A Review of the Environmental Impacts for Marine and Hydrokinetic Projects to Inform Regulatory Permitting:

Summary Findings from the 2015 Workshop on Marine and Hydrokinetic Technologies, Washington, D.C.

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Preface

Marine and hydrokinetic (MHK) power generation is an energy source with great potential to provide a portion of the nation's ongoing energy needs. However, this technology is currently in its infancy from a deployment standpoint and introduces new challenges to regulators, from early-stage prototype testing through initial commercial deployments. Given the early stage of MHK development, many federal, state, and local regulators responsible for permitting these projects (as well as other stakeholders such as industry/developers, the fishing community, and environmental groups) are not as familiar with the technologies and their potential environmental impacts as they are with existing offshore structures or onshore energy. To allow appropriate technical development, in-water testing is currently being conducted for single devices and small arrays at test centers or early development sites. Eventually the technology will evolve into larger, commercial-scale arrays of MHK devices. The applicability of the science and technical information gathered at small-scale installations to larger commercial installations is uncertain, but technologies will evolve and environmental impacts will be better understood through single device and test centers/small-scale arrays experience before fully commercial, cost-competitive devices are available.

To help address the knowledge and experience gap and increase the number of early MHK device deployments, beginning in FY14, the U.S. Department of Energy (DOE) funded efforts to develop and implement technology- and application-focused workshops on MHK systems. The workshops engaged resource managers and other decision makers at key regulatory organizations, providing a review of current research and facilitating discussions with leading national and international experts on environmental topics such as possible and observed physical interactions with MHK devices, environmental effects on marine ecosystems, ongoing and needed research, and identifying ways to apply lessons learned from other renewable energy industries into the regulation of MHK systems. The workshops also allowed participants to discuss evolving "best practice" approaches to measurement and monitoring, as well as the application of risk-based approaches for baseline characterization and monitoring. Workshops in the Pacific Northwest and Washington, D.C., were hosted in late FY14 and mid-FY15, and efforts to summarize the discussions and knowledge gained were finalized in FY16. This document summarizes the workshop held in Washington, D.C.

Acknowledgments

The authors wish to thank the U.S. DOE Wind and Water Power Technologies Office for funding the successful MHK Regulator Workshop series and this report. Thanks to Jocelyn Brown-Saracino, Samantha Eaves, and Hoyt Battey for their leadership, assistance in developing this document, and general support of this project.

Thank you to the technical experts who made this work possible, taking time out of their busy professional lives to take part in the workshop and then support the development of this document:

- Chris Bassett, Woods Hole Oceanographic Institute
- Brian Polagye, University of Washington
- Jocelyn Brown-Saracino, U.S. DOE
- Andrew Gill, Cranfield University
- Craig Jones, Integral Consulting
- Jesse Roberts, Sandia National Laboratories.

Thanks to Anna West, Kearns & West, and Sharon Kramer, H. T. Harvey & Associates, for facilitating components of the workshop.

The authors would also like to thank the participants and speakers who directly contributed to the workshop, including the following: Mary Ann Adonizio, Verdant Power; Hoyt Battey, U.S. DOE**;** Jim Beyer, Maine Department of Environmental Protection; Stephen Bowler, Federal Energy Regulatory Commission; Joshua Gange, National Oceanic and Atmospheric Administration; Nate Johnson, Ocean Renewable Power Company; Al LiVecchi, National Renewable Energy Laboratory; Jeff Murphy, National Oceanic and Atmospheric Administration; Brian Polagye, University of Washington; Casey Reeves, Bureau of Ocean Energy Management; Ron Smith, Verdant Power; and Ryan Sun Chee Fore, formerly of the U.S. DOE.

Many others contributed their experiences and ideas through interviews conducted prior to the workshop, including Cameron Fischer, 48 North Solutions; William Staby, Resolute Marine Energy; Jason Bush, Oregon Wave Energy Trust; Simon Geerlofs, Pacific Northwest National Laboratories; Justin Klure, Pacific Energy Ventures; Rahul Shendure, Oscilla Power; Michael Morrow, M3 Wave; Cherise Gaffney, Stoel Rives; Julia Wood, Van Ness Feldman; and Alexandra DeVissier, U.S. Navy.

Lastly, we would like to thank all of the workshop participants whose thoughtful discussions made this report possible.

List of Abbreviations and Acronyms

AC	alternating current
CEC	current energy converter
dB	decibel
DC	direct current
DOE	U.S. Department of Energy
EMF	electromagnetic field
Hz	Hertz
IEA	International Energy Agency
kW	kilowatts
mT	milli Teslas
MHK	marine and hydrokinetic or marine hydrokinetic
NMREC	National Marine Renewable Energy Centers
NREL	National Renewable Energy Laboratory
OES	Ocean Energy Systems
ORPC	Ocean Renewable Power Company
R&D	research and development
RD&D	research, development, and deployment
SNMREC	Southeast National Marine Renewable Energy Center
TWh	terawatt-hours
VAC	Volts, alternating current
VDC	Volts, direct current
WEC	wave energy converter

Executive Summary

Marine and hydrokinetic (MHK) technologies generate energy from predictable currents, tides, ocean thermal resources, and waves. With more than 50% of the American population living within 50 miles of the coast, a cost-effective MHK industry could provide a substantial amount of electricity for the nation. The U.S. Department of Energy's (DOE's) Water Power Program is committed to developing and deploying innovative, water-based energy generation technologies.

However, the nascent MHK industry faces challenges. The technology is in an early stage of development, and there are few devices in the water; therefore, project impacts on the environment are unknown. In addition, given that the MHK industry is global, those involved in a specific project may not be familiar with experience and insight gathered elsewhere. A "catch 22" exists in that there are uncertainties with these new, emerging technologies, and yet it is necessary to have projects in the water to be able to learn about potential project effects and the appropriate actions to minimize, avoid, or mitigate for them. Furthermore, the scientific information is still evolving as early projects, baseline and site characterization efforts, laboratory studies, modeling efforts, and studies conducted on similar structures in the marine environment contribute to the existing global knowledge base.

Only small array or one-device installations and test centers are currently proposed or being implemented, and these facilities may not be able to support extensive characterization and monitoring given their scale. If the required technology and project cost reductions can be achieved, however, small-scale and eventually commercial development of MHK device arrays would be expected. The MHK community, including regulatory agencies, is gaining experience and information on the potential impacts and risks with these early deployments. This is contributing to the fundamental understanding of the appropriate level of ongoing monitoring required for single devices or small arrays versus the appropriate level for full-scale commercial deployments.

In 2014 and 2015, DOE initiated efforts to develop and implement technology- and application-focused MHK workshops to share the global experience and knowledge base on evolving MHK technologies, observed and not-observed impacts, monitoring and measurement methods, and regulatory needs. The resulting MHK Regulator Workshops engaged resource managers and other decision makers at key regulatory organizations, scientists, researchers, facilitators, and technical experts and provided an opportunity to examine the risks of single-device and small-scale deployments, explore what can be learned and observed from single devices and small-scale arrays, and consider requirements for projects at varying scales of deployment. Experts and stakeholders identified key remaining information gaps. Initial discussions focused on differentiating between monitoring required for single or small-scale deployments and MHK impact research that, although important, goes beyond what is feasible or should be needed to meet specific project regulatory requirements but is appropriate for broader research and development.

Four areas of identified potential environmental impacts provided the focus for the workshop:

- Acoustic output impacts
- Electromagnetic field (EMF) emissions

- Physical interactions
- Environmental effects of MHK energy development on the physical environment.

Discussions also focused on the regulatory process and experience, adaptive management, industry drivers, and lessons that can be learned from the wind energy industry. The discussion was set in the context of the types of MHK technologies that are currently proposed or planned in the United States. All presentations and the following discussions are summarized in this document, and the presentations are provided in the Tethys Knowledge Base.[1]

Key Findings from General Discussion

Discussions were largely framed around what we understand regarding risk level based on data collected to date, what knowledge gaps remain, and whether these gaps are likely to represent significant enough risk to require monitoring on a project-by-project basis for single- or small-scale arrays or are questions that should be addressed through broader research efforts.

The outcome of the workshop discussions bifurcated ongoing information-gathering into two general categories around the deployment of single or small-scale projects, required monitoring, and monitoring for research purposes.

- **Monitoring appropriate to smaller-scale projects:** Conduct studies, monitor, and collect avoid/minimize/mitigate strategies that are appropriate for smaller-scale or temporary projects (e.g., one to 10 devices) where some potential impacts can be detected and addressed. Monitoring or modeling of acoustics, physical strike potential, and physical environmental impacts should be conducted if the project is to be located in a sensitive location or there is a high probability of interaction with a species of concern. Monitoring and modeling should provide information to estimate the level or risk and inform the need for an adaptive management strategy.

- **General research/studies and monitoring to improve the understanding of the potential impacts of larger-scale projects:** Based on what is known to date, some environmental impacts that may occur at larger-scale projects are not likely to occur at single devices or smaller arrays. Strategic research could be conducted opportunistically around small-scale projects or in other research endeavors to augment the state of understanding and help clarify the level of risk for larger-scale projects.

The resulting discussion of the four areas addressed as part of the workshop is summarized in Table ES-1.

It should be noted that there is potentially much to be gained from conducting research and obtaining data from small-scale deployments that may assist in addressing future questions around larger-scale deployments. However, one of the main outcomes of the discussion was the general consensus that the collection of this information should not be required of a small-scale project as it does not pertain to the actual or potential impacts of these projects.

[1] http://tethys.pnnl.gov. Tethys is a DOE-funded database of MHK-related, environmental documents that is hosted by Pacific Northwest National Laboratory.

Table ES-1: Recommendations for Monitoring and Research from the Workshop Presentations and Discussions

	Monitoring for Single Devices/Demonstration-Scale Projects	Research for Single-Device/Demonstration-Scale or Commercial-Scale Projects
Operational Noise	Information collected to date indicates that operational devices are typically less noisy than other anthropogenic sources. Monitoring is generally not warranted as significant acoustic impacts are unlikely and difficult to distinguish from background noise.	Data collection at demonstration scales may be appropriate, if detectable, to inform modeling for larger-scale arrays. Research on biological and behavioral implications of sound and particle motion would be helpful.
Electromagnetic Fields	No significant effects to organisms have been observed to date. Monitoring is generally not warranted since EMFs are likely to be low intensity and approach background levels within a few meters from the source.	EMF emissions are relatively scalable as power and voltages increase but the responses of any receptive animals are not; thus research on single devices or small-scale arrays may not be directly transferable to larger-scale projects. Existing energy subsea cables can be utilized to assess EMF levels and animal behavioral responses.
Physical Interactions (Strike)	No physical interactions have been observed in the field. Lab experiments have found that fish can easily detect and avoid or swim around turbines and have very high survival rates when forced to pass through turbines. Any required monitoring should be based on risk posed at the project of interest and should consider that strike events are likely to be rare, difficult to detect, and very costly to monitor.	Research to better understand the risk of strike and development of predictive models (e.g., location in the water column relative to the device, avoidance and evasion behaviors) and identification of potential mitigation actions would be helpful.
Impacts on Physical Systems	Numerical modeling consistently predicts that arrays <10 devices will have minimal impact on wave heights, flow patterns, and sediment transport. Monitoring is generally not warranted as impacts from a single device or small arrays will likely be minimal.	Impacts of larger arrays are unknown and will require more research. Data from eventual large arrays are needed to validate predictive models.
For the purposes of the workshop and this table, "monitoring" was defined as activities required of the developer by federal, state, or local entities to assess project impacts during operations and to fulfill legal regulatory obligations. The level of monitoring should be based on the level of assessed risk/potential project impact posed by the project in question and should be directed to address specific objectives. "Research" is performed to fill gaps in understanding and answer questions beyond those required to meet fundamental legal or regulatory mandates. Research is typically performed by academia or government agencies.		

