U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

WIND AND WATER POWER PROGRAM

1st Advanced Marine Renewable Energy Instrumentation Experts Workshop

April 5-7, 2011

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Executive Summary

The U.S. marine energy industry is actively pursuing development of marine hydrokinetic (MHK) and offshore wind energy systems. Experience in the wind energy and marine sectors shows that to reduce technology risk and accelerate development timelines, site characterization and field measurement of device performance, loads, and response are essential. To do this, the marine energy industry needs robust instrumentation systems that can operate in the harsh ocean environment, with the ability to provide a broad set of coordinated, high quality measurements. Presently, no instrumentation system solutions have been demonstrated that effectively meet the measurement needs of the marine energy industry.

The 1st Advanced Marine Renewable Energy Instrumentation Experts Workshop brought together technical experts from government laboratories, academia, and industry representatives from marine energy, wind, offshore oil and gas, and instrumentation developers to present and discuss the instrumentation needs of the marine energy industry. The goals of the meeting were to:

1. Share the latest relevant knowledge among technical experts
2. Review relevant state-of-the-art field measurement technologies and methods
3. Review lessons learned from recent field deployments
4. Identify synergies across different industries
5. Identify gaps between existing and needed instrumentation capabilities
6. Understand who are the leading experts
7. Provide a forum where stakeholders from the marine energy industry could provide substantive input in the development of new marine energy field deployable instrumentation packages.

Sixty people attended the three day workshop and 35 presentations were made. It is clear that the instrumentation systems presented will need further development to meet the needs of the marine energy industry. Lessons learned were presented and the top instrumentation development needs were identified:

1. Device developers lack the resources and capabilities to instrument pilot-scale deployments for performance, environmental, and ecological monitoring
2. Standards are needed for both the collection and analysis of field data
3. No comprehensive instrumentation system solution exists for MHK systems
4. Standardized instrumentation systems and measurement methodologies are needed for MHK device deployment
5. Communication between instrument and sensor manufacturers and the offshore wind and MHK communities should be encouraged

The following report summarizes the workshop.

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Acronyms

COTS	Commercial Off-The-Shelf
MHK	Marine Hydrokinetic
NREL	National Renewable Energy Laboratory
NWTC	National Wind Technology Center
RDT&E	Research Development Testing and Evaluation
TEC	Tidal Energy Converter
WEC	Wave Energy Converter

1 Overview

The 1st Advanced Marine Renewable Energy Instrumentation Experts Workshop was held April 5-7, 2011, at the Renaissance Hotel in Broomfield, CO, USA.

1.1 Workshop Purpose

The U.S. marine energy industry is actively developing offshore wind and MHK technologies, including ocean wave, tidal current, river current, open-ocean current, and fixed and floating wind energy devices. It also is identifying promising deployment sites where marine energy resources can be harnessed. The offshore wind and MHK devices are multifaceted, electro-mechanical machines that are used in complex environments to convert various forms of renewable ocean energy to produce electricity.

As technologies mature from concept to commercial readiness, extensive testing and monitoring efforts occur as part of RDT&E. Accurate measurements to verify loads and performance are essential to advance the state of offshore wind and MHK technology. The availability of a reliable, accurate, high resolution, and high speed instrumentation system that can be deployed in marine environments will help accelerate the development and deployment of marine renewable energy. Presently, no turn-key instrumentation system solution that includes software, hardware, and sensors exists to meet the necessary requirements to advance the state of technology readiness in the marine energy industry. However, many marine and land-based instrumentation systems do exist and are being used in related marine applications, such as offshore oil and gas and land-based wind energy. The challenge is to identify the relevant state-of-the-art instrumentation components and systems and then integrate them into a customized system that is capable of meeting the needs of the MHK and offshore wind industries.

1.2 Workshop Scope

The workshop focused on marine grade instrumentation systems used for open water site characterization, structural field testing, certification testing and verification, commissioning, and operational monitoring. The technology scope is offshore wind, wave, and current (tidal, river, and open-ocean) systems in water-based testing facilities and at open water sites. Participants were technical experts in the fields of instrumentation, monitoring, and field testing. They have hands-on roles in the development or use of instrumentation in support of offshore wind and MHK technology RDT&E, or aligned and relevant fields.

The relatively small technical workshop included 60 invited participants from industry, national laboratories, and academia. The size of the conference was intentionally kept small to facilitate open and in-depth discussion of various subjects relevant to the MHK industry. Attendees of the conference were informed that the conference was not a venue to market or advertise products, programs, or facilities. Our intent is to establish this as an annual workshop.

1.3 Workshop Objectives

The objectives of the workshop were to:

1. Share the latest relevant knowledge among technical experts
2. Review relevant state-of-the-art field measurement technologies and methods from the offshore wind, MHK and related industries

3. Review lessons learned from recent MHK and offshore wind device field deployments
4. Identify synergies across different industries
5. Identify gaps between existing and needed instrumentation capabilities
6. Identify leading subject matter experts
7. Provide a stakeholder forum to elicit substantive input for the development of new marine energy field-deployable instrumentation packages.

1.4 Format

This was a single track workshop, with 10 sessions and seven distinct topic areas. Some topic areas contained breaks and were considered to be two separate sessions. To ensure participation in the discussion sessions, it was decided not to have multiple sessions that would divide the small audience. The topic areas for the sessions were:

1.4.1 Sessions 1 and 2: Lessons Learned from In-water Deployment and Operation

Deploying and operating instrumentation in the field is technically challenging and obtaining quality field data can be elusive and fraught with unforeseen pitfalls. This session presented field experience and lessons learned when deploying instrumentation and taking measurements in the ocean and/or on land.

