing Instrumentation and Sensors

Gaps: There are no reliable sensors for advanced detection of hazardous objects in the water. Additionally, there is no standard method for preventing debris from colliding with MECs.

Impact of Gaps: Impacts from debris can cause significant damage to MEC technologies, leading to costly repairs, testing failure, or loss of the device entirely.

Next Steps To Close Gaps:

- Research debris avoidance techniques using existing instrumentation and identify gaps in capabilities.
- Develop debris detection sensors, instruments, and control algorithms to fill the identified gaps.
- Develop best practices for debris avoidance leveraging industry-accepted instrumentation.

3.1.3.3 Guidance for onboard data requirements and down-sampling

Devices not connected to shore via a communications cable frequently run into onboard data storage issues. In many cases, the current guidance is to collect as much data as possible, since there are many open questions about ME technologies that require substantial data analysis—and therefore data—to answer. This impulse leads to over-instrumenting devices and collecting at higher than necessary sample rates. Adding more instruments at higher sample rates leads to higher power requirements for powering sensors and DASs, larger data storage capacity, and higher costs for data acquisition hardware and installation. Heavy battery packs are often added to accommodate the DAS power and storage requirements, which can lead to space and weight issues on smaller devices.

Key Theme: Determination of the Volume of Data To Collect

Gaps: While some IEC technical specifications prescribe data capture matrices, further assessment of these guidelines are needed. Additionally, no standardized methods for onboard down-sampling of the data exist in terms of the analysis and code used to conduct the down-sampling.

Impact of Gaps: Impacts include higher budgets due to over-instrumenting devices; negative impacts on device weight due to instruments, DASs, and batteries; shorter test durations due to data storage limitations; loss of data due to data storage limitations; and costly operation and maintenance trips to retrieve data.

Next Steps To Close Gaps:

- Research necessary data requirements for assessing system and component performance for model validation and design improvements.
- Develop recommended down-sampling guidelines, techniques, and algorithms.
- Provide feedback on data requirements to the IEC TC 114 for inclusion in technical specifications.

3.1.3.4 Understanding of sensor and instrument life span

Because there have been few long-term ME device demonstrations, there remains little understanding on how long device sensors and instruments can survive and remain within calibration during operations. ME devices are deployed in harsh environments where weather systems and marine conditions can significantly impact instrumentation, especially if the instruments are not specifically designed for the environment. Extreme temperatures, salt corrosion, mechanical wear and tear, marine growth, and flooding can all have detrimental effects on instrument performance or even lead to device failure.

While information can be pulled from similar industries—such as oil and gas, shipping, and offshore wind—unique ME requirements, applications, and operating environments for sensors and instruments have not yet been fully characterized.

Key Theme: Development of New and Improvement of Existing Instrumentation and Sensors

Gaps: There is limited understanding of the survivability and life expectancy of sensors and instruments typically used during MEC operation.

Impact of Gaps: There is an incomplete understanding of the survivability and life expectancy of existing sensors and instruments when used for ME applications, which could lead to difficulties in monitoring system performance and meeting operations and maintenance needs in the long term.

Next Steps To Close Gaps:

- Research and test sensor and instrument life spans.
- Characterize the impact that long deployments in marine environments have on instrument and sensor performance to determine calibration, service intervals, survivability, and life expectancy.

3.1.3.5 Cost-effective, standards-compliant, small-form-factor data acquisition system

The 2017 ME Instrumentation and Data Workshop results highlighted the need for robust, standard, ME-specific DASs. Since then, the MODAQ system and Mini-DAQ have been developed to meet the needs of open-water and small-scale lab testing, respectively.