The group also discussed the potential of setting thresholds or acceptable ranges of potential effects for certain environmental topics to help better define more uniform assessment needs across single-device or small-scale array projects, although the authors are not sure how viable or useful such a process might be. The level or range of thresholds was not discussed, and based on the level of uncertainty regarding the potential impacts and importance of location-specific information, it is unclear if generally applied ranges could be identified or be applicable.

As explained in further detail in the following sections, workshop participants reflected on the type of information available from small projects; given the likelihood of actual small-scale project impacts compared to the insight gained for the industry and future implications for larger-scale projects, workshop participants generally agreed that with the exception of site-specific concerns or the potential impacts on species of concern known to frequent areas considered for development, the remaining questions resulting from the deployment of small-scale projects are more appropriately research focused. This suggests that one should consider the nature and scale of a project and what is appropriate if there is little direct value relating to the project of concern from active measurement/monitoring programs. In locations where measurement or monitoring needs to take place, adaptive management should be employed so that measurement efforts better match the need and potential impact.

The group discussed the utility of an umbrella collaborative effort or organization such as Ocean Energy Systems (OES) Annex IV to serve as a central clearinghouse for the MHK industry to address research and monitoring needs globally. The collaboration among agencies, scientists, industry, environmental groups, and others can set the stage to address potential effects for MHK projects by researching technology innovations, providing science to support policy and regulatory decision-making, and enabling an information exchange to build shared knowledge and decrease uncertainties and perceived or real risks.

Findings of Technical Discussions

Experts provided technical presentations in the four primary areas of acoustic output, EMF emissions, physical interactions between aquatic animals and devices, and how the devices may impact the physical environment.

Acoustic Output Impacts

The following provides an overview of the key findings on acoustic output impacts with a focus on small-scale MHK projects:

- Small-scale projects are unlikely to result in physiological damage to most species since decibel (dB) levels are lower than those that can cause harm.

- Small-scale projects may produce sound at levels that result in behavioral impacts (i.e., species may avoid the device based on sounds they hear), but researchers to date have not gathered sufficient information to make a determination.

- For small-scale projects, it is difficult to differentiate the project-emitted acoustics from ambient noise in the area; therefore, required monitoring of acoustic output impacts may not be appropriate, especially where anthropogenic or natural background sound is likely.

- The biological implications of sound are highly uncertain and are driven by taxonomic differences; with biological relevance for certain groups being better understood than others. Potential biological response and behavioral context for sound emissions are unknown and will depend greatly on the expected receptor taxonomy.

- It is worth noting that it is unknown how the acoustic output and propagation will scale to larger arrays, which was one of the research-level questions identified during the discussions.

Electromagnetic Field Emissions

Research conducted to date on the EMF impacts for high-voltage subsea electrical transmission cables found the following:

- Electrosensitive species can detect EMF emissions from subsea cables with likely higher sensitivity to direct current (DC) (0 Hertz, or Hz) than alternating current (AC) (60 Hz) cables because of the lower transmission frequency. Magnetosensitive species are likely to be able to detect EMFs from DC cables (and potentially AC cables, but to a lesser degree as the magnetic fields emissions are lower for AC cables).

- Behavioral responses, such as attraction to EMFs from subsea electric transmission cables, have been demonstrated through field and lab studies, but extrapolation to impacts of marine renewable energy power cables on critical behaviors of sensitive species or their populations would be speculative, especially for the very low power levels typically found in single-unit or small-array deployments.

- Since the main source of EMF emissions is the transmission cable, benthic and demersal species (which are closer to the source) could be exposed to higher field strengths than pelagic species.

- It should be noted that the difference between the existing research on EMF emissions impacts (e.g., 33,000 volts, alternating current (VAC) and 200,000 volts, direct current (VDC)) and the size of the MHK deployments currently seeking U.S. permitting (480 VAC) is orders of magnitude in difference. Although there are no identified studies on the impacts of EMFs, when considering low-voltage electrical cables, the impacts of small-scale MHK deployments on biota are considered to be inconsequential as any emission will be at very low levels within a very short distance (e.g., less than a couple of meters).

Physical Interactions

Findings based on studies to date on the potential direct and indirect physical effects of MHK devices (apart from issues surrounding entanglement,[2] reefing,[3] and benthic habitat changes,[4] which were not discussed) reveal the following:

[2] Marine mammals can become entangled in equipment mooring or electrical lines.
[3] Reefing is the ability of the MHK device structure to attract various marine life forms and become a habitat.

- There are no observations to date of strike injury (referred to as a collision in European literature) or mortality in the field from tidal or current turbines, but limitations on monitoring are noted.

- There is growing consensus among members of the scientific community that strike events for tidal turbines are likely to be rare, especially if focused on specific species of interest.

- Given the current limited data and limited likelihood of obtaining actual observations of interactions with devices in open-water settings, research to better understand avoidance rates coupled with predictive modeling may be the optimal course of action.

- The limited studies using electronically tagged species (typically mammals and in some cases fish) demonstrate changes in use patterns to avoid turbines; however, whether this is the case with other untested species or whether acclimation will occur is not yet known.

Environmental Effects of MHK Energy Development on the Physical Environment

Discussions around the potential indirect physical impacts of MHK devices within the ocean system, such as sediment transport, resulted in the following general findings:

- Modeling can be used to predict the potential changes to waves and/or water circulation caused by arrays of wave, tidal, and current devices in coastal regions and rivers.

- Numerical evaluations show that small arrays (~10) of current or wave energy devices have minimal effect on the physical environment and effects may become undetectable as array size decreases. However, site-specific conditions and technology will drive the potential impact.

- As array size increases, effects will likely increase and require further study.

- Devices in coastal near-shore locations may potentially be used to enhance coastal sediment management programs.

- Small arrays of current energy devices will likely have localized effects on potential benthic habitat and the water column, with minimal effects the farther one gets from the device.

- Deploying small offshore arrays (~10) of wave energy devices will have minimal near-field effects on sediment dynamics and circulation and minimal potential for affecting far-field transport patterns of sediment, flow, and wave dynamics. The installation of single units for defined short time periods will again likely have limited, if any, long-term impacts.

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[4] Benthic habitat is the ecological zone at the ocean floor that can be disturbed by the installation and presence of electrical cables, mooring lines, and other ground-mounted project equipment.

- Initial evaluation suggests that for small-scale arrays of MHK devices likely to have measureable physical impacts, adaptive management strategies that include up-front analysis then appropriate monitoring requirements with clear thresholds (as possible) leading to flexible management is likely the most appropriate path to consider.

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1 Introduction

The nascent marine and hydrokinetic (MHK) industry faces challenges. Although efforts are underway across the globe to gather and share information on MHK experience, many regulatory agency staff with permitting responsibilities and other stakeholders may not yet be familiar with all aspects of the technology and their potential for environmental effects. Furthermore, the scientific information on environmental impacts is still evolving as early projects, baseline efforts, laboratory studies, modeling efforts, and studies conducted on similar structures in the marine environment contribute to the existing knowledge base.

In 2014 and 2015, DOE funded technology and application-focused workshops on ocean energy systems to help address the knowledge and experience gaps and increase the number of deployments of single and small-scale MHK arrays. The resulting MHK Regulator Workshops implemented by the National Renewable Energy Laboratory (NREL) engaged resource managers and other decision makers at key regulatory organizations, providing a review of global experience with deployed MHK devices. Scientists, researchers, facilitators, and technical experts shared science and research about the environmental effects of MHK technology. The workshops also provided information about the technical aspects of this technology and potential impacts from future projects. They provided an opportunity for regulators and stakeholders to examine the risks of single-device and small-scale deployments, explore what can be learned and observed from single devices, and consider requirements for projects at varying scales of deployment. Experts and stakeholders identified remaining information gaps that can inform future research and, if addressed, could improve regulatory approaches and address the most important issues given the current level of technology development. Initial discussions focused on possible paths forward to fill the information gaps, as well as whether the responsibility for meeting those needs lies with the research community, regulating agencies, or industry.

This report provides a summary of the Washington, D.C., workshop held May 5-6, 2015, capturing the findings and study results shared and discussions among participants. An annotated workshop agenda can be found in Appendix A, and Appendix D lists the organizations represented at the workshop. All presentations and the following discussions are summarized in this document, and the full presentations are provided in the Tethys Knowledge Base.[5]

During the MHK Regulator Workshops, participants discussed:

- Observed and theorized impacts from MHK devices
- Evolving "best practices" for measurement and monitoring of key potential impacts
- Effective implementation of adaptive management practices and other "risk-based" approaches as part of the regulatory process for new MHK installations.

[5] http://tethys.pnnl.gov. Tethys is a DOE-funded database of MHK-related, environmental documents that is hosted by Pacific Northwest National Laboratory.

Armed with knowledge of the state of the science, technical aspects of the technologies, and potential impacts from future projects, regulators and stakeholders attending the workshops could examine the risks of single-device and small-scale deployments, explore what can be learned and observed from single devices, and consider requirements for projects at varying deployment scales. Experts and stakeholders identified key remaining information gaps and research needs that would better inform the regulatory processes. Participants considered viable paths forward to fill the remaining information gaps and discussed what was possible to learn with projects of different scales.

During the MHK Regulators Workshop, adaptive management and monitoring were discussed but not defined. An adaptive management strategy typically involves conducting monitoring or ongoing measurement of potential project impacts and setting thresholds or ranges within which actions to minimize, avoid, or mitigate the impacts should be taken. If no impacts are found, the need for continued monitoring can also be evaluated and potentially eliminated for the project. This report frequently refers to adaptive management and monitoring, but we recognize that it is not a panacea for addressing every environmental uncertainty and should be carefully considered in the context of permitting and decision-making for small-scale MHK projects.

The workshop provided a forum for regulators to become more familiar with the state of the science to inform their decisions in the MHK permitting process and to share their perspectives and experiences, providing opportunities for improved cooperation and coordination among organizations at the state and federal levels. The workshop focused on four areas of identified potential environmental impact:

- Acoustic output impacts
- EMF emissions
- Physical interactions
- Environmental effects of MHK energy development on the physical environment.

Risk is a concept used frequently in the workshop but also not clearly defined. The concept of risk—the relative potential harm a project may have on a resource—was shared, as well as the idea of "proportional risk" (meaning that a relatively high risk of impacts might lead to higher investments in monitoring with an associated range of adaptive management measures, depending on the outcomes). Vice versa, a relatively low risk of potential harm would indicate a lower expectation on the extent of monitoring and expected adaptive management measures necessary. The concept of proportional risk can also inform monitoring needs in that gaining information to answer questions, thus understanding and documenting impact risks to inform decision making, is one of the primary objectives of monitoring.

In this document, Section 1 provides an introduction to the types of MHK technologies, the larger environmental issues identified in the deployment of MHK technologies, and the regulatory permitting process. Section 2 provides summaries of the technical presentations, and more general topical sessions are found in Section 3. Section 4 provides a review of the research needs identified by workshop participants.

1.1 Technology Overview

Marine renewable energy is categorized as energy generated by waves, tidal currents, open-ocean currents, river currents, ocean thermal gradients, and salinity gradients, as defined in the Ocean Energy Glossary of the International Energy Agency (IEA) OES Agreement.[6] In the United States, the generation technologies that combine hydrokinetic processes in the marine environment are often referred to collectively as MHK energy technologies. The primary forms of MHK discussed during the MHK Regulator Workshops were wave, tidal, tidal stream, and ocean current.