1.4.2 Sessions 3 and 4: Structural Loads and Response

This session presented state-of-the art techniques and technologies used to measure structural loads including systems and sensors for field measurement of the strains, forces, moments, deflections, and accelerations in device structures. Structural loads may be measured on blades/foils, towers, housings, drive train, mooring lines, foundations and other components, as well as environmental forces acting on the device, such as wave slamming, wind, and underwater current loads. Field measurements of these forces are crucial design inputs for device developers.

1.4.3 Session 5: Device Electrical Power, Performance, and Condition Monitoring

Instrumentation and methods used to monitor the function and state of MHK and offshore wind technologies, while operating in normal and extreme conditions, including power generation and quality, device condition, device stability and response, and device integrity were covered in this session.

1.4.4 Session 6: Sensors, Instruments and Platforms

This session covered a range of sensors, instruments, and instrument platforms needed to support in-water testing, demonstration, certification, and operation of MHK and offshore wind technologies.

1.4.5 Session 7: Environmental Inflow Monitoring

This session covered measurements needed to accurately quantify the underwater inflow and outflow conditions of marine renewable energy systems, such as velocity profiles, turbulence conditions, wave fields, and meteorological conditions. These measurements are essential inputs into many of the device measurements, including the structural, mooring, dynamics, and power performance monitoring, as well as computational design tools and models.

1.4.6 Session 8: State-of-the-Art Integrated Monitoring Systems

The development of advanced measurement systems for MHK and offshore wind will require the integration of a wide array of sensors that operate and communicate in different ways that can be located in different environments and far apart. Instrumentation can include device, environmental, and ecological sensors operating together that require fine temporal coordination and can be controlled from a central location. This session presented case studies of systems that have successfully and reliably integrated complex sensor networks to meet specific measurement needs.

1.4.7 Sessions 9 and 10: Ecological and Environmental Monitoring

Under current regulatory oversight, all MHK and offshore wind technologies likely will be required to perform ecological monitoring. This session reviewed the state-of-the-art instrumentation and methods for detecting, classifying, and tracking sea life.

2 Findings and Gaps Identified by Participants

During the workshop, discussion sections followed each grouping of presentations. In each discussion, the presenters from the topic section answered questions from the audience. The discussions were open and not scripted. To the best of our ability, we captured the ideas, views, and conversations. The following findings, gaps, and recommendations were gleaned from the discussions and presentations and are not listed in any particular order.

2.1 Lessons Learned from Field Deployments

2.1.1 MHK and offshore wind technologies are complex technologies – be prepared to expand measurement scope to capture the unknown

In early wind energy development, circa 1970-80s, there was a general underestimation of the complexity of technology and operation in the field. The interaction between the environment and wind turbines was not well understood. Numerous initial assumptions, like "…inflow turbulence will not be a significant load…", were eventually found to be false. Ultimately, turbulence was found to be a significant factor and much effort was put into characterizing the turbulent regimes and the corresponding loading and response of turbine systems. From this experience, the MHK industry should expect unknown conditions, interactions, and responses to arise and be prepared to deploy measurement equipment to characterize and understand the phenomena. Measurements of these unexpected phenomena are essential and can be used to develop design tools that will serve as a basis for design revisions. However, a compromise must be reached in terms of any characterization effort's equipment costs and data processing and account for man-hours versus the design benefit for the device developers.

2.1.2 Ensure that sufficient measurements are available to forensically analyze failures

Experience in the wind industry has demonstrated that no matter how well a system is designed, if it is new and/or being deployed in a new environment, some mechanism of failure is probable. Ensure that there are sufficient measurements to analyze a failure and to determine the appropriate loading to guide subsequent design iterations.

2.1.3 The 1, 3, 8 rule

This validated rule from naval architecture states that what would take one hour (dollar) to install in a shore/land facility will take three hours (dollars) in a dry dock and at least eight hours (dollars) in the field. Therefore, every effort should be made to attach all sensors and instrumentation on land prior to moving to a dry dock. Not only is installation in the field expensive, it can be unsafe and time consuming. Often, time is limited and installation can occur during calm conditions only. For tidal systems, installation time is limited to slack tide, which can be compressed into minutes.

2.1.4 Temporally synchronize all measurements during data collection

It is prudent to synchronize all measurements during data collection. Aligning measurements during post processing can be complex and time consuming. Single, synchronous data streams are preferable to multiple data streams.

2.1.5 Careful sensor selection is crucial for long term sensor operation in the marine environment and for acquiring correct data

Be judicious in sensor selection:

- Many commercial off-the-shelf (COTS) sensors, instruments, and components sourced from vendors are labeled "water-proof" or have water ingress protection through IP68 (International Protection Rating interpreted as Ingress Protection Rating). While this rating may be applicable for short duration deployments or operation in laboratory environments, it is not suitable for extended deployments in the energetic, corrosive ocean environment where ocean energy is extracted. COTS enclosures rated for IP68 rapidly fail due to leaks when deployed for any length of time.
- Instruments designed to work in the offshore oil and gas industry or for other marine industry applications may not work properly or fail because they are not designed for the energetic current or wave environments found at MHK sites.
- Adaptation of sensors developed for land-based applications to the MHK sector must be done carefully and their performance must be re-verified. The ocean is a very different environment and many assumptions from land-based operation do not hold true. For example, in land-based applications, it is often assumed that sensor mounting is stationary and rigid, which is typically not the case in marine applications (see following bullet). Another example is seen in the difference in reflective properties of the ocean surface from those on land, which can effect radar and radio transmission.
- If a sensor is to be mounted on a floating platform, the motion of the platform will affect the sensor's performance and applicability – many remote sensors used on land cannot be used on floating platforms without extensive modification in hardware and software. It is possible, though potentially difficult, to account for the motion during data post-processing, but the floating platform's motion must be accurately known.