MODAQ was developed with IEC technical specifications and larger-scale, grid-connected technologies in mind. Mini-DAQ is a lightweight, small formfactor DAS designed for small-scale wave energy converter testing, particularly during benchtop and wave tank testing. With the current near-term focus of ME on PBE applications, there is a growing need for new DASs. PBE devices are designed to power non-grid-connected applications, ranging from small oceanographic sensors to remote community microgrids. PBE ME devices are typically smaller than traditional grid devices, in terms of both physical size and rated power. Some maritime PBE markets will require ME technologies to be deployed far from shore. Other PBE applications—such as water desalination—do not have electricity as the ME device output. These differences between PBE and grid-integrated devices change the requirements for data acquisition. WPTO has begun funding an effort to develop a smaller-scale, low-power-consumption DAS as a follow-on to the MODAQ system. This effort aims to address many of the gaps identified below.

Key Theme: Development of New and Improvement of Existing Instrumentation and Sensors

Gaps: ME-specific data acquisition solutions featuring a small form factor, low battery consumption, and unlicensed software do not meet the requirements for all IEC technical specifications, including power quality, and have not been demonstrated during open-ocean deployments.

Impact of Gaps: Selecting a DAS for smaller, non-cable-connected, open-water tests is challenging. Currently, each developer must design and select their own solution, increasing both cost and time. The use of licensed platforms increases costs for eventual commercialized technologies.

Next Steps To Close Gaps:

- Collect requirements for DASs from developers and stakeholders.
- Develop thorough guides and recommendations for ME DASs.

3.1.3.6 Weather-conditioned sensors and instruments

As ME technologies are deployed in a variety of environmental conditions, the sensors used to monitor device health and status; wave, tidal, and current resources; and environmental impacts need to be able to perform in a variety of conditions. This includes extreme cold and ice, strong tides and waves, and vast temperature swings.

Key Theme: Development of New and Improvement of Existing Instrumentation and Sensors

Gaps: Instrumentation required for ME testing and permitting malfunctions in extreme conditions. There is a lack of affordable weather-rated instruments, including sensors and cameras needed for environmental and wildlife monitoring.

Impact of Gaps: Collecting data from environments with extreme conditions is difficult to impossible, especially in cold environments where freezing temperatures can cause icing of the equipment.

Next Steps To Close Gaps:

- Understand the operational bounds of existing sensors and instruments as well as extreme-condition impacts on calibrations.
- Learn from other industries where weatherization and extreme-condition operation is common.
- Research and develop weatherization techniques for sensors and instruments.
- Work with instrument developers to produce more robust instruments and sensors.

3.2 Topic 2: Measurement Strategies and Best Practices

Standardization of ME practices—ranging from design procedures, testing, instrumentation, data collection, and data analysis—is essential for maturing the ME industry toward commercialization and device certification. To introduce the breakout session focused on measurement strategies and best practices, researchers from NREL, Pacific Northwest National Laboratory (PNNL), and industry presented on best practices and standards they follow related to working with marine energy technologies.

The session introduction included a discussion about sensor selection and placement and data collection best practices used for designing a measurement campaign. Presentations covered both device performance measurements and regulatory and environmental monitoring considerations. Additionally, information was presented about the 62600 suite of technical specifications developed by IEC TC 114 "Marine Energy – Wave, tidal, and other water current converters." During the breakout sessions, workshop participants were encouraged to comment on, question, and even challenge the presented best practices and standards.

3.2.1 Recommended Sensor, Instrument, and Channel Lists

ME devices typically monitor a variety of parameters for the purposes of tracking device health, making control decisions, and assessing device performance. They also measure potential environmental interactions that could cause harm to marine animals, habitats, or oceanographic processes.

Different types of sensors are used depending on the type of test being conducted. Often, sensors and instruments need to be included in the device design to facilitate optimal positioning, installation, and power or cabling requirements so that the sensor itself does not interfere with device performance. Environmental effects monitoring is often carried out from sensor packages that stand off from the marine energy device, including the use of active and passive acoustic instruments and optical cameras.

Key Theme: Standardization of Data Collection Practices, Instruments, and Data Formats

Gaps: No standard recommended suite of sensors, instruments, or data channels exists for the various types of ME tests.