In the continental United States, the technical resource potential has been assessed at between 438 and 657 terawatt-hours (TWh) of generation per year from wave, ocean current, and tidal technologies (DOE 2015). River-based current technology adds an additional 100 TWH per year of generation potential in the Continental United States (DOE 2015). Expanding the assessment to include all of the United States dramatically increases this estimate; however, much of that potential is in areas not presently accessible to the larger electrical grid. Regulatory and ecosystem constraints will further limit the near-term practical developable resource. Despite this potential, the capacity of MHK devices installed around the world is currently quite small (only tens of megawatts, excluding tidal barrage plants that have very different environmental impact considerations not considered in this document), and these installations are generally engineering prototype test devices or small several-unit demonstration wave and tidal projects. There are no full-scale, multiple-device commercial deployments in the United States at this time.

Although MHK technologies have been under development since the 1970s, progress has been sporadic and they remain in an early stage of research and development (R&D), with primarily prototypes and early production models being deployed for testing or in demonstration projects. In addition to these pre-commercial models, many MHK concepts have been proposed or are in various stages of development with a variety of methods for energy conversion.[7,8] At least 40 MHK concepts are in development in the United States, demonstrating little convergence of the technology toward a particular configuration or energy resource and indicating that, at this point, no particular technology or configuration is deemed to be superior. Figures 1 and 2 show examples of the primary types of wave and tidal energy devices being developed. Some of these development efforts have undergone open-water testing while others have utilized international testing facilities.

[6] IEA-OES 2007. Hydrokinetic forms of energy include any kinetic energy inherent to a moving fluid, such as a wave or flowing water.
[7] DOE MHK Technology Database, available at http://en.openei.org/wiki/Marine_and_Hydrokinetic_Technology_Database
[8] IEA OES Annual Report available at http://report2014.ocean-energy-systems.org/

To date, MHK testing facilities have been established primarily in Europe. The European Marine Energy Center on Orkney Island, United Kingdom, provides commercial testing services for pre-commercial wave and tidal devices. Wave and tidal testing facilities have also been developed or are in development in Ireland, Portugal, Denmark, France, Spain, and South Korea. Numerous pre-commercial devices, including full and subscale devices, are being tested. DOE designated three National Marine Renewable Energy Centers to perform research, development, and testing of MHK technologies in the United States. All three centers are engaged in MHK research and are in various stages of implementing test infrastructure. The Hawaii National Marine Renewable Energy Center,[9] Navy Wave Energy Test Site tests wave energy converter (WEC) devices. The testing arm of the Northwest National Marine Renewable Energy Center,[10] the Pacific Marine Energy Center, is testing WEC technology in off-grid applications and in the permitting process to provide the infrastructure to allow testing of grid-connected WECs. Florida Atlantic University's Southeast National Marine Renewable Energy Center[11] is focusing on technology development and testing for current energy converters (CECs), although a test site has not been developed. There are no available U.S.-based test centers for tidal energy converters. There is no requirement that devices must be tested at defined test centers. Several companies have elected to use their own testing/deployment locations in North America, although it is expected that permitted test centers will reduce the overall cost and time requirements for testing pre-commercial MHK technologies.

Moving MHK technologies from their current level of maturity to commercially viable systems will require significant investment in research, development, and test deployment (RD&D), followed by significant investment in the deployment of commercial projects. MHK technologies will probably require an appropriate form of market support to initiate early deployments and reduce risk for early adopters, similar to the support provided for wind and solar technologies. The level of support must be sufficient to make these new technologies cost-competitive and allow a relatively low-risk development of the manufacturing and user experience base. This, in turn, will allow learning and manufacturing cost reduction that, with aggressive RD&D, can make MHK technologies competitive in future electricity markets.

1.2 Environmental Effects and Processes

Publications and other information sources about potential environmental effects of MHK projects are available for the United States and Europe, fueled by a need for improved understanding of the permitting ("consenting" in the European context) and licensing of MHK projects. Available information includes results of monitoring environmental effects of device deployments and studies of other structures in the marine environment. MHK environmental information is gathered, catalogued, and made available in the Tethys Knowledge Base, which also serves as a clearinghouse for information and metadata associated with MHK deployments in the member nations of the IEA's OES Annex IV project (including the United States).

[9] For more information on the Hawaii National Marine Renewable Energy Center, see http://hinmrec.hnei.hawaii.edu/

[10] For more information on the Northwest National Marine Renewable Energy Center, see http://nnmrec.oregonstate.edu/

[11] For more information on the Southeast National Marine Renewable Energy Center, see http://snmrec.fau.edu

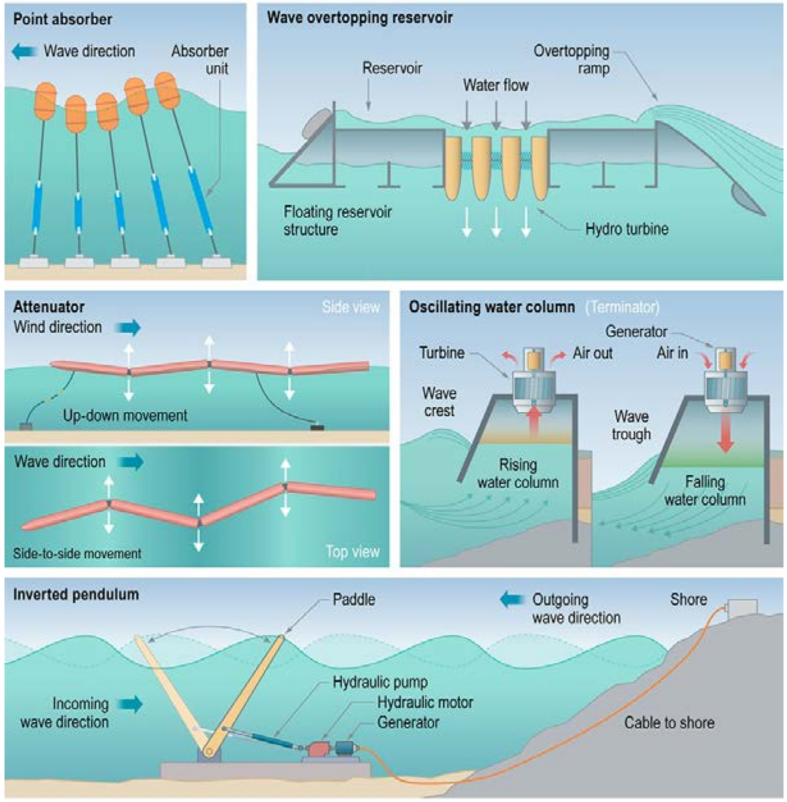

Figure 1. Primary types of wave energy devices (as cited in Chapter 9 of the Renewable Electricity Futures Study; illustrations not to scale)

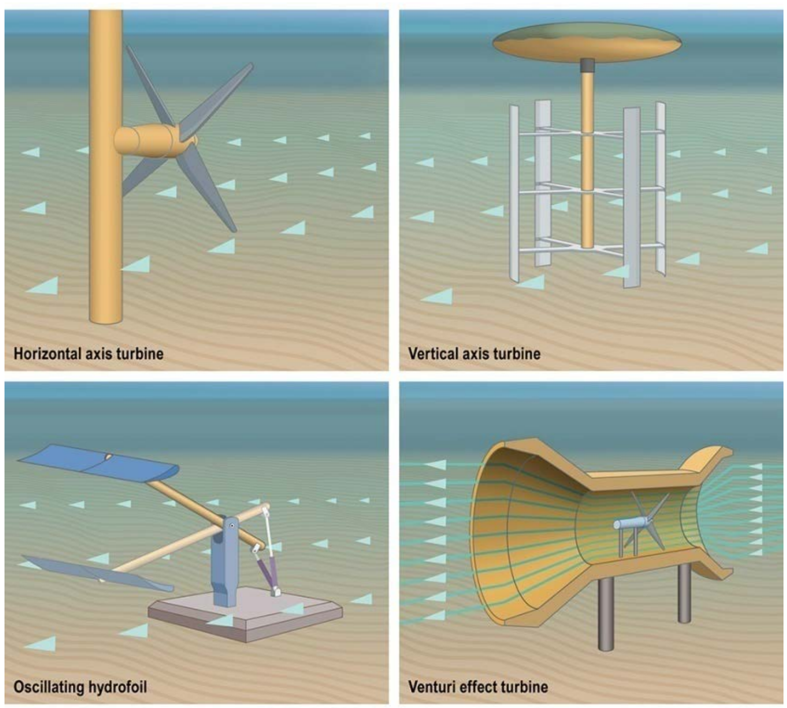

Figure 2. Primary types of tidal flow energy conversion devices (as cited in Chapter 9 of the Renewable Electricity Futures Study; illustrations not to scale)

Europe leads recent data gathering and assessment efforts with the European Marine Energy Center and other deployments such as Marine Current Turbines' SeaGen Tidal Energy Converter; U.S. deployments such as Ocean Renewable Power Company's Cobscook Bay Tidal Energy Project are contributing to the expanded knowledge base as well. Ongoing efforts in the United States and Europe are evaluating environmental effects of these pre-commercial deployments, as well as studies of existing marine structures that serve as analogues or surrogates for MHK projects, modeling and simulations of potential effects, and laboratory studies. In addition, developing technologies and protocols to monitor environmental effects is also underway.

Based on case studies, known environmental effects are varied but can include pinniped haul-out[12] and seabird roosting for devices with surface expression. Attraction of fish to structures, mooring lines, or disturbances to the sea floor can change the local ecosystem around MHK devices. Uncertainty surrounds fish, mammal, and seabird strikes (collisions) at tidal projects and EMF emissions effects of all MHK projects; however, laboratory and field studies and modeling are increasingly providing support for decision-making and improving understanding. Additionally, modeling can improve our understanding of the potential significance and likelihood of potential effects, such as collision risk, changes to the physical environment, EMF emissions, and acoustics.

It is also uncertain how information learned from single and pre-commercial deployments will apply to commercial-scale arrays. Scaling results from small, local projects to larger arrays will be aided by modeling and scaling effects from individuals to populations and from habitats to ecosystems. Monitoring and adaptive management will play a role in addressing uncertainties and allow for informed decision-making; however, although adaptive management can provide some certainty for a range of potential outcomes, effective adaptive management plans should consider monitoring at levels proportional to environmental risk, complexity, ability to determine effects, and monitoring costs.

1.3 Roles and Responsibilities within the Permitting Process

There are more than 22 applicable laws and executive orders relevant to permitting and licensing MHK projects in the United States.[13] An MHK project requires a license from the Federal Energy Regulatory Commission in state waters within 3 nautical miles of the U.S. coastline, in U.S. rivers, and in federal waters (3 nautical miles out to 200 nautical miles) under the Federal Power Act if the project will be connected to the electrical grid. If the project is located in federal waters, it also requires a lease and right-of-way from the Bureau of Ocean Energy Management under the Energy Policy Act. Several state and federal agencies are involved in the licensing and lease processes, including the following:

Federal agencies:

- National Marine Fisheries Service: Protects and recovers threatened and endangered species, marine mammals, and essential fish habitat under the Endangered Species Act,

[12] The process of pinnipeds (seals, sea lions, fur seals, etc.) temporarily leaving the water and climbing onto the MHK device

[13] See Appendix B for the complete list.

the Marine Mammal Protection Act, and the Magnuson-Stevens Fishery Conservation Management Act, respectively

- U.S. Fish and Wildlife Service: Protects and recovers threatened and endangered species under the Endangered Species Act and seabirds and bats under the Migratory Bird Treaty Act

- U.S. Army Corps of Engineers: Responsible for the use of navigable waterways under the Rivers and Harbors Act and protecting water quality and wetlands under the Clean Water Act

- U.S. Coast Guard: Responsible for siting and navigation aids in coastal waters under 33 CFR 66, Code of Federal Regulations.