2.1.6 Considerations for more efficient instrumentation system development and deployment

Considerations for instrumentation system development and deployment:

- Conduct onshore integration testing before full deployment – ensure/verify **ALL** functionality prior to deployment – see the 1, 3, 8 rule in section 3.1.3
- Full mechanical sea trials are essential prior to final deployment
- Ensure the installation sequence is reversible. If something goes wrong or needs to be corrected, it is useful to be able to back through the process. Permanent fixtures/attachments can make this impossible
- Use multiple recovery options; failure of a component in a recovery mechanism is common and mobilizing and using underwater vehicles and divers for recovery is very expensive
- Knowing the exact location of underwater instruments is very important. Uncertainty in location and delays between environmental measurements and device measurements will lead to inaccurate estimates of power, efficiency, and other quantities. High accuracy positioning in energetic wave or current environments can be difficult to achieve without acoustic positioning systems

- There are many different causes of failure and these include human handling, connectors, extreme events, corrosion, welding, leak, and fatigue
- Avoid underwater connections, if possible. Connector failure is the most common type of failure.

2.1.7 Expect sensor failure and monitor data to catch these failures

Sensor failure is common. When a sensor fails, it does not necessarily stop sending data. The effect of bad sensor data can range from inaccurate assessments of performance to extreme actions taken, such as rapid machine shutdown. Within an instrumentation system, mechanisms are needed to determine/infer the status and performance of a sensor, especially critical sensors, which should have redundancy. Often sensor models, sensor-to-sensor comparisons, and thresholds (measurement values and their derivatives) are used to detect sensor failures.

2.1.8 Control systems are often the cause of failures in wind turbines

Control systems typically utilize a broad set of inputs and complex multi-layered algorithms to determine the state of an energy system. Because of this complexity, wind and initial MHK experiences have shown that failures often arise from unforeseen or improper control system actions. It is important to ensure that the control system has several levels of safety checks so that the system is able to shut down safely in the case of a control system fault or failure.

2.1.9 Stainless steel and other "passive" materials are not corrosion proof

Stainless steel and other materials are not corrosion resistant/proof in the marine environment or in the presence of other materials and electrical fields. Careful attention must be give to material selection and measures taken to inhibit corrosion.

2.1.10 Always include rigorous specifications that include reliability requirements when purchasing instruments

When working with vendors, be very detailed when specifying performance and absolutely include reliability. An instrument can be delivered that meets the performance, but rapidly fails in the harsh marine environment.

2.1.11 When the number of sensors is limited, choose sensors that have the broadest measurement capabilities

If funding is limited, and all the desired sensors cannot be used, it is best practice to choose sensors that have broader, more encompassing measurement capabilities. It is, however, essential to ensure that all critical measurements are made to ensure device and personnel safety. In choosing fewer sensors than needed, there is increased risk. For example, if a failure occurs and measurements did not capture the event sufficiently to determine the cause, a definite solution may not be possible.

2.1.12 Try to avoid grounding devices to seawater for any duration other than very short term deployments

Grounding devices to seawater is not good practice for long term installations. Using the seawater ground may save money by reducing the number of conductors in a cable, but it will create an electric dipole and create an electromagnetic field (EMF). In addition, grounding to seawater accelerates corrosion or leads to increased replacement of cathodic corrosion protection anodes.

2.1.13 Burying cables may not suppress EMF noise

EMF noise may not be suppressed by burying the cable. If a cable is buried, coupling may occur with the EMF conductive layers of sediment that could increase transmission. Using DC transmission does not eliminate EMF issues due to fluctuations in the line current and coupling to the earth's magnetic field. These can create magnetic fields which may affect some sea life.

2.2 Measurement Gaps and Recommendations

2.2.1 Loading and inflow measurements are insufficient to develop loading profiles needed for blade and dynamometer testing

Blade testing facilities exist that are capable of testing all existing water current blade designs, including both horizontal and cross-flow designs, although, in some cases, custom fixtures would be needed. Dynamometer facilities exist that are capable of testing all rotating and some linear MHK drive trains, although, in some cases, some modification also would be required. If the full capabilities of these facilities are to be realized, accurate loading and inflow measurements are needed so realistic conditions can be simulated. These include the loading on different blade profiles (both axial and cross-flow designs), as well as inflow conditions, such as turbulence, velocity profiles, wave pressure forces (including wave slamming), etc.

Recommendation: Acquire detailed measurements of wave, current, and wind inflow conditions at characteristic locations for the likely deployment of MHK and offshore wind energy conversion devices. Synchronously measure the inflow, loading, and response of devices in the field under a range of conditions from calm to extreme storms. Measurement sampling rates should be determined from the MHK devices' predicted response frequencies.

2.2.2 Insufficient model and field data are available to calibrate and validate the various Computer-Aided Engineering (CAE) tools under development

Several CAE tools are being developed and some existing COTS CAE products are being adapted to support design and development of MHK and offshore wind systems. MHK and offshore wind systems are at an intermediate scale, larger than conventional buoy systems and smaller than offshore platforms. Therefore, existing models have not been validated at scales relevant to the MHK and offshore wind industries. Data are needed to validate these models.

Recommendation: Acquire comprehensive sets of measurements from laboratory experiments and field deployment that will provide baseline data to calibrate and validate the CAE tools.