Impact of Gaps: It is difficult to integrate sensors/instruments after a design is finalized. Inconsistent measurements across tests lead to a reduced ability to capture lessons learned and improve future designs. There is additional time and cost associated with programming DASs to collect different, nonstandard sensors.

Next Steps To Close Gaps:

- Work with developers, standards committees, and stakeholders to identify and tabulate measurement needs.
- Research available sensor and instrumentation options and compile reliable, fit-for-purpose options in PRIMRE.
- Publish recommended minimum requirements for instrument and sensors.
- Incorporate sensor and instrument selection in the design phase of projects to ease integration.

3.2.2 Standardized Turbulence Measurements and Data Processing

Turbulence can have a significant impact on tidal turbine performance. Phenomena such as flow separation (Milne et al. 2013) and increased blade bending moments (Milne et al. 2015) are caused by turbulent flows. These phenomena can have significant negative impacts on turbine performance or result in more frequent maintenance cycles. As such, turbulence should be monitored and considered when assessing performance and loads during a test.

Many of the procedures developed in the marine energy technical specifications follow those developed for wind turbine assessments. In the IEC 61400-12-1 Ed. 3 "Power performance measurements of electricity producing wind turbines" international standard for wind turbine power performance assessment, there is a section dedicated to a turbulence normalization procedure (IEC 2022). Given the similarities between wind and tidal turbines, similar considerations should be made in the context of marine devices.

Presently, there is no guidance in IEC TS 62600-200 Ed. 1 "Electricity producing tidal energy converters - Power performance assessment" for tidal power performance on how to account for turbulence (IEC 2013). The first-edition TS contains a statement indicating that guidance with respect to turbulence will be added in a future revision. Maintenance Team 62600-200, within IEC TC 114, is actively working on a second edition of this TS.

Measuring and understanding turbulence impacts on performance could play a role in determining control settings and strategies for optimizing the performance of devices and minimizing structural loading on blades and other substructures. Creating standard practices for instrument placement, data collection, and processing could also enable the development of advanced control strategies for ME devices by creating standard data sets researchers can use for controls development work.

Key Theme: Standardization of Data Collection Practices, Instruments, and Data Formats

Gaps: No standard measurement strategy or data processing methodology exists for tidal flow turbulence.

Impact of Gaps: There is decreased understanding of the impacts of turbulence on technology performance and loading, leading to an inability to mitigate these effects through the employment of control strategies, which results in decreased tidal turbine performance.

Next Steps To Close Gaps:

- Develop standards for turbulence measurements, sensors and instrumentation, and data processing, accounting for impacts in turbine performance assessments and control strategies.
- Integrate these standards into relevant IEC TC 114 technical specifications.

3.2.3 Standards Training and Implementation

Standards are difficult to implement if they are not fully understood. Even knowing which standards are applicable to a particular test can require quite a bit of time and research because standards cover such a broad range of topics.

Key Theme: Better Access to Lessons Learned, Best Practices, and Training

Gaps: No easily accessible and standard offering of training for standards implementation exists. There is incomplete understanding by ME developers and researchers on the importance of independent, third-party verification of compliance to standards.

Impact of Gaps: Standards are not applied due to lack of knowledge and preplanning for their implementation, which leads to decreased quality of device design, testing, and performance assessment.

Next Steps To Close Gaps:

- Develop example case studies of how to implement standards.
- Work with groups like the IEC and the IECRE to create and offer training for developers and stakeholders on standards and certification.

3.2.4 Access To Best Practices

A number of initiatives have been launched in recent years to improve access to recommendations and best practices in the ME field. PRIMRE, for example, (https://openei.org/wiki/PRIMRE) provides wiki pages and databases in Telesto (https://openei.org/wiki/PRIMRE/Telesto) for sharing and finding best practices and recommendations for instrumentation. In some cases, these pages have been successful at collating lessons learned and recommendations, but overall, the pages have not been adopted or even discovered by the broader ME community. Workshop participants expressed a lack of awareness of these PRIMRE pages or indicated that the information the pages included was incomplete, difficult to navigate, or difficult to contribute to.