State agencies:

- State agencies can be responsible for Clean Water Act 401 certificates[14] under the Clean Water Act.

- State historic preservation offices protect historical and archeological resources through the National Historic Preservation Act and relevant state laws.

- State coastal zone management and land management agencies provide protection of coastal resources through the Coastal Zone Management Act and state laws (where relevant) while protecting species and habitats through state laws (where relevant). This may include specification of environmentally sensitive areas or the requirements to conduct environmental impact assessments.

The major topics addressed in licensing and leasing projects include:

- Commercial and recreational fishing

- Migratory bird species

- Protected species and associated habitats (marine mammals, birds, turtles, and fish)

- View shed

- Department of Defense military training and operating areas

- Port access

- Navigation and safety

- Archeological and cultural resources

[14] A section of the Clean Water Act that addresses compliance. More information can be found at http://www.epa.gov/cwa-404/clean-water-act-section-401-certification

- Historic places and sites
- Socioeconomic issues and environmental justice
- Sensitive offshore and coastal habitats.

A panel discussion at the DOE MHK Regulator workshop revealed the following:

- MHK projects face increased uncertainties given that the high-energy locations may also have high ecosystem value, such as containing essential habitat for protected species or commercially important species. *Suggested solution(s): Identify risks early. Review and gather baseline information to inform monitoring and adaptive management planning.*
- A "chicken and egg" situation exists: There is a need for information to avoid or minimize impacts; but without projects in the water, there is no way to gather that information. Additionally, the likely very limited impacts of small projects may make it difficult to obtain statistically accurately information that can be used in assessing the impacts of larger projects. *Suggested solution(s): As projects become large enough to obtain reliable data, work with developers to collect data to allow research questions to be addressed, relying on adaptive management to enable learning and adjusting.*
- Given the early stage of technology development and range of device types, it is challenging to anticipate the range of impacts. *Suggested solution(s): For test centers that will use different devices, analyze a broad range of alternatives that include different device types so the full range of device types can be anticipated and evaluated. For issues of high risk and uncertainty, develop monitoring and adaptive management accordingly.*
- Understanding the extent of sensitive species in the project area is very important to understand potential impacts and then how to address them. *Suggested solution(s): Conduct studies to understand if and how sensitive species use the project area as part of permitting to determine the extent of the presence of those species; then based on risks, consider post-installation monitoring and adaptive management.*
- Identifying and analyzing impacts is a requirement. *Suggested solution(s): Focus and scale the size of the study and monitoring requirements with the size of the project and the risk it might impose (proportional risk management). One approach might be to hypothesize the best- and worst-case scenarios; estimate the most likely impact; conduct real-world testing, including monitoring; and appropriately and adaptively manage based on early post-installation results.*
- Information gathering should occur post-deployment but with solid study designs established during permitting, providing regulatory and industry certainty. *Suggested solution(s): At a minimum, monitor potential high-probability and high-risk impacts.*
- It benefits all to understand collective interests and needs; to prioritize potential impacts; and to develop studies, monitoring, and adaptive management plans that, to the extent possible, work for all. *Suggested solution(s): Transparent, open dialogue is important and ultimately is more efficient; be open to different perspectives.*

2 Technical Summaries

The potential environmental impacts of MHK devices are varied, and due to the current state of the technology, not much is known about the current and potential long-term impacts of MHK deployment.

As mentioned earlier, representatives from industry and government organizations discussed four key areas of high concern to regulators and local policy makers on MHK devices and projects:

- Acoustic output impacts
- EMF emissions
- Physical interactions
- Environmental effects of MHK energy development on the physical environment.

The following section provides a summary of the discussions on each of these areas. To help facilitate a better understanding of the environmental impacts, scientists and researchers shared their knowledge, ideas on which areas require further research, and how best to measure or obtain that knowledge. The workshop addressed the topics of research and knowledge in three levels to reflect our current understanding of the potential environmental impacts of this nascent technology:

- "**Known Known**" topics in the technical presentations identified issues that the science community wants to continue to gather information about or issues that are understood well enough that no further monitoring is warranted.
- The **"Known Unknowns"** section of the technical presentations identified issues for which the research community has the knowledge and technology to study but for which the impact and cost of a study are uncertain. Presenters examined areas that should be measured to enable a better understanding of the impacts, as well as what measurement technologies and protocols are currently available or in development and which capabilities are needed to study identified issues. Additionally, experts differentiated potential project impacts by exploring different technology scales, deployment levels, fluid flow rates, and MHK technologies.
- Finally, presenters considered **"Unknown Unknowns,"** areas that have not been widely assessed, and whether it is necessary to further study the issue and make it known. For issues that should be studied further, presenters discussed when and how to address the issue and whether the technology exists to study it effectively.

At the conclusion of each presentation, experts were asked to discuss their level of confidence in the available data for addressing the identified issues. Presenters also discussed the relevance of the current understanding to single- and small-array deployments of MHK technologies underway in the near term, how best to use the data collected from these projects in the future, the potential implementation of new technologies, and key remaining questions.

2.1 Acoustic Output Impacts

The acoustic output of MHK deployment and operation on ocean ecosystems and marine species is one of the key potential impacts that concern regulators and stakeholders. This section provides an overview of current research and an assessment of the different methodologies to determine potential impacts to marine species and habitats. A workshop session provided a wider view of the following topics:

- What is known about sound from MHK devices?
- How can we couple measurements and models to address potential acoustic impacts?
- What tools are available to study this issue?
- What can we learn from other industries?
- How can we best apply and then advance current knowledge?

2.1.1 Known Knowns

Impulsive sound pressure levels below 180 dB re 1 μPa are considered unlikely to cause physiological damage to most species and fall below the conservative interim threshold for Level A harassment[15] of marine mammals (NOAA Fisheries 2016). For continuous sound, a level of 120 dB has been identified. MHK devices produce sound, and sound levels for a few MHK technologies (wave, tidal, and riverine converters) have been measured. The impulsive radiated sound levels from the noisiest technology studied were reported to be up to 180 dB and dependent on the sea state (Lepper et al. 2012), although most other studies have suggested much lower levels of radiated sound. They consist mainly of mechanical sound (bangs, rattles[16]) and generator noise. However, other measurements for single units at the pre-commercial scale are typically indistinguishable from background noise at ranges greater than 100 m. Based on this and other information, we know that:

- Operational devices are likely to produce measurable sound levels.
- Sound intensity and frequency are likely to vary in time (based on the operational state and device characteristics).
- MHK devices are uncooperative sources in energetic environments, which make them relatively difficult to measure and quantify.

Although full-frequency sound propagation and animal receptor sensitivity is a complicated relationship, the likely impacts of measured radiated sound from single MHK devices are small

[15] The highest level of acoustic harassment permitted by NOAA under the Marine Mammal Protection Act

[16] Findings were reported in the following: "Acoustic Noise Measurement Methodology for the Billia Croo Wave Energy Test Site," https://tethys.pnnl.gov/publications/acoustic-noise-measurement-methodology-billia-croo-wave-energy-test-site and the "Annex A: Summary of Operational Underwater Noise from a Wave Energy Converter System at the EMEC Wave Energy Test Site May 2011: Comparison of Pelamis System Operational and Baseline Noise Measurements," https://tethys.pnnl.gov/publications/annex-summary-operational-underwater-noise-wave-energy-converter-system-emec-wave.

and confined to limited areas near devices. Thus far, observed radiated sound levels are below those that are considered likely to cause physiological damage. Sound is also derived from the movement of the device in the ocean space, so it would not start without warning, naturally deterring sensitive species. These findings generally hold for the small converters studied to date (e.g., small-scale pre-commercial devices currently being tested by industry). Other observed findings are that, although study results are typically specific to the technology, local conditions, and species of concern, results can be cautiously used to draw general conclusions about the potential impacts of technology deployment. More data would be helpful, but data are often confounded by the presence of other anthropogenic noise sources in the project area (e.g., sound produced by MHK devices may not be detectable in an area with high levels of ambient noise).

From a larger assessment perspective, the insight gained from small-scale or pre-commercial deployments may not be fully translatable to full sized devices or to larger arrays of devices, although data gathered on single units may inform modeling of larger-scale deployments. This is important because the impact of a single or small array of devices is being permitted currently. Although the industry may find value in conducting detailed assessments of single devices, the sound produced by a single device or small-scale array is likely not impactful.

Nothing can replace measurements to understand the radiated sound of a specific device and potentially help to improve modeling algorithms, but ongoing sound measurements will benefit the device manufacturers and their future technology refinement more than improving understanding of the impact of a single device or small array. Measurement strategies and equipment are well understood, but the availability of modeling-based strategies is still limited by the availability of device measurements. Models, especially those backed by measured data, can help us understand potential range of audibility or when measurable impacts may occur, but they cannot assess potential behavioral responses of nearby marine organisms to device noise.

2.1.2 Known Unknowns

The results from any study are specific to the technology, local conditions, and species of concern; however, researchers can cautiously draw general conclusions about the potential impacts of technology. The acoustic footprint of an MHK project can be predicted with a framework that couples radiated sound measurements to infer an acoustic source level and then applies sound propagation models and the best available animal hearing thresholds to predict detection of the sound. Factors controlling radiated sound levels are largely unknown due to limited data, but the operational state (including currents or sea state), device scale, and technology type are likely important. Other important unknowns regarding radiated noise levels from different types and classes of MHK devices include the frequency distribution and directionality. Many of these questions, however, are likely immaterial to the permitting of current devices because based on the small numbers of systems studied, radiated sound levels from single or small-scale device arrays are limited to small areas near the devices and at intensities below those that are considered likely to cause physiological damage.

2.1.2.1 Measurement Technology, Protocols, and Standards

No standards exist for the measurement, analysis, and documentation of sound produced by wave, current, and ocean thermal converters, but development has begun (IEC TC114 PT-62600-40). The required measurement technology exists, although improvements are being made as researchers better understand the challenges associated with taking quality passive acoustics measurements in energetic environments. The primary challenges include the interference of turbulence, strong currents, or wave motion, which cause “flow-noise” that can mask MHK device noise (Bassett et al. 2014). In strong currents, stationary measurements may be contaminated whereas drifting measurements, which can reduce or eliminate flow noise, may enable device noise to be measured. However, even drifting measurements of WECs may be contaminated if the wave motion is insufficiently decoupled from the hydrophone. It is also pertinent to note that sound measurements currently focus on sound pressure, although a number of marine organisms (e.g., many fish species, crustaceans, mollusks) actually can’t detect sound pressure; rather, they respond to particle motion, a relatively new research question with no biological thresholds defined (Thomsen 2015).

2.1.3 Unknown Unknowns

The concerns related to acoustics are well known even for the relatively new MHK technologies. Although more research, model development, data collection, and ongoing vigilance will be needed as MHK technologies increase in size and are deployed in larger arrays, the research community does not believe that there are additional issues that have not been considered regarding the environmental impacts of acoustic output of MHK power systems.

The biological implications of sound and particle motion are highly uncertain; even though thresholds have been established for harassment for certain species, the biological response and behavioral context for sound emissions are still unknown. Identifying any direct biological responses to radiated noise from MHK devices continues to be difficult.

2.1.4 Summary and Paths Forward

The following conclusions were drawn from existing research:

- Demonstration-scale (single-device and small-scale array) projects are unlikely to have a significant acoustic impact since broadband dB levels that cause these effects are above 180 dB and studies to date have only found decibel levels of 120 dB to 180 dB.