2.2.3 Insufficient baseline resource, environmental, and ecological data

Long term baseline resource and site characterizations of the environment and ecosystem are needed at a site prior to deploying a device. Marine life and ecosystems have seasonal cycles, and even annual cycles, that are unknown. Prior to deploying a device, these should be well characterized to avoid speculation that the technology is affecting the ecosystem. Measurement should be statistically significant to detect changes caused by an MHK installation. Measurements need to be made at, or near, the site since environmental and ecological conditions can vary significantly over relatively short distances. This type of monitoring is often too expensive for a developer to perform at each new deployment site, especially in terms of hardware costs (see 2.4.1), deployment costs, and analysis costs (see 2.5.1).

Recommendation: The national laboratories and national marine renewable testing centers should develop a pool of instruments and instrumentation systems for resource, environmental, and ecological monitoring so device/site developers can afford, and are able to conduct, comprehensive site studies (see 2.4.1). This would reduce the uncertainty in environmental and ecological impact studies. Alternatively, if the government provided baseline environmental characterizations, it would accelerate the pace of MHK project development. Note that the cost of the instrumentation may be a small fraction of the total cost to deploy, recover, and analyze the data.

2.3 Overall Instrumentation Systems Gaps and Recommendations

2.3.1 No comprehensive instrumentation system solution exists for marine energy systems

No publicly available instrumentation system exists that meets the necessary device, environmental, and ecological measurement capabilities, with the required breadth and depth, needed to support MHK testing. This results in:

- custom instrumentation systems developed by each technology developer, often customized to each experiment, adding to project cost, timelines, and risk
- limited measurement capabilities and insufficient data sets
- difficult integration/reconfiguration of sensors and instruments, especially across technologies and resources
- reduced certainty and credibility of measurements
- difficult comparisons between technologies and project sites.

Recommendation: Develop a publicly available instrumentation system, with extensive measurement capabilities and extensible architecture that is configurable for wave and current energy measurement applications. This system would help standardize sampling approaches for inflow and performance data.

2.3.2 Wind turbine measurement technologies and procedures have not been leveraged to their full potential to support MHK and offshore wind

Within the national laboratories, many instrumentation systems, software, and measurement/calibration procedures/protocols have been developed to support laboratory and field testing of wind energy systems. These include systems for loads, environmental, structural, inflow, mechanical, electrical, health, power, and device performance monitoring. These represent significant capabilities that, if adapted to MHK and offshore wind, could help accelerate technology development, increase credibility, reduce risk, yield more comprehensive data sets, and reduce developer costs.

Recommendation: Work with the national laboratories to adapt wind turbine measurement technologies and procedures for MHK and offshore wind.

2.3.3 *Standards development is not sufficiently comprehensive*

To help develop consistent methods and measurements across the industry, the MHK and offshore wind industries need to develop standards for:

- Instrument performance
- Instrument reliability
- Instrument survivability
- Instrument/sensor mounting
- Instrument calibration
- Data processing and reporting.

Recommendation: Increase participation in IEC/ISO standards development, particularly by industry, to provide relevant input and provide sufficient manpower to develop a robust set of MHK standards. This will be an evolving process. For example, insufficient information exists on how turbulence affects tidal device performance to establish a meaningful standard that characterizes turbulence at a site.

2.4 Instruments and Sensors Gaps and Recommendations

2.4.1 *High instrument/hardware costs limit access to instrumentation*

Marine sensors and instruments are typically much more expensive, often by an order of magnitude, than land-based equivalents. This results in increased testing and development costs and fewer-than-needed instruments deployed. Because of the relatively small market and harsh operating environments, it is unlikely that instrument and sensor costs can be appreciably decreased.

Recommendation: The national laboratories, or DOE, could support of supply instruments and data acquisition systems to device and site developers in early stages of in-water testing. Additionally, many other federal agencies, e.g. NOAA and DoD, have large inventories of environmental sensors that could be leveraged.

2.4.2 *Need an approved list of sensors and instruments for application in the MHK and offshore wind industries*

The industry would benefit from a certification process that provides an "approved list" of instruments and sensors. Presently, standards, such as the IP68 highest ingress protection rating, are vague. This leaves the rating open to interpretation by manufacturers. It also has limited applicability to the marine energy industry. Instrumentation costs are high (see 2.4.1) and choosing the wrong sensors can add significant costs and time to a project. Independently-certified sensors and instruments that meet a standard for the marine energy industry would help reduce costs and development timelines while increasing certainty in the measurements. Some factors to consider include operating depth, sensor life under continuous submerged use, and characterized effects of saltwater and temperature on output.

Recommendations: Develop a set of performance and survivability standards for different classes/uses of instrumentation for MHK and offshore wind (see 2.3.3). Use these standards to develop testing protocols and perform tests at national laboratories and/or certification agencies/bodies to rate performance. Make the results publicly available.

2.4.3 Underwater acoustic monitoring capabilities in tidal flows are limited

Any ecological assessment must consider the noise generated by an MHK device and characterize the sound level and frequency relative to the ambient noise and known animal communication/detection frequencies. Instruments used to passively measure noise in the ocean work well in low-flow environments. However, as flow speed increases, the pseudo-noise received by conventional hydrophones also increases. In parallel, the ambient noise at some frequencies also increases with flow speed. Conventional hydrophone deployments may not be able to accurately differentiate between flow noise and turbine noise.

Recommendation: Develop a standardized approach to hydrophone measurement that achieves low pseudo-noise when deployed in, and exposed to, tidal currents in excess of 1 m/s.