Key Theme: Better Access to Lessons Learned, Best Practices, and Training

Gaps: No standardized, easy-to-use format for sharing and disseminating lessons learned and best practices exists. There is little awareness and uptake of the existing best practices resources.

Impact of Gaps: Mistakes are repeated, and lessons learned have little impact on the broader ME community, leading to a decreased number of successful projects and technology demonstrations.

Next Steps To Close Gaps:

- Assess why existing best practice and lessons learned tools have not been widely adopted and utilized.
- Develop or revamp standardized and searchable tools for disseminating/sharing best practices based on assessment of current tools.
- Link best practices and recommendations to risk matrices.
- Incorporate best practices into standards.

3.3 Topic 3: Key Challenges for PBE and Environmental Effects Monitoring

3.3.1 Powering the Blue Economy

The session focused on PBE instrumentation and data needs was introduced with a presentation providing an overview of the PBE portfolio of work. The two primary areas of the PBE portfolio, “Resilient Costal Communities” and “Power at Sea,” were described, and an overview was given of previous and ongoing projects under each. These included competitions such as the Waves to Water Prize and Ocean Observing Prize.

During the introductory presentation, feedback was shared about data and instrumentation needs determined as part of the research into ocean observing ME applications. Participants raised concerns about the need for higher data sampling rates, onboard data processing, and energy storage and power challenges associated with long deployments. These challenges could be met by the inclusion of marine energy devices to provide power for ocean observation platforms. This challenge also helped seed discussion during the breakout sessions.

3.3.1.1 Onboard data processing and condition monitoring

ME technologies used for PBE applications are often not connected to shore via a cable, as data cables tend to only be laid for grid-connected test sites. PBE devices are often deployed far from shore or at non-pre-permitted testing locations. This limits the data that can be sent back to shore or to the cloud for analysis. Data that can be sent back are often at a lower fidelity than what are collected and would be needed for data analysis. Near-real-time data are required to make operational decisions and monitor device performance and health to determine appropriate maintenance cycles.

There are ongoing areas of research in the ME community investigating advanced data and modeling techniques for monitoring system performance and health. Such techniques include the use of digital twins, machine learning, and structural health monitoring. All of these techniques require near-real-time data. In the absence of a reliable data link, onboard processing for data quality control may be necessary. This onboard processing would be essential to adequately set device controls and monitor device health and status.

Key Theme: Determination of the Volume of Data To Collect; System Characterization and Predictive Sensing

Gaps: Current hardware and software solutions for onboard data processing and analysis are limited. Condition monitoring, in particular, requires significant processing capabilities. The hardware solution must also meet the space and power consumption requirements of smaller PBE devices.

Impact of Gaps: Impacts include limited operational controls and monitoring of ME technologies for PBE applications, limited performance, and greater uncertainty regarding maintenance cycles.

Next Steps To Close Gaps:

- Adapt onboard data processing capabilities developed by other industries to ME applications.

3.3.1.2 Wireless communications and data transfer

Data often must be transferred via wireless methods over both short and long distances. The option to wirelessly transmit data enables a broader range of measurements, eases sensor and DAS integration, and allows for data transmission from the device under test. For example, for short distance data transfer, collection of data from a rotating frame, such as the blades and hub on a tidal turbine, often requires significant engineering to accomplish. Furthermore, data must often be transmitted long distances for device monitoring and data analysis using satellite, cell modems, or Wi-Fi, depending on the device location. There are currently no standard protocols to guide the choice of equipment or methods used to accomplish either short- or long-distance data transfer.

Key Theme: Standardization of Data Collection Practices, Instruments, and Data Formats; Development of New and Improvement of Existing Instrumentation and Sensors

Gaps: There is no industrywide accepted method to wirelessly transmit data from a sensor or instrument to a central DAS. Additionally, there is no standard method for transmitting data from the MEC to shore or to a cloud repository.