- Small-scale projects may produce sound at levels that result in behavioral impacts (i.e., species may avoid or be attracted to the device based on sounds they hear), but researchers to date have not gathered sufficient information to make a determination.

- Injury and mortality from MHK sound emissions are highly unlikely. Although device source levels are likely to exceed 120 dB re 1μPa (harassment), in many cases projects are deployed in naturally noisy environments where ambient background pre-project sound sources exceed this level.

- The biological implications of sound are highly uncertain; even though thresholds have been established for harassment, the biological response and behavioral context to sound emissions and particle motion are not known (Committee on Characterizing Biologically Significant Marine Mammal Behavior et al. 2005).

- Although potentially outside of any permitting requirements appropriate for these small-scale projects, opportunistically collected measurements of radiated sound at deployed small-scale projects can help inform important modeling parameters, provide valuable data to help perform model validation, improve measurement techniques, and help to identify the risks associated with larger developments.

2.2 Electromagnetic Field Emissions

To understand any impact of EMF emissions typically associated with marine renewable energy developments, it is necessary to consider the devices, the types of subsea power cables (AC and DC) and their characteristics, and the current state of knowledge regarding the effects of EMF emissions from marine renewable energy developments on marine organisms.

The main source of EMF emissions associated with MHK energy is regarded as the subsea cable(s), although depending on the device design, there may be localized EMF emissions associated with the actual device. The focus on the power transmission subsea cables arises because of the higher emission intensity associated with the cables (as compared to a device) and that some MHK developments may have multiple cables in a network between the devices before being transmitted to shore via higher power-rated cables.

It should be noted that the studies to date have focused on EMF emissions associated with subsea cable, in turn associated with deployment of large-scale offshore renewable technologies such as offshore wind that typically use medium-transmission voltage of 33,000 to 150,000 V (AC – 50 Hz) and long-haul undersea DC transmission lines up to 200,000 V (DC). Typical single- or small-array pre-commercial MHK technologies being deployed in the United States are only testing very small power generation devices (up to 100 kilowatts, or kW) with voltages up to 480 VAC; 2 orders of magnitude smaller than most of the studies that are available to assess the impacts of EMFs on marine species. The difference in target voltage and electrical current of ongoing research on the impacts of EMF emissions and the size of the MHK deployments currently seeking U.S. permitting is quite large, meaning that the findings discussed below represent impacts that are unlikely to be seen in small-scale deployments. No documented study of EMF levels for devices currently deployed or under permitting has been undertaken.

2.2.1 Known Knowns

Ability to sense and respond to EMFs is widespread across taxonomic groups, ranging from bacteria to whales. Since the main source of EMF emissions is the transmission cable, benthic,[17] and demersal[18] species, which are closer to the source, are considered to be more likely to be exposed to higher field strengths than pelagic species. Interest tends to be focused on:

- Elasmobranchs (sharks, skates, and rays)
- Agnatha (lampreys)
- Chondrosteans (sturgeon, paddlefish)
- Crustacea (lobsters, crabs, and prawns)
- Mollusca (snails, bivalves, cephalopods)

[17] Species that live on or in the sea floor
[18] Species that live close to the sea floor

- Cetacea (whales and dolphins)
- Bony fish (teleosts)
- Marine turtles.

Consideration of potential impacts is similar across large-scale energy devices in the marine environment and typical subsea power networks. The impact is based on the cable material characteristics, the transmission voltage, and current being transmitted, which generates the magnetic fields. These directly emitted magnetic fields are the source of induced electric fields, thereby giving both magnetic and electric fields in the environment. For transmission-level power systems studied to date, with voltages of 30,000 VAC or above and power levels of multi megawatts (thousands of kilowatts), the following findings are generally accepted:

- Electrosensitive species can detect EMFs from subsea cables with likely higher sensitivity to DC (0 Hz) than AC (60 Hz) cables because of the lower transmission frequency and higher power rating of the transmission cables (Normandeau Associates Inc. et al. 2011). The most highly sensitive taxa are elasmobranchs (sharks and rays) and agnathans (jawless fish) (Normandeau Associates Inc. et al. 2011; Gill et al. 2014).
- Magnetosensitive species are likely to be able to detect EMFs from DC cables and potentially AC cables but to a lesser degree as the magnetic fields emissions are lower for AC cables (Westerberg and Lagenfelt 2008; Gill et al. 2014).
- Behavioral responses, such as attraction to EMFs from subsea electric transmission cables, have been demonstrated through limited field and lab studies, but extrapolation to impacts of marine renewable energy power cables on critical behaviors of sensitive species or their populations would be speculative (Öhman, Sigray, and Westerberg 2007; Woodruff et al. 2013; Gill et al. 2014).
- Since the source of EMFs is the cable on the sea floor, benthic and demersal species, which are closer to the source, are considered to be more likely to be exposed to higher field strengths than pelagic species (Woodruff et al. 2013; Gill et al. 2014).
- Laboratory studies have shown that exposure to EMFs of 3 milli Teslas has documented impact on a number of marine species, including Atlantic halibut, rainbow trout eggs, and coho salmon. It should be noted that 3 milli Teslas EMF levels are much higher that what would be expected for the deployment of single-unit or small-array MHK systems (Woodruff et al. 2013).
- Measurements taken as part of an assessment for multi-megawatt offshore wind projects using transmission-voltage power cables in Europe found EMF levels of up to 18 micro Tesla (0.018 milli Teslas, 2 orders of magnitude below the levels of EMF documented as being impactful) for AC systems and ~275 micro Tesla (0.275 milli Teslas, 1 order of magnitude below the levels of EMF documented as being impactful) for DC-based systems (Normandeau Associates Inc.et al. 2011). Small-scale MHK projects will operate

at voltage and power levels likely 3 orders of magnitude smaller than current offshore wind farms.

2.2.1.1 Measurement Technology and Protocols

The European Union Environmental Impacts of Noise, Vibrations and Electromagnetic Emissions from Marine Renewable Energy (MaRVEN) project provides the most current review of the state of the art for measurement technologies and protocols. This work includes:

- Examples of measurement instruments, sensors, results, applicable standards
- Potential for models to support or replace the use of measurement
- Information required for measurement programs to develop valid modeled impact assessments
- A summary of the level of uncertainty around existing measurement and modeling options for the interpretation of their results.

Outputs from the MaRVEN project are not available to the public at the time of writing; a summary of the outputs is available (Thomsen 2015).

2.2.2 Known Unknowns

Several aspects of known concern should be determined to enable understanding of the impacts of EMFs. These aspects center on dose-response relationships, particularly knowing the response/effect on key marine species at their most sensitive stages of life to exposure to a range of EMF emissions (sources and predicted intensities).

- Knowing how EMF receptor species respond to multiple encounters with subsea cables in relation to movement/migratory behavior is required, such as through animal tracking field studies using multiple individuals.
- Any effects/responses measured need to be considered over the range of biologically relevant EMFs, which may result in attraction to cables rather than avoidance.
- The determination of impact lies in the data analysis that needs to apply analytical methods to assess emergent properties associated with impact at the biologically relevant unit of the species population.

Additional unknowns include a large uncertainty about the actual levels and characteristics of EMFs emitted from the marine renewable energy development cables and the fact that cables vary according to different manufacturing processes and different cable characteristics and deployments (e.g., burial vs. rock armoring), and the power generation units/devices will differ. These differences create uncertainty in emitted levels that cannot be modeled owing to lack of baseline data. Hence, it is important to understand the sources of variability in the emitted fields and to develop affordable techniques for measuring EMF emissions that receptors are likely to be exposed to so as to validate EMF predictions within models.

If EMF emissions are deemed to be significant, then guidelines and standards for measuring EMF emissions should be developed.

2.2.3 Unknown Unknowns

Given that the expanded use of undersea transmission cables and the deployment of marine-based power generation technologies are recent occurrences, there are still many unknowns about the potential impact of EMF emissions. Three such potential unknowns include:

- Possible differences in the potential behavioral response of EMF-receptive species within a cable "mesh" with cables oriented in different directions and relatively close together, typical of a collection system for an array of devices, compared to single long linear shore landing cables

- Potential impacts on the life stages of migratory animals due to the potential cumulative impact of encountering repeated EMF sources along a migratory path given that multiple projects and thus multiple shore landing cables from larger-scale marine renewable energy may eventually be implemented

- Potential longer-term EMF impacts on early life stages as many early life stages are relatively immobile and therefore may be exposed for long periods during development.

2.2.4 Summary and Paths Forward

Most of the understanding relating to EMF impacts is for medium-voltage transmission and above, typically in the range of 33,000 to 150,000 (VAC – 50 Hz), and relatively large power ratings, typically more than 50,000 kW. Current small-scale deployment for MHK technologies is at relatively low voltages (1,000 VAC or below) and low power ratings (less than 100 kW).

Although there is value in understanding the impacts of EMFs for larger-scale deployments, the assessment of EMFs for small, single, or small-array projects is not likely warranted.

When considering larger power systems, there is still a low level of confidence in the data for assessing whether there is an issue/concern. Additional work should build on the extensive deployment of offshore energy cables in Europe and the subsea cable industry in general to assess and share data on EMFs, cables, and impact studies, much of this relating to the offshore wind sector and the related subsea cable, network, and grid-connection sector.

Workshop participants reviewed the potential impacts of EMF emissions from subsea AC and DC cables and the current state of knowledge regarding the effects of EMFs from subsea cables on marine organisms. It should be noted that the studies to date have focused on the EMFs for transmission-level power cables associated with the deployment of large-scale offshore renewable wind energy technologies from multiple high-power devices (1 to 5 MW) that typically use medium-transmission voltage and long-haul undersea DC transmission lines up to 300,000 V (DC). Small-scale MHK technologies currently seeking permitting for deployment test low-power-generation devices (up to 100 kW) with voltages up to 480 VAC; 2 orders of magnitude smaller. Although there are no identified studies on the impacts of EMFs on receptors, over the longer term a considerable improvement in understanding of EMFs from MHK devices will be needed to aid the permitting process for large-scale deployments. At present, the impacts of small-scale MHK deployments on biota are considered to be of low overall biological significance because any EMF emitted that is detectable is likely to be low intensity and approach background levels within a very short distance (e.g., less than a few meters) from the source.

2.3 Physical Interactions

The direct and indirect physical interactions of marine species with MHK devices and systems, moorings, and electrical interconnections are another potential environmental concern. While potential physical interactions between MHK devices and marine organisms have been identified through broader consideration, the workshop focused on blade strike. The workshop session did not focus on other potential interactions, which are listed and described below:

- **Entanglement in moorings and electrical interconnections.** Entanglement from MHK device moorings and other cables is generally considered to be a relatively low risk due to cable thickness and mooring line tension.

- **Changes to movement/habitat use patterns.** Substantial changes to movement patterns are unlikely to result from small-scale projects; as such, this hasn't been an area of extensive research to date. Studies examining changes in movement patterns have revealed only localized change in movement patterns around devices, as opposed to MHK devices serving as barriers to movement on a broader scale. This question will need to be addressed as project sizes increase.

- **Reefing/fish aggregating devices.** While MHK devices may act as fish aggregating devices and artificial reefs, these effects are likely to be very location dependent and relatively minor with small-scale projects. For larger-scale projects, reefing effects may have positive, negative, or neutral effects on local populations. Additionally, this effect is likely to be similar to that of other ocean structures, so existing data may be used to assess likely MHK project risk.