2.4.4 Instruments are insufficient to measure inflow/outflow conditions for tidal energy resource assessment and performance/loads measurement

Inflow and downstream turbulence are major factors in the loading and fatigue on wind turbine blades. With the strong analogy between wind and water current technology, it is also assumed that turbulence will play a strong role in MHK blade design and survivability. Many of the acoustic instruments used in oceanographic turbulence measurements have the base capabilities needed to observe a wide range of length and time scales for inflow/outflow characterization. The limiting factor is that Doppler profilers have high measurement uncertainty for time scales shorter than 10 seconds. Doppler velocimeters (point measurements) require a rigid mounting to eliminate vibration and probe motion. In wind, turbulence is typically measured from met towers that provide a stable measurement platform. Instruments are positioned in the flow, across the span of the turbine blades. On large towers, the turbulence sensors often are extended forward of the tower and equipped with motion measurement to compensate for platform motion. In the ocean, using a tower that extends throughout the water column will likely not be viable and a flexible mooring would be required. (Bottom mounted profiling devices cannot capture the instantaneous motions at the resolution and accuracy needed). Sensors mounted on a mooring line will experience large motions and vibration in a tidal flow, even when using vibration mitigation schemes. Technology is needed to provide motion compensation of the measurements and to synchronize measurements from sensors distributed along a mooring.

Recommendation: Develop motion measurement hardware and motion compensation algorithms that can be embedded into existing water velocity probes. Develop mounting systems that enable placement of Doppler velocimeters on mooring lines.

2.4.5 No instruments are able to adequately measure incoming wave fields for wave energy converter resources

Wave fields are composed of a distribution of waves, with many different properties, including different wave lengths, heights, velocities, and directions. As a result, wave profiles change as they propagate. As such, to characterize the time response of a wave energy converter to incoming waves, the waves need to be measured as close to the wave energy converter (WEC) as possible. Otherwise, analysis is limited to the frequency domain. Technology is needed to measure the incoming wave field close to the WEC. Measurement of the incoming wave field is especially relevant for developing and implementing efficient power take-off control systems for WEC devices.

Recommendation: Develop measurement technology that can provide a time series of wave surface elevation and wave propagation direction at each grid point of a horizontal grid extending from a wave energy converter. This has been demonstrated in the laboratory, but these technologies need to be evaluated for field deployment.

2.4.6 No in-situ sensors to adequately monitor and measure fouling

Fouling, from biological and non-biological sources, is likely to have a significant impact on the performance of marine energy systems (both devices and monitoring equipment). Quantifying fouling would help identify its effect on performance, as well as identify when servicing is needed. However, monitoring technology is limited to video surveillance, which is, itself, subject to degradation by fouling. Methods to evaluate fouling use coupon testing, which is typically done in a laboratory and limited to just one organism colonization versus the community colonization that occurs in the field.

Recommendation: Investigate methods and develop sensors for in-water detection and measurement of biofouling on MHK devices. However, until the objectives of biofouling monitoring are established, developing sensors will not be possible.

2.4.7 No standardized methods or hardware are available to mount instruments

The way in which instruments and sensors are mounted (i.e., installed) can have a significant impact on measurement accuracy. For example, the wind industry has standards for sensor mounting on meteorological towers to ensure that the wake from the tower does not affect the measurement accuracy. Currently, there is no standard for mounting instruments on or near MHK devices. An instrument mounting standard would help ensure measurement consistency and provide guidance for proper use.

*2.4.8 Recommendation: **Develop standards that specify how instruments should be mounted (see 2.3.3).***

2.4.9 Insufficient input to instrument and sensor manufacturers/suppliers from the offshore wind and MHK community

One consistent point that was made throughout the workshop is the lack of sensors and instrumentation specifically designed for the MHK and offshore wind industries. Therefore, manufacturers need a detailed and consistent set of requirements from industry to address these hardware and performance deficiencies. With industry consensus, manufacturers could comfortably develop the needed solutions.

Recommendation: Develop standards for MHK and offshore wind instrumentation (see 2.3.3) and make these available to instrumentation manufacturers. Better collaboration and communication between the MHK industry and oceanographic instrument developers may be the best way to balance MHK industry desires and instrument development constraints.

2.4.10 Fiber-optic structural and motion sensor performance in salt water and the effects of static and dynamic pressure are not well characterized and understood

Fiber-optic sensors hold great promise in underwater structural, load, and response monitoring. They offer a solution to the use of foil-type strain gauges, which are highly susceptible to rapid corrosion and electrical shorting in sea water. Fiber-optic sensors also can be connected in series, requiring less cabling. Because they use fibers, not electrical lines, they are not subject to electro-mechanical (EM) noise and the sensors can be located relatively distant from the supporting instrumentation. However, the outputs from fiber-optic sensors are affected by hydrostatic and dynamic pressure. These pressures may have a significant impact on measurements. Also, the long term sensor reliability when exposed to sea water is unknown. The cost of fiber-optic systems is several times higher than comparably sensitive mechanical strain gauges.

Recommendation: Characterize the response of fiber-optic structural and motion sensors to pressure and develop correction tables and algorithms, if they are able to be used for underwater measurement. Characterize sensor degradation in sea-water.

2.4.11 Cavitation is an important design consideration, but is difficult to detect and monitor in the field

Cavitation occurs when the static water pressure drops below the local vapor pressure of water. If cavitation occurs over surfaces of MHK devices, it can negatively affect device performance and cause erosion of blade surfaces. Water current turbine blades are particularly susceptible to cavitation and appropriate calculations should be performed to ensure that cavitation does not occur. Nevertheless, in some cases, small amounts of blade tip cavitation cannot be avoided. Cavitation has been extensively studied by the designers of marine propellers and lessons learned from this industry should be leveraged by the MHK industry.