Impact of Gaps: Significant time and effort are required to engineer wired data collection solutions. Physically smaller devices and remote deployments not connected to shore via a fiber often run into data storage limitations, leading to shorter deployments or loss of data.

Next Steps To Close Gaps:

- Survey existing techniques for wirelessly transmitting data over both short and long distances.
- Test various methods for transmitting different types and quantities of data and publish the results, along with recommendations by application.
- Develop recommendations and standard practices for transmitting data.

3.3.1.3 Small sensors, instruments, components, and data acquisition systems

ME devices designed to power PBE applications are often of a smaller physical size due to the lower power requirements of the PBE application. Due to the smaller size, there are space and weight limitations for the installation of any additional hardware. Data acquisition systems and instruments are also required to have their own power source, i.e., batteries, which can exacerbate these space and weight limitations.

Key Theme: Development of New and Improvement of Existing Instrumentation and Sensors

Gaps: Few small-scale, low-power-consumption, marine-ready instruments and DASs exist that meet the needs for ME device testing, operation, monitoring, and controls.

Impact of Gaps: Reliable data collection from small, non-cable-connected devices is difficult to impossible, leading to limited learning from device deployments. In the long run, this will slow device advancement to commercialization.

Next Steps To Close Gaps: WPTO began funding an effort to develop a smaller-scale, low-power-consumption DAS solution as a follow on to the MODAQ system. Additional steps could include:

- Survey existing sensors and instruments and identifying areas for investment and development.
- Develop best practices and recommendations for data collection on small devices.

3.3.1.4 Shared sensors between MEC and end use

The focus on PBE applications for ME technologies has changed some of the measurement needs for ME technology testing. When the application for the MEC is not electricity generation, for example, the measured quantities for efficiency may change. Water desalination is an example of a PBE application where the end product is fresh water, not electricity. Efficiency and performance are assessed by the amount and quality of the fresh water produced. For electricity-producing PBE MECs, when not connected to the grid, the power produced by the MEC and the consumption by the end use will also need to be monitored for efficiency in powering the PBE application. As such, integrated sensor systems between the MEC and the end use would improve measurement efficiency.

Key Theme: Development of New and Improvement of Existing Instrumentation and Sensors

Gaps: Often, data collection between the MEC and the end application are conducted separately or by different entities. Integrating the sensors and data collection requires significant time and effort.

Impact of Gaps: Separate sensors and DAS for the MEC and PBE application performance are sometimes used, leading to higher instrument costs and overall data collection power requirements. Integration of measurement systems leads to higher project costs. Processing data from different measurement systems creates challenges when sample rates are different and/or there is clock drift.

Next Steps To Close Gaps:

- Survey common sensor and instrumentation requirements for various PBE applications.
- Develop sensor and DAS capabilities and best practices for integrated data collection.
- Encourage co-design of ME and end-use technology.

3.3.2 Environmental Effects Monitoring

Environmental effects monitoring encompasses a broad range of measurements required by regulators to ensure that the presence of ME technologies have minimal impact on marine life, habitats, ecosystems, oceanographic processes, water quality, and sediment transport.

These measurements require unique instrumentation apart from that which is needed for performance or engineering monitoring. Measurements include observations of wildlife presence; collision between ME devices and wildlife; emissions of noise and electromagnetic fields and their effects on marine animals; changes in benthic and pelagic habitats, changes in water circulation and wave height; changes in sedimentation patterns; and discharge of contaminants.

Measurement campaigns may need to be carried out over long periods of time to track the environment before, during, and after the deployment of an ME device and to account for cumulative effects that may not become observable for months to years after deployment and operation of ME devices and arrays. The introductory presentation for the environmental monitoring sessions provided an overview of the measurements needed, often keyed to the life cycles of the marine animals at risk. Some of the key challenges that need to be addressed are discussed below.