- **Benthic habitat changes.** While changes to benthic habitat around anchors and/or benthic expressions of devices are likely with both positive and negative impacts possible, such changes are likely to be localized for small-scale projects. Additionally, this effect is one common among all ocean equipment with a benthic expression; existing data may be used to assess likely MHK project risk.

- **Blade strike.** Additional attention and research have been devoted to assessing the potential risk of blade strike from tidal, ocean, or in-river devices. While varied in design, most CECs and tidal turbines have moving blades that are used to capture kinetic energy from moving water. This design structure, informed in part by historical issues regarding fish injury and mortality from hydropower turbines, have led to concerns regarding strike injury and mortality from tidal turbines.

Risk of blade strike from tidal turbines to date has been informed by modeling, laboratory studies, and field studies. The IEA OES Annex IV Final Report[19] provides an overview of

[19] http://www1.eere.energy.gov/water/pdfs/annex_iv_report.pdf

research conducted to date, and much of the material presented at the workshop was included in or informed by this document.

2.3.1 Framing Strike Risk

Risk is generally considered to be a function of the probability of an event occurring and the consequence of the event, should it occur**.** To understand the ultimate effect of such impacts, risk to populations, rather than individuals, will need to be analyzed. Population risk is dependent on the vulnerability of a population. Consequently, when considering the potential risk due to blade strike, risk to individuals should then be placed within a broader population framework.

Blade strike risk to individuals depends on a number of variables, including:

- The individual probability of being struck (probability of encounter), which will depend on key considerations such as:
    - Where is the device in the water column relative to a species' swimming patterns, presence, and abundance?
    - Do organisms respond to the device in such a way as to increase or decrease their strike risk through attraction, avoidance of the turbine (macro-scale) or the rotor-swept area (micro-scale), and evasion (the organisms' ability to time their passage through the turbine in such a way to avoid being struck)?
- If an individual strike event occurs, what are the consequences of that impact (impact of encounter)? Consequences will depend on:
    - The force associated with the strike event
    - The organism, the location of strike, and a number of device-specific design considerations.
- Based on the probability of a strike and its direct impact, is there a resultant population-level effect that is of concern?

2.3.2 Comparison with Other Sources of Blade Strike Mortality

Since concerns regarding blade strike from MHK turbines are rooted in a history of concerns regarding mortality from hydropower turbines and ship propellers, a comparison of the mechanisms of mortality between these technologies can be informative to our understanding of relative strike risk. An Electric Power Research Institute report (Jacobson et al. 2012) compared fish mortality mechanisms between hydropower and MHK technologies and concluded:

> *"Fish passing through the blade sweep of a hydrokinetic turbine experience a much less harsh physical environment than do fish entrained through conventional hydro turbines. The design and operation of conventional turbines results in high flow velocities, abrupt changes in flow direction, relatively high runner rotational and blade speeds, rapid and significant changes in pressure, and the need for various structures throughout the turbine passageway that can be impacted by fish (e.g., walls, stay vanes, wicket gates, flow straighteners). Most, if not all, of these conditions do not occur or are not significant factors for*

> *hydrokinetic turbines. Furthermore, compared to conventional hydro turbines, hydrokinetic turbines typically produce relatively minor changes in shear, turbulence, and pressure levels from ambient conditions in the surrounding environment."*

Further, the potential for device avoidance is a critical difference between the two systems. Fish passing through hydropower turbines are entrained in rapidly flowing water and confined within the draft tubes, with relatively little ability to evade blade strike. In contrast, if organisms sense and perceive MHK turbines as they do other objects in the aquatic environment, they have the potential to swim around the devices or to evade blade strike by timing their passage through devices.

At times, risk of blade strike from MHK turbines has been compared to that of ship propellers. Since force is a function of mass multiplied by acceleration, the relative force of strike from tidal turbines is likely to be far less than that of ship propellers, as propellers have external energy source and tidal turbines move with the current.

2.3.3 Known Knowns

Risk of blade strike from tidal turbines to date has been informed by modeling, laboratory studies, and field studies (Copping et al. 2013), summarized in the findings section below.

2.3.3.1 Measured and Observed Impacts for Deployed MHK Systems

The following summarizes known impacts of deployed MHK systems.

2.3.3.1.1 Fish Strike Models

Numerous approaches to the modeling of direct fish strike from tidal and current MHK technologies have been developed, ranging from models adapted from hydropower to new computational fluid dynamic models. The models examine the two main issues introduced above: the probability of an interaction and the consequence of that interaction.

It is important to note that most of these models do not incorporate avoidance or evasion rates but tend to model the fate of fish that pass through turbines rather than the likelihood that any fish passing through an area will encounter a turbine, fail to avoid it, and fail to evade the strike. Thus the results of these models should be viewed in this context.

Several models have been developed that are informed by field data for development. The Eulerian-Lagrangian-Agent Method (ELAM)[20] model uses data informed by mobile hydro-acoustic surveys at the Ocean Renewable Power Company Cobscook project and a model being developed by Oak Ridge National Laboratory using data from Verdant Power's Roosevelt Island Tidal Energy project in New York.

2.3.3.1.2 Laboratory and Field Testing of Fish Interactions

Laboratory-based work has been performed to help understand the survival rate of fish based on flume studies, including the following:

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[20] See U.S. Army Corp of Engineers Cognitive Ecology & Ecohydraulics Research description: http://el.erdc.usace.army.mil/emrrp/nfs/elam.html

- Laboratory tests indicate high survival rate (close to 100%), including avoidance (not entering the rotational plane) and evasion rates (successfully moving through the rotor plane without being struck), for multiple exposed fish species in light and dark conditions.

- Multiple field tests have also been conducted for MHK technologies using rotating blades across multiple locations, water types, and turbine technologies for fish and marine mammals, including:

  - A Hastings, Minnesota, project that consisted of a Hydro Green Energy Turbine on the tailrace of an existing hydroelectric dam on the Mississippi River (completed in 2009). The organisms of interest included the yellow perch (*Perca flavescens*), bluegill, catfish, smallmouth buffalo (*Ictiobus bubalus*), and bigmouth buffalo (*Ictiobus niger*). In this study, fish were outfitted with radio-frequency tags and balloon tags that inflated after passage through the turbine. The fish introduced directly upstream of the turbine and retrieved downstream after passage through the turbine were assessed for mortality and injury 1 hour and 48 hours after retrieval. The key findings were that survival was ≥99% after 48 hours, with only one yellow perch sustaining what may have been a test process-induced injury out of a total sample of 396 (Normandeau Associates Inc. 2009).

  - The Gorlov Helical Turbine Test examined naturally occurring fish in a subtropical tidal channel in Mozambique using a stereo-optical camera measurement system. Fish movements were recorded with and without the rotor in place for a turbine rotation up to 70 rpm. Although differing by species, fish movements through the test area were reduced when the rotor was present and increased with current speed. No fish collided with the rotor, and only a few passed through rotor blades (Hammar et al., Andersson and Eggertsen 2013).

  - In 2006, the European Marine Energy Centre conducted a study of the impacts of OpenHydro 6-m ducted tidal turbines, primarily on Pollack (*Pollachius pollachius*). Hundreds of hours of video footage using natural light have been collected at the face of the OpenHydro turbine. Pollack were the only species detected in the vicinity and only at low-tide states. Pollack abundance was significantly inversely associated with velocity, with no fish present at flow rates above 1.2 m/s in 2009 and 1.7 m/s in 2010. Collision and entrainment were not observed (Broadhurst, Barr, and Orme 2014).

  - In Cobscook Bay, Maine, testing was conducted on an Ocean Renewable Power Corporation (ORPC) turbine. Single-beam hydroacoustic technology was used to collect pre-deployment data on the presence and vertical distribution of fishes. DIDSON cameras then recorded fish behavior around the turbine. Based on 3 years of data collected, fish density was usually highest near the sea floor (below the depth of the turbine), although this varied with seasons. A few fish were seen actively avoiding the turbines, but 35% fewer fish went through turbines when spinning. Additionally, fewer schools passed through turbines than independent fish. It is possible that larger fish avoid the turbine farther outside of the view of the cameras, but this could not be proven (Zydlewski 2015).

- The Roosevelt Island Tidal Energy Project in New York's East River considered the impact of six tidal turbines from Verdant Power in 2008. The project looked at resident and migratory fish using two acoustic cameras, downward-looking split beam biosonic transducer and a DIDSON camera system oriented toward a turbine to observe fish movement and behavior (Verdant Power LLC 2010). The monitoring system was deployed for three 15- to 17-hour periods. Key findings were that resident and migratory fish avoided the areas where turbines were located and tended to prefer inshore, slower-moving waters. Fish behavior was primarily influenced by the natural tidal currents and secondarily by the presence of the operating turbines. There were few fish present while turbines were operating, which only occurred when the flow velocity increased to greater than approximately 0.8 m/s, the turbine cut-in velocities. Limited observations showed fish passing by the rotating turbines following the hydrodynamics of the system, indicating that fish were able to detect and successfully swim around operating turbines (Tomichek 2015).

Additionally, two studies have examined blade strike risk for marine mammals.

- The SeaGen marine current turbine's testing at the Strangford Lough special area of conservation in Ireland focused on gray and harbor seals and harbor porpoises. The project worked to eliminate strike risk to marine mammals by shutting down the turbine during daylight hours when marine mammals were sighted nearby and also after dark. Distances and protocols triggering shutdown were reduced over time, and the role of marine mammal observers was augmented and then replaced by a sonar unit. At the start of the project, turbines shut down on average three times per 24 hours of operation; later in the project, shutdown occurred less than once per 24 hours of operation. Shutdowns were more frequent on the ebb tide than the flood tide. Turbine shutdown procedures did not allow for observations of direct interactions of the animals with turbine blades, but seal telemetry data showed that seals transited farther away from the center of the narrows after SeaGen installation, suggesting avoidance of the turbine. This project continues operation (Sea Generation Ltd. 2016) although it is expected to be removed in 2016 to further understand the decommissioning process of MHK devices (BBC News 2016).

- Sandia National Laboratories and the Pacific Northwest National Laboratory conducted an assessment of the strike risks to an adult killer whale by an OpenHydro Open-Center Turbine, tidal turbine blade.[21] This study provided an estimate of the worst-case scenario results of a modeled blade strike on material with properties similar to killer whale tissue. The modeling concluded that interaction was likely to result in bruising or minor laceration under a worst-case scenario; however, the study did not account for aspects of whale behavior nor provide detailed information about the strengths of specific whale

[21] http://www.openhydro.com

tissues. This analysis may not be generally applicable to encounters between other species of animals and other turbine designs and is still ongoing (Carlson et al. 2014).

2.3.4 Known Unknowns

Several major known unknowns have been identified.

Measurement technologies:

- There are currently no commercial off-the-shelf technologies that are ideal for monitoring collision or evasion in the near field in low-light, high-energy environments. Of the current technology solutions, optical systems require natural or artificial light sources (artificial light may attract or repel some organisms), are at risk for biofouling and clouding lenses, and produce large amounts of data. Active acoustic systems result in clutter around the blade surface that makes collision events hard to detect, are typically data intensive to operate over long periods, and have limited species classification capabilities. Accelerometers applied to blades or devices that are capable of detecting strikes are still in a research stage.

- The most promising monitoring solutions likely integrate an instrumentation package. The University of Washington Northwest National Marine Renewable Energy Center, among others, is developing packages, but they are in the research phase of development and testing. However, such packages are likely to be expensive and data intensive and will likely be more appropriate for answering research-based questions, rather than routine project monitoring.[22]

- Attempting to monitor strike events has been and will continue to be very expensive. It may be more appropriate for research to inform a broader understanding of risk, rather than aiming for continuous monitoring at projects.