Recommendation: Design the system to avoid cavitation. If that is not possible, then leverage existing techniques used in labs, and by the Navy, to develop a system for use with current turbine technology. Two possible methods (among many) for detecting cavitation are video inspection and acoustic monitoring.

2.5 Data Processing Gaps and Recommendations

2.5.1 Processing of acoustic data from underwater animal monitoring sensors is costly and time-intensive

Many active acoustic sonar systems used for underwater monitoring of fish, mammals, birds, and turtles produce massive amounts of data. Presently, people sift through the data to detect and identify targets. They analyze for species target types, numbers, and tracks. This is very time consuming and expensive. In addition, it is easy to miss detections because of the quantity of information that must be analyzed. The development of computer-aided detection and classification algorithms would help reduce the time and cost of analysis and possibly increase accuracy. For example, if a real time detection algorithm were available, data would need to be stored and analyzed only where a positive detection occurred.

Recommendation: Develop computer-aided detection and classification algorithms to post-process the voluminous data gathered from acoustic monitoring and reduce the volume of information requiring manual review.

2.6 Feedback from Audience - Potential Roles for Government RDT&E

The audience was asked what role the government can play in research, development, testing, and evaluation in the MHK and offshore wind industries. Based on the conversation, the following list of potential roles, in no particular order, was identified:

- Perform site and resource characterization to provide site specific data for the permitting process
- Develop a standardized instrumentation system and measurement protocols
- Develop a pool of approved instrumentation and sensors to support resource assessment, characterization, and field testing
- Develop specific instrumentation standards
- Provide third party testing of COTS sensors and report on accuracy, reliability, and applicability
- Develop loading and inflow models based on field measurements
- Develop data processing algorithms for detection and classification of marine animals (fish, mammals, birds, and turtles)
- Assist device and site developers through permitting and other regulatory processes by providing hardware, software, data and data acquisition system designs.
- Develop loading and inflow models based on field measurements
- Develop a list of materials' performance in salt water.

3 Appendix A: Agenda

Day 1		
8:00	8:10	**Welcome and Logistics**
8:10	8:30	**Workshop Overview and Framing** – Description of the motivation and goals of the meeting. Walt Musial and Rick Driscoll (NREL)
8:30	9:45	**Session 1: Lessons learned from in-water Deployment and Operation** **David Simms** (NREL), NREL Overview of NREL Wind Testing Capabilities **Nate Sinclair** (NAVFAC), Navy Projects, lessons learned **Matthew Reed** (Marine Current Turbines), SeaGen Project
9:45	10:00	Break
10:00	11:20	**Session 2: Lessons learned from in-water Deployment and Operation** (**continued**) **Ryan Beaumont** (ORPC), A Review of Sensors Used With the ORPC Turbine **Questions and Discussion** (10:50 – 11:20)
11:20	12:00	**Session 3: Structural loads and Response** **Jon White** (Sandia National Labs), DOE/SNL Distributed Time-Synchronized Inflow and Structural Measurement Technologies **Scott Hughes** (NREL) Overview of Blade Testing
12:00	1:30	LUNCH including the presentation "The Important Role, Proper Use and Challenges of Instrumentation System in Offshore Monitoring" **Tasneem Abbasi (Technip)** Monitoring of Offshore Assets
1:30	3:30	**Session 4: Structural loads and Response (continued)** **Jim O'Sullivan** (Technip), Offshore Wind Platform Design Model Calibration **Nate Sinclair** (NAVFAC), Structural Loads & Response - Buoy Moorings **Robb Wallen** (NREL), EtherCAT Based Distributed Data Acquisition **Tom Graver** (Micron Optics), Verifying MHK Loads and Performance Using Fiber Optic Sensors **Questions and Discussion** (2:30 – 3:30)
3:30	3:45	**Break**
3:45	5:30	**Session 5: Device Electrical Power, Performance, and Condition Monitoring** **Jeremy Sheldon** (Impact Technologies), Key Technologies and Lessons Learned in WT Monitoring Applications **Ismael Mendoza** (NREL), NREL Wind Turbine Testing **Ean Amon** (Oregon State University), Power Analysis and Data Acquisition Systems for MHK Device Testing **Joseph Williams** (Sandia National Labs), Power Quality and Power Quality Monitoring **Questions and Discussion** (5:05 – 5:30)

Day 2		
8:00	8:10	**Welcome Back and Logistics**. Walt Musial and Rick Driscoll (NREL)
8:10	10:30	**Session 6: Sensors, Instruments, and Platforms** **Martin Wosnik** (University of New Hampshire), Cavitation on Turbine Blades: Detection, Observation, Measurement, and Mitigation **Pierre Beaujean** (Florida Atlantic University), Underwater Acoustic Communications – Technology and Challenges **Bill Straka** (Penn State University), Cavitation **Adam Schultz** (Oregon State University), Monitoring the electromagnetic Emission and Sensitivity of fish, cetaceans, and pinnipeds **Bernadette Hernandez-Sanchez** (Sandia National Labs), Biofouling Monitoring for MHK Technology **Questions and Discussion:** (9:50 – 10:30)
10:30	10:45	Break
10:45	12:15	**Session 7: Environmental Inflow Monitoring** **Arnie Fontaine** (Penn State University), Turbulence Measurements of Tidal and River Flows: MHK Turbine Applications **Andrew Clifton** (NREL), Resource Characterization **Mark Ivey** (Sandia National Lab), ARM Climate Research Facilities on the North Slope of Alaska – Barrow, Atqasuk, and Oliktok **Questions and Discussion:** (11:45 – 12:15)
12:15	1:30	LUNCH
1:30	3:10	**Session 8: State-of-the-Art Integrated Monitoring Systems** **Paul Fleming (NREL),** Advanced Controls Research at NWTC **Jonathan Colby (Verdant),** State-of-the-Art Integrated Monitoring Systems: RITE Project Case Study **Greg Willden (Southwest Research Institute),** Sensors and Sensor Networks in Harsh Environments: Lessons Learned **Patrick McEnaney (NOAA),** Characterizing the Resource Baseline: Marine Instrumentation Usage in Renewable Energy Infrastructure
3:10	3:30	Break
3:30	5:00	**Open Discussion** Device monitoring instrumentation needs and gaps Role of measurement standards in defining instrumentation requirements
5:00	5:30	Day 2 Closeout Discussions