3.3.2.1 Best practices and standards

Environmental effects monitoring requires a unique set of instrumentation and measurements to meet regulatory requirements. There are, however, a variety of ways that the data are collected and processed, which to a large extent depends on the animals, habitats, and ecosystem processes present at the marine energy site. Standardized practices and instrumentation would help the ME industry meet the regulatory requirements with less time and effort required to determine instrumentation and measurement plans. It is important to note that the huge range of marine animals and the systems that support them will make it very challenging to standardize methods and even instruments. However, a set of best practices could be helpful to set the stage for some degree of consistency in data collection, analysis, and interpretation.

Key Theme: Standardization of Data Collection Practices, Instruments, and Data Formats

Gaps: There are no existing standards for assessing environmental impacts from ME technologies, nor is there any guidance for ME stakeholders on what instruments to use, how to place them, and how to process the data. In addition, developers may not be aware of the existence of baseline data collected for other purposes, which can help inform their data collection and analysis efforts.

Impact of Gaps: Environmental effects monitoring measurements are often an afterthought for MEC technology developers, leading to more difficult and incomplete environmental studies and arduous certification processes due to nonstandard data collection and processing.

Next Steps To Close Gaps:

- Develop standards, recommendations, and best practices where appropriate.
- Create and present training materials on best practices and standards.

3.3.2.2 Guidance on level of necessary monitoring

When it comes to assessing the impact a ME technology may have on an ecosystem or wildlife, studies often span long periods. This is to ensure that the risk to the environment is fully characterized and mitigated if needed, particularly as many of the marine animals of concern may be long-lived and have a complex life history. Moreover, interactions between marine animals and ME devices are likely to be rare.

Regulators must ensure that ME devices will not cause significant harm to the marine environment and the animals living in it. As ME devices are often a new type of installation for many regulators and certification bodies, they are likely to raise concerns for the environment and wildlife, even if the impact is not significant.

Key Theme: Determination of the Volume of Data To Collect

Gaps: There are currently no standards for the duration of monitoring campaigns or the volume of data required (i.e., duty cycles) to fully characterize the impact of a ME device on the environment and wildlife. There is no guidance on when a concern can be characterized as insignificant. However, work under Ocean Energy Systems-Environmental is approaching this concept through an organized process of risk retirement and data transferability. (https://tethys.pnnl.gov/risk-retirement).

Impact of Gaps: Measurement campaigns can be long and costly. There is a lack of understanding of requirements from regulators for measurement planning, and there is continuing confusion around priorities for data collection at new projects.

Next Steps To Close Gaps:

- Conduct research into the volume and duration of data necessary to alleviate concerns and characterize risks.
- Work with researchers to reach consensus on a consistent set of data collection practices for each major environmental effect.
- Work with regulators to understand their concerns and requirements and to ensure that scientific findings and outcomes are accessible and available to them.

3.3.2.3 Methods for preventing instrument interference

Environmental effects monitoring instruments often leverage various methods of remote sensing. As such, instruments of similar types can interfere with each other if not positioned and operated appropriately.

Methods for mitigating interference include programming instrument operation and timing to avoid interference, selecting instruments with no interreference concerns, or orienting sensors away from each other. There are cases, however, where applying these strategies is not possible. Furthermore, guidance on how to implement these strategies is not widely available.

Key Theme: Standardization of Data Collection Practices, Instruments, and Data Formats; Development of New and Improvement of Existing Instrumentation and Sensors

Gaps: There is currently no easily accessible guidance on implementing strategies for preventing interference. Some instruments are not programmable to prevent interference.

Impact of Gaps: Data can be compromised during environmental monitoring campaigns, leading to costly redeployments, a lack of results needed for permitting, and overall project delays. Bad data will also limit learning on the impacts of ME technologies on the environment.