Other remaining questions:

- What is the degree to which different species will avoid turbines in their path? The limited studies show that mammals, and in some cases fish, demonstrate changes in use patterns to avoid turbines; however, for fish these rates have varied among studies. How this may change over time or with different untested species in different flow regimes and light conditions is not yet known.

- How do turbine arrays affect fish avoidance ability? High survival rates for fish passing through turbines are promising, even if avoidance rates are low.

2.3.5 Unknown Unknowns

No specific concerns were identified based on the experts' experience.

[22] For more information, see http://tethys.pnnl.gov/sites/default/files/publications/Instrumentation_Workshop_Final_1_2014_0.pdf

2.3.6 Summary and Paths Forward

Workshop participants discussed what is known regarding risk of blade strikes from turbines to marine organisms; findings to date include the following:

- There have been no documented observations to date of strike, injury, or mortality in the field from tidal turbines. There are limitations on monitoring efforts to date, so there is the potential of strikes that have not been documented.

- Field data findings are supported by flume studies, which also indicate high survival rates following passage through MHK turbine blades (likely due to the relative slow rotation rates and thus strike force, as well as the ability of fish to avoid and evade strike).

- When applying or interpreting the results of MHK strike models, users should pay close attention to whether models include avoidance and evasion rates. Those that don't are predicting the fate of organisms that pass through turbines, rather than the probability of passing through.

- There is growing agreement in the scientific community that strike events are likely to be rare at small or pre-commercial projects, especially if focused on species of interest.

- Rareness of strike events will make them inherently hard to observe; therefore validating monitoring technologies and modeling results using observed strike events will be difficult.

- Different turbine types have different rotor-tip speeds and strike forces; thus understanding the properties of a specific turbine is important in predicting strike and the potential impact of that strike. Site-flow rates will also affect rotational velocity and thus strike force, adding an additional degree of freedom.

- Strike monitoring has been and will continue to be very expensive, with limited expected avenues for improvement given the scale of the issues and technology currently in use and being developed.

Given the limited likelihood of obtaining observations of interactions with devices in open water settings, research to better understand avoidance rates coupled with predictive modeling may be one viable course of action.

2.4 Environmental Effects of MHK Energy Development on Physical Environment

The presence of MHK devices in the natural environment has the potential to create changes in local ocean ecosystems. The physical environment is considered the water body and seabed in which the device is located, and the potential effects would include changes in water flow, water quality, and sediment dynamics. Key questions for assessing this impact over the course of the installation include:

- How is the physical environment changed by MHK installations?

- Are the changes significant and cause for concern?
- Can mitigation strategies be effective in reducing or eliminating the impacts?
- Can the installations be engineered to improve conditions or address other concerns?

This review does not examine acute impacts, including short-term disturbances around the installation of devices (e.g., pile driving, vessel traffic) or the more conventional and better understood physical impacts of the anchoring systems or power transmission trenching.

2.4.1 Known Knowns

Limited studies have been undertaken to date to consider physical environmental effects due to the presence of MHK arrays in aquatic systems. The studies include numerical simulations of the physical effects of arrays of MHK devices, including WEC effects on waves and currents and subsequent seabed changes. Researchers have also analyzed the effects of CECs on the natural currents, sediment dynamics, and water quality in tidal and riverine systems. However, few devices have been deployed in multiple environments, which make results difficult to interpret more broadly.

Although site-specific conditions and technology will drive the potential impact, numerical evaluations show that small arrays (~10) of WEC and CEC devices generally have minimal effect on the physical environment. Depending on the type and duration of small-scale installations, the impacts of these deployments are expected to be minimal. If the deployments are temporary to allow development testing, the impact of these devices is likely not meaningful. However, as array size increases, effects increase and require further study.

Findings from CEC studies have shown that small arrays of devices will likely have localized effects on potential benthic habitat and the water column but minimal effect far-field. The impacts of a single device for testing purposes are also expected to be small to negligible.

The deployment of a small offshore array (~10) of WEC devices will have minimal near-field effects and minimal potential for affecting far-field transport patterns. The installation of single units for defined short time periods will again likely have very limited, if any, long-term impacts.

Researchers have undertaken several studies and modeling efforts for WEC devices, with findings that include:

- Modeling using the Simulating Waves Nearshore (SWAN)[23] wave model showed that change of shoreline wave climate caused by the installation of a small array of WEC devices at probable wave energy transmission levels predicted only small changes in the shoreline wave climate (Jones, Magalen, and Roberts 2014).
- The distance of a wave farm to the coast is one of the key aspects in a wave energy project. Modeling results show that a small array of WEC devices within 2 to 3 km of the

[23] For more information on SWAN, see http://swanmodel.sourceforge.net/

coast results in beach erosion reduction of up to 20% (Abanades, Greaves, and Iglesias 2015).

Methodologies to understand and estimate impacts around wave energy and subsequent sediment dynamics have not been universally accepted. Baseline observations and modeling at a proposed wave energy array site near Reedsport, Oregon, included beach and shoreline morphodynamics assessments, direct survey, and video observations of the submerged bathymetry, wave modeling, and in-situ and radar observations of the waves (Ozkan-Haller et al. 2009).

Similar studies and modeling efforts have been undertaken for current energy devices, with findings that include:

- Numerical models used to investigate changes due to the presence of large-scale tidal turbine arrays found that arrays in excess of 85 turbines have the potential to affect bed shear stress distributions (Martin-Short et al. 2015).
- 2-D numerical modeling of Shannon Estuary (a very unique estuary close to Limerick, Ireland) predicted that water levels and flushing parameters would be altered with the installation of arrays of current energy devices. With decreased device rotor spacing, inundation and increased residence times were identified, which could change habitat and pollutant transport in the region (Nash et al. 2014).
- Measurements of sediment type and bathymetry were collected at a site in the Irish Sea. A high-resolution, unstructured morphodynamic model and a spectral wave model were developed to quantify natural variability due to tidal and wave conditions. The impacts of tidal-stream energy extraction using the morphodynamic model were simulated. The results suggest that the sedimentary impacts of "first generation" tidal energy converter arrays (i.e., less than 50,000 kW) at this site are within the bounds of natural variability and are, therefore, not considered detrimental to the local environment (Furness et al. 2012). Devices currently under development and permitting in the United States are typically less than 100 kW, 3 orders of magnitude smaller than the modeled array size.

Numerous studies are available as part of the Tethys Knowledge Base, which can provide examples of data collection, analysis, and modeling efforts for wave, current, tidal, and more generic MHK technologies. Additional analysis for associated technologies, such as scour analysis associated with offshore wind installations, are also included.

2.4.2 Known Unknowns

Several areas of concern regarding the wider impacts of MHK technologies on regional systems are not well understood: feedback to regional ecology; defined impacts on habitat of species of concern; and the potential effects on far-field regional circulation, seabed, and water quality from larger-scale MHK deployment.

Measurement technology and protocols are continually being upgraded and developed, including unique tools that are being improved to inform modeling of seabed stability, sediment transport, and ocean energy impacts. These models include information collected from tools such as the SEDflume (Roberts et al. 1998), ASSET Flume (Roberts, Jepsen, and James 2003), and

SEAWOLF Flume (Jepsen, Roberts, and Gailani 2004) for sediment erosion testing; sediment profile imaging for benthic monitoring (Nilsson and Rosenberg 2000); and other available oceanographic monitoring tools. These tools are also being developed with increased functionality to asses conditions such as extreme storm events.

2.4.3 Unknown Unknowns

Largely unknown effects include the potential impacts of salinity and temperature stratification or mixing due to the devices and the resulting impacts that this might have on birds and other non-aquatic species.

2.4.4 Summary and Paths Forward

In summary, the following conclusions are appropriate given the current state of research in this area:

- Quantitative methods, including measurement and modeling, can be used to evaluate the effects of MHK arrays in coastal regions and rivers.
- Modeling can be used to predict the potential changes to waves and/or water circulation for wave, tidal, and current devices.
- Numerical evaluations show that small arrays (~10) of current or wave energy devices have minimal effect on the physical environment, although site-specific conditions and technology will drive the potential impact.
- As array size increases, effects will likely increase and require further study.
- As the array size decreases, effects will likely decrease, especially for projects that are expected to be operated for short periods of time.
- Devices in coastal near-shore locations may potentially be used to enhance coastal sediment management programs.
- Small arrays of current energy devices will likely have localized effects on potential benthic habitat and the water column, with minimal effects far-field.
- The deployment of a small offshore array (~10) of wave energy devices will have minimal near-field effects on sediment dynamics and circulation and minimal potential for affecting far-field transport patterns of sediment, flow, and wave dynamics. The installation of single units for defined short time periods will again likely have very limited, if any, long-term impacts.
- Initial evaluation strongly suggests the most appropriate path to consider for progressive development and evaluation of impacts, especially for the development of small-scale arrays of MHK devices, includes adaptive management strategies with up-front site characterization, analysis, and then appropriate monitoring leading to flexible management.

- The studies to date indicate that site-specific analyses where stratification is present and important to local ecology are useful and do typically provide an accurate assessment of potential impacts such as water flow and sediment transport. Tools exist to study these effects (such as SEDflume, ASSET Flume, SEAWOLF Flume, and SPI camera), and the linkage between physical and ecological processes is being further developed.

Determining whether a direct local assessment is needed remains a project-by-project assessment; however, numerical modeling of small arrays of devices shows limited near- and far-field impacts. The implementation of small-scale devices, especially for short periods of time, is not expected to have noticeable impacts on physical processes such as overall sediment transport, water flow, and ocean/wave energy. For projects in which more detailed assessments are needed, modeling tools and guidance for the application of these tools are being deployed to provide easy end-user applications for site-specific evaluation.

3 Topical Summaries

In addition to the introductory and technical topics explored above, workshop participants and experts discussed other influences on MHK technology development and deployment. They reflected on lessons learned from the wind industry, heard from MHK industry members, and considered the applicability of adaptive management practices. Following are summaries of the materials presented and discussed.

3.1 Lessons Learned from the Wind Industry

The growth of the U.S. wind industry over the past 40 years presents some lessons that are appropriate for the potential development of the MHK industry. Without delving into a more exhaustive history of the development of the wind industry, enough parallels exist to offer the following lessons:

A collaborative approach involving the key stakeholders facilitates an understanding of the potential impacts so that appropriate mitigation and monitoring strategies can be developed and implemented and the technology can advance, conceptually leading to cost-effective development. Some key points include:

- Early and frequent engagement with all appropriate stakeholders builds trust and collaboration, which will help address ongoing or new unforeseen issues as the development process unfolds. Stakeholders could include regulators, members of industry and environmental groups, the fishing community, etc.

- Data on impacts can be shared while respecting company intellectual property and industry-wide competitiveness.

- Quantitative science-based research with independent science-based oversight as a starting point is important to address identified issues, including a need to pool funds to conduct required studies to address identified or potential problems early in the development process.

- In the wind energy industry's early years in the United States (primarily through the late '80s), there was a great deal of mistrust among environmental organizations, environmental regulators, and the larger wind industry. Some of this mistrust lingers today. Even into the early 2000s, project development was seen as needing limited community engagement. The development of the National Wind Coordinating Collaborative, the Utility Variable Integration Group, and DOE's deployment and education efforts helped articulate potential impacts more clearly and supported expanded community engagement. Expanded collaborative efforts by the American Wind Energy Association and the American Wind Wildlife Institute demonstrate more recent efforts to bring disparate organizations together to confront challenging issues. The quick launch of the Bat and Wind Energy Cooperative once wind turbine and bat interactions were identified as an issue is a good example of how building trust prior to the identification of a problem can help lead to faster collaboration and understanding of the issues and more informative impact mitigation.