Day 3		
8:30	8:40	**Welcome Back and Logistics**
8:40	10:10	**Session 9: Ecological and Environmental Monitoring** **Richard Jepsen** (Sandia National Laboratories), Sediment and Water Quality Measurements **Tom Carlson** (Pacific Northwest National Lab), Passive and active acoustic systems for detection, classification, and localization of resident killer whales in Puget Sound's Admiralty Inlet **Jason Wood** (SMRU Ltd), Telemetry and acoustic techniques for monitoring marine mammals **Tom Fedenczuk** (University of Hawaii), Instrumentation for passive acoustic monitoring of marine mammals **Sidney Gauthreaux** (Geo-Marine Inc.), Radar Studies of bird movements in the offshore environment
10:10	10:30	Break
10:30	12:30	**Session 10: Ecological and Environmental Monitoring (continued)** **Brian Polagye** (University of Washington), Passive acoustic monitoring for tidal energy projects **Mike Slater** (SAIC), Ecological and Environmental Monitoring - Tracking and measuring effects of submarine electromagnetic fields (EMF) **Sarah Henkel** (Oregon State University), Surveying Benthic Habitats and Biological Communities in Areas Targeted for Offshore Wave Energy Development **Questions and Discussion:** (11:30 – 12:30)
12:30	1:30	Lunch
1:30	3:00	Tour of National Wind Technology Center – if you intend to attend this tour, please inform Arielle Wolfe because we will need to get you a site pass.

4 Appendix B: List of Attendees

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5 Appendix B: Response to Follow-up Survey

A survey was distributed to workshop attendees after the workshop to collect information on how to refine the next workshop. A total of 25 responses were received.

Question 1: Please rate the overall quality of the workshop.

Excellent:	60 %
Good:	40 %
Fair:	0 %
Poor:	0 %

Question 2: The workshop was informative and the content was relevant.

Strongly Agree	47.8 %
Agree	47.8 %
Somewhat Agree	0 %
Disagree	0 %

Question 3: The workshop achieved the following goals:

- Share the latest relevant knowledge among technical experts
- Review relevant state-of-the-art field measurement technologies and methods
- Review lessons learned from recent field deployments
- Investigate synergies across different industries
- Identify gaps between existing and needed instrumentation capabilities
- Understand who are the leading experts, and
- Provide substantive input in the development of new field deployable instrumentation packages capable of making the necessary measurements to promote technology advancement.

Strongly Agree	52.%
Agree	36 %
Somewhat Agree	0 %
Disagree	0 %

Question 4: What goals were not achieved and how could they be better achieved?

This was an excellent first workshop on the subject, and the stage is set for future workshops. People on both coasts are actively involved in the planning of test platforms/turbines and/or the actual testing of hydrokinetic turbines (University of Washington, University of New Hampshire, Florida Atlantic University), so there should be plenty to discuss at future workshops.

Discussion of how to turn the knowledge into action within the industry, including interaction with the relevant devices and deployment areas, resulted in an understanding that most results must be publicly shared.

I think a (sic) generation of a guide of best practices derived from collective experience would be useful. Also, it seems that an industry driven list of measurement requirements is needed to let people know when measurements are good enough.

Develop a roadmap for the path forward. Identify a plan, timeline, and budget sources.

I think that lessons learned from field deployments was weak; however, this is probably the most difficult to get people to commit to. (sic) Also, when dealing with state of the art measurement techniques a lot of the focus was academic, which is good but more current industrial presence would be good.

[Conduct] further discussions of the data and accuracy requirements so that data can feed into device design. Some of the presentations did not seem to 'match' the description in the agenda.

[There are] some possible mismatch[es] between [the]cost structure for marine energy installations and instrumentation used for terrestrial wind and for oil and gas.

Not all of the experts were in attendance and I would have enjoyed a breakout session focusing on actually measuring inflow/outflow around MHK turbines.

[There was a] lack of discussion of new field deployable instrument packages.

Question 5: What topics should be included if another marine energy workshop was held next year? Please prioritize the topics?

Hydrodynamics of hydrofoil (incl. under conditions of fouling, cavitation, corrosion). Flow around structures. Performance of turbines under effects of waves or turbulence.

The topics were very good. I'd really like to see the national labs and test centers report results of using their knowledge and equipment to evaluate as many devices and deployment sites as possible.

More on monitoring environmental/ecological effects, as this is likely to be a driver in what types of devices will be allowed.