Next Steps To Close Gaps:

- Conduct a literature review on published methodologies used by other industries.
- Work with relevant industries and experts to develop best practices and guidelines for avoiding instrument interferences.
- Work with instrument developers to develop better and more broadly used controls for avoiding interferences.

3.3.2.4 Standardized data processing methods

Related to standard practices for conducting environmental effects monitoring assessments, the establishment of standardized data processing algorithms, techniques, and methods for interpreting data would greatly improve the outcomes of environmental monitoring campaigns.

Key Theme: Standardization of Data Collection Practices, Instruments, and Data Formats

Gaps: No standards exist for analyzing and interpreting environmental monitoring data.

Impact of Gaps: Data analysis and interpretation of environmental data can be inconsistent. There is a greater burden on developers and researchers to develop their own data analysis code. Inconsistent analyses lead to inconsistent reporting, making it harder for regulators to streamline permitting processes.

Next Steps To Close Gaps:

- Work with research groups to increase consistency and develop consensus around analysis and interpretation of environmental effects monitoring data collection.
- Develop standard open-source data processing code.

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Appendix A. Workshop Agenda

4th International Marine Energy Instrumentation and Data Workshop

Day 1: March 16, 2022	
8:30 (MT)	**Welcome/Introductions** Jeff Rieks, WPTO Rebecca Fao, NREL
8:55	**National Lab Data and Instrumentation Updates** • MODAQ – Rob Raye, NREL • Mini-DAQ – Budi Gunawan, Sandia • Loads Measurement – Budi Gunawan, Sandia • MHKIT – Rebecca Fao, NREL • ME Data Pipeline – Max Levin, PNNL
9:25	**Speed Session – Workshop Participant Updates** • Pierre-Philippe Beaujean, FAU • Kelley Ruel, Sandia • Martin Wosnik, UNH
9:45	**Break (15 min)**
10:00	**Speed Session – Workshop Participant Updates** • Xiaofan Li, Virginia Tech • Raju Dalta, Stevens U. • Kaelin Chancey, ORPC • Olatz Larrieta, IDOM • James Joslin, MarineSitu • Ean Amon, PacWave
10:45	**Session 1 Wrap up**
11:00	**Break (1 hour)**
12:00	**Welcome and Housekeeping**
12:05	**Leveraging Testing Facilities and Infrastructure to Drive R&D and Commercialization,** Rick Driscoll
12:20 **1:05**	**Breakout 1** • *Topic 1: National Laboratory instrumentation and data needs (Leads – Bharath, Gunawan)* • *Topic 2: University and NMREC instrumentation and data needs (Lead – Driscoll)* • *Topic 3: Open water deployment and test facility instrumentation and data needs (Leads – Ainsworth, Fao)* **Regroup**
1:20	**Break (15 min)**
1:35	**Regroup**
1:40	**Breakout 2 –** Participants change topics (same topics as above)
3:00	**Adjourn for Day**

Day 2: March 17, 2022	
9:00 (MT)	Housekeeping and Welcome
9:05	**Measurement Strategies and Best Practices,** Andrea Copping – PNNL, Rob Raye – NREL
9:35	Measurement Best Practices Breakouts (Leads – Copping, Raye, Colby, Ainsworth)
10:20	Regroup
10:30	**Break (1 Hour)**
11:30	Housekeeping
11:35 11:55 12:15 1:00	**Key Measurement and Data Challenges for Environmental Monitoring**, Emma Cotter – PNNL **Key Measurement and Data Challenges for PBE Applications**, Rob Cavagnaro – PNNL Breakouts • Environmental Monitoring (Leads – Cotter, Copping) • PBE (Leads – Cavagnaro, Driscoll) Regroup
1:05	**Break (15 min)**
1:20	Breakouts – participants switch topics • Environmental Monitoring (Leads – Cotter, Copping) • PBE (Leads – Cavagnaro, Driscoll)
2:05	Regroup and Closing Remarks
2:30	**Meeting Close**