Something on modeling, it seems like everything is modeled (whether it is needed or not)1)Review progress made since first workshop, particularly in area of instrumentation development and deployment strategies for proper use. 2) Since environmental impact and permitting appears to be a dominant driver in getting devices in the water, what are the right measurements that need to be made and how to do it? 3) How can the field test process be optimized to improve efficiency and cost? 4) A session on device use with hands-on examples illustrating proper (and improper) use and processing - may be hands on if time permits

We are definitely moving into an area where more site characterization and environmental assessment is required; so that should be emphasized a bit more.limitations with current equipment

Performance requirements for a MHK instrumentation package.

More constructive organization of what the development community may need from the resource management and observation community, ie., how NREL can use data from NOAA, Sandia, and other national labs? Each organization is subject to considerable challenges w.r.t. funding availability in the current political/economic climate. Communicating shared priorities to the White House, Congress, DoC, DoE, etc., can assist with securing support for mutual benefit if there is comprehensive understanding of where the shared data priorities are.

Discussion of how to work with, and process data collected by, instrumentation to address key uncertainties - tie the data back to the problem.

Applying COTS technology to satisfy the needs of the Renewables community would be interesting.

Question 6: What topics should not be included?

A couple of the vendor and vendor-related presentations were a little too self-serving from a marketing standpoint (i.e., companies trying to develop a product they'd ideally like to make the case is required on every MHK installation - this is a red flag to developers because it is all adds to the cost of energy). On the flip side, I do want to hear about the latest technologies; just not hear the message that I need it from a regulatory standpoint. I'd rather them make the business case for its value.

How to know when your measurements are good enough (perfection is not required).

All of the covered areas where (sic) relevant and should remain.

I felt there was too much "land based" talks.

Question 7: Please rate the balance between presentation and discussion.

Excellent: 48 %

Good: 44 %

Fair: 8 %

Poor: 0 %

Question 8: Please comment on any changes you would recommend for the workshop format and schedule.

Include "focus groups," where people with first-hand experience can discuss issues.

Actually, the format and schedule worked really well. Timing was good.

Overall the schedule was good. Just want to be sure the presentations will be made available. Also, I'd have fewer presenters and longer discussions.

Larger audience - should have been done in cooperation of other conference/venue. Size of workshop limited discussions.

Maybe 25% fewer presentations, but allow for longer presentations and Q&A.

See above with incorporating a session (hands on) illustrating sensor/instrument operation.

Question 9: If the workshop were to be held next year, what would be a good location?

Colorado works. Or alternating North East/North West - based on where most people who are working on this are located.

Somewhere coastal where we could see an MHK device in the water.

Same location.

Same.

I thought the current location was great!

DC or anywhere a substantial lab/test facility tour can be conducted (Sandia, ORNL, NNMREC, FAU).

Where ever (sic) it is at. It should be better advertised. There was no public announcement of this workshop. I bet there may have been more interest but relevant companies/organization if it was. (sic)

A location where a field trip can be undertaken to see a device deployed.

The UK so I don’t have to travel (EMEC?).

Timberline Lodge, OR or Skamania Lodge, WA

It would be good to have another instrumentation workshop.

Site with an operating MHK device.

NREL is in CO, which is always great to visit, especially since I have a handful of good friends and family in Boulder and Denver. It might be good to hold it in other places that have strong renewable energy presence.

Boulder is fine.

I actually enjoyed Colorado. It's central for most people to get to (sic). If you need to move it...possibly the Pacific Northwest?! Maybe have a different lab host it every year.

NREL or the same location.

Local to NREL seems to be a good location - central and well connected.

Question 10: Based on the discussion at the workshop and from your experience, please list the instrumentation gaps that the national laboratories and DOE can focus on to help advance the marine energy industry.

Instrumentation development for accurate prediction of turbulence in tidal, river and ocean currents, thus enabling “calibrated” energy extraction device development and evaluation (sic). Both performance and loading of turbines are directly related to the highly variable hydrodynamic conditions encountered in turbulent flows. An integrated laboratory and open water test site study to develop “calibrated” instrumentation for tidal, ocean, and river currents would be desirable. Of particular interest is turbulence at the “blade scale,” which are eddies of sizes down to, say, one quarter of the chord length of the turbine blades.

Environmental monitoring. Both measuring the resource (esp. wave) and measuring environmental/ecological parameters as affected by devices in an economical way.

floating offshore wind

Standardized performance measurement techniques and packages (velocity and area in, mechanical and/or electrical power out, loss breakdown). 2. Standardized methods to correlate off-ideal cubic curve data. 3. Standardized results for EMF emissions from AC and DC cables. 4. Standardized results for EMF interaction with navigation and communication equipment (don't believe there is any, but developers are being asked to do repetitive useless work in this area that the DOE could put to rest). 5. Results for AC and DC EMF interactions with an expanding database of biota. 6. Standards on where and why acoustic and EMF field measurements SHOULD (not could) be made both for baseline environments and with MHK equipment.

All areas since this is a new area. But the key will be to stress the "minimum/cost effective approach" that is needed. DOE/National labs tend to over instrument.

Cheaper, more reliable sensors that are more intuitive to use and analyze. (sic)

Field test measurements are very challenging. While new instrumentation capabilities may come forward, the proper use of current state of the art instruments and understanding of limitations could be very important. Often, novice to inexperienced instrument users will be deploying the devices in the field. The quality of the data obtained can be strongly dependent on the experience of the user.

Support of partnerships to develop environmental monitoring capabilities.

appropriate data to feed into device design

Sensors for fish behavior and mammal detection.

Integrated inflow measurement devices that satisfy the requirements of the Marine Energy Community. These can range from COTS ADV's, ADCP's, Wave buoys, subsurface systems, etc.

Comparison of turbulence measured by ADCP against that seen / felt by MHK devices

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