MHK technology needs to evolve to become competitive. The wind industry has achieved a miraculous metamorphosis over the past 40 years. Starting with small turbines on low towers in the late 1970s, the cost of wind energy has decreased from about $0.80/kWh to $0.05/kWh at the best sites. Turbine development has also changed dramatically, from fabrication in machine shops to manufacturing in industrial-scale production facilities costing hundreds of millions of dollars. This metamorphosis, however, was built on a successive series of technology deployments, allowing rapid learning and design refinement (Figure 3).

The ability to conduct this deployment/testing/re-deployment cycle across many projects enabled wind energy to develop rapidly. The process included testing at defined test sites, such as the National Wind Technology Center; at company test sites; and most important, as part of commercial project deployments. Due to the lack of accurate system models and a limited understanding of wind system dynamics, equipment testing greatly assisted early wind turbine design efforts.

Baseline studies to measure and prioritize wildlife impacts have greatly supported wind energy development, while the lack of these studies early in the development process resulted in poor deployment decisions and unnecessary (in hindsight) impacts. A small number of early projects cannot identify all impacts, and it is impossible to foresee, and thus study, some of the impacts that only wider-scale deployment will illuminate. These conceptually opposing issues require a balanced approach, one that the wind industry faced as the technology developed and one that the MHK industry now faces. Limited oversight and study allow real issues to be missed or dismissed until they become large and potentially crippling problems. At the same time, too many early pre-full-scale projects and ongoing assessment of the potential impacts limit the ability of the technology to evolve and deploy into new areas where new issues will arise. Either extreme leads to a failed industry, resulting in the loss of a technology which may help reduce the overall high level of impact that other energy generation technology currently pose on the planet and its inhabitants. A balance between light-handed regulation of small-scale development paired with ongoing broader research and development, and a heightened ongoing sensitivity to potential problems and strong collaboration, will help identify issues and more quickly address them as they emerge.

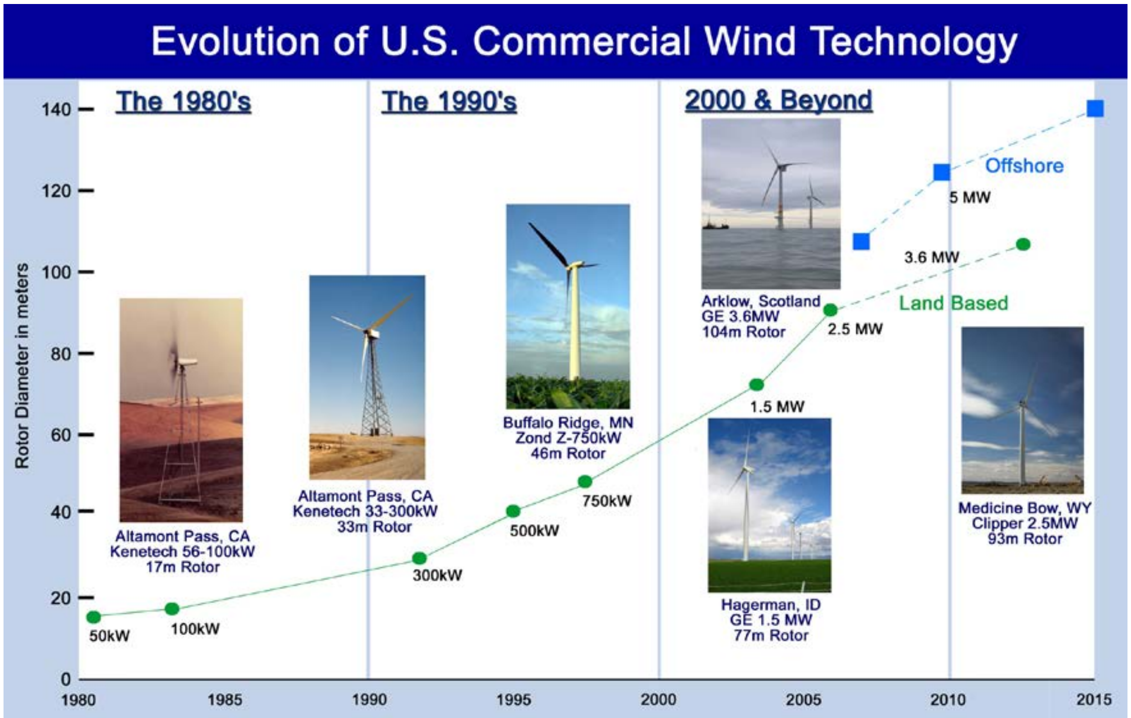

Figure 3. The evolution of commercial wind technology

A wind industry example of this approach is the understanding of wind turbine and bat interactions. After almost 30 years of active turbine operation and the installation of tens of thousands of turbines, in the early 2000s the first projects installed in new areas highlighted bat interactions as a potential issue. The community is making progress and addressing this issue. If the industry had to tackle this issue as one of many hypothetical impacts in the early years, there would have been no way to assess the impact and potential mitigation options.

Assess avoidance and mitigation options as early as possible. Although this may seem obvious, a high level of trust and collaboration is required to engage and solve problems. The first step is always being able to identify a potential issue with limited concern of potential liability, being open to scrutiny, and stakeholders being willing to support the research required to identify an acceptable and timely solution. A confrontational attitude only leads to retrenching and avoidance of the issues, making them harder to address.

The issues around wind turbine and bat interaction provide another positive lesson from wind energy development. Following the identification of the issue, the formation of the Bats and Wind Energy Cooperative led to co-funded impact research and, most recently, the development of mitigation strategies and technologies. However, 15 years after the problem was first identified, acceptable solutions are just being realized. This process timeline could be shortened if appropriate collaborative mechanisms were in place to allow more rapid progress.

The size of the companies engaging in new technology development limits their ability to address known issues at early industry stages. All of the companies that started the wind industry were small, with few remaining active in the market. The ability of these companies to engage in detailed impact studies was limited, and in the case of early wind development, the studies were largely not required. This lack of regulation helped speed technology development, but it meant that the industry could largely ignore growing issues, resulting in a reputation that the industry still works to overcome. As the wind industry has grown, so has its ability to support research and technology programs to mitigate identified impacts such as sound levels, avian impacts, and bat fatalities. As noted earlier, in recent years the industry has also been able to fund collaborative organizations addressing known issues, such as the American Wind Wildlife Institute. The lesson is that the condition and capabilities of the industry must be weighed as part of the regulatory process. Too much regulation and it will be impossible for the industry to advance—driving it to extinction or at a minimum, out of the United States. Too limited regulation allows the industry to sidestep important questions that in the end will be bad for the environment and bad for the industry. Finding a balance to achieve both needs and sorting through what is appropriate through broader collaboration and what is appropriate for individual projects at different stages of development are important for success.

Global market potential makes a huge difference in supporting technology development and understanding potential impacts. A large potential market is critical to attract private or public funding to address issues, spur research, and allow technology development to progress to commercial development. The wind industry, like the MHK industry, has clear market drivers and a wide market potential if the technology cost is competitive with other energy sources. However, this wide market can hinder development if every potential impact in each market must be understood or measured to document impacts prior to early project deployment, especially while the industry is still small and undercapitalized.

A strong federal role is needed to support ongoing technology innovation, development, and impact assessment. The energy sector is relatively unique because of the role federal and state governments have in its regulation and support, either directly or indirectly, to allow continued innovation. Federal organizations can also play a unique role as independent third-party collaborators, with the ability to not only support the resolution of long-term issues but also to identify parallels and shared experiences. The difficult lessons from the relatively new wind industry should be considered by technology developers, project developers, and the regulation community to enable smooth development of the fledgling MHK industry.

3.2 Differences that Could Slow Industry Advancement

Although it may be possible for MHK technologies to follow a similar, though better informed, path as wind technology, there are a few differences between the current MHK and early wind industries that are important to note in the context of this document:

- ***Cost of early device testing*:** Although developing and testing wind turbines in the wind industry's early stages were expensive, they were significantly less costly than completing similar work in the marine environment. From the simple logistics of deploying similar-stage technology to the ability to closely watch and record operation during extreme events, land-based deployments are much less costly. Given the available resources of the current MHK and early wind industries, this is a significant impediment.

- ***Complexity of the testing environment*:** Adding to the high costs, measurement equipment to understand the system and the system environment is much more complex and costly in the marine environment. Additionally, given the complexity and limitations forced by the environment, any data collected may be harder to analyze or interpret.

- ***Regulatory landscape*****:** During the early years of wind development, there was very limited regulatory oversight, especially for projects on private land. This situation allowed for rapid testing and technology development. Similar testing of pre-commercial MHK technologies can take many months of regulatory engagement to seek approval, including the need to receive additional approval for any major change in the testing or system configuration. These regulatory requirements will slow the development process, including the refinement of measures that could help the industry reduce potential impacts.

How these items play out over the next 20 years will likely determine how well MHK technologies develop, both domestically and internationally.

3.3 Information and Perspectives from Industry

This section outlines key points identified from interviews conducted prior to the workshop with representatives from U.S. MHK device companies.

3.3.1 Project and Regulatory Perspectives

As MHK technologies are not yet at commercial readiness, present MHK “project development” is very different from present project development of commercial or near-commercial technologies such as wind power. Because of the complexity of the permitting process and lack of defined test centers, technology developers are being forced into the role of project developers to allow testing of pre-commercial units, further stretching the resources of these small companies. The implementation of defined test centers will help to alleviate some of this complexity as test centers will have many permits already in place and expanded environmental and regulatory related expertise on staff to support the assessment of individual applicants. MHK technology developers are now deploying devices so they can work with researchers and regulators to validate computer design models/designs; identify key areas for performance, reliability, and environmental interaction improvements; get experience to inform optimization of installation and operation; optimize and demonstrate performance and environmental compatibility; and obtain data for technology certification. These activities are required to develop commercial-ready, sustainable, MHK renewable energy systems with minimal environmental impacts.

MHK industry representatives posed a number of questions (see Appendix E) regarding the regulation process and identified the following general themes for a successful path forward:

- Find ways to install projects that allow manufacturers/developers to improve the technologies while obtaining operational experience and learning and understanding potential impacts

- From these experiences, improve ways to minimize and avoid impacts.

3.3.2 Themes from Industry: Objectives

The MHK industry fears that the extensive permitting requirements and long permitting timelines will impede the exploration of the potential of MHK technologies to produce renewable energy sustainably and support climate change objectives.

Near-term desires from MHK technology developers include: 1) Consistent leveraging of relevant existing information, models, and best measurement practices to establish risk-based baseline site understanding, and 2) Adoption of adaptive management practices to enable single and small arrays of devices to be deployed, allowing the level of technical and environmental impact learning that must be undertaken to allow the industry to responsibly develop.

3.3.3 Themes from Industry: General Process

General themes of lessons learned from the direct regulatory experience of MHK project developers and test centers have emerged. All organizations recommended early engagement with a broad group of stakeholders to identify all potential project challenges. It was also recommended that clear and effective lines of communication are established to build and maintain trust. All parties must be honest and open, understand regulatory needs and constraints, and deliver on commitments. Other recommendations include clarify regulatory requirements and study needs as soon as possible; initiate adaptive management discussions early in the process; and deliver informed, detailed project applications.

Industry representatives desire that regulatory agencies encourage greater coordination and information sharing among agencies. Industry parties also noted that insufficient intra-agency coordination (e.g., connections between different regional offices and headquarters) has also been a challenge.

3.3.4 Themes from Industry: Risk

Industry representatives questioned whether imposed data requirements from regulatory agencies are always risk-based. The overall perception was that the uncertainty of long-term effects, especially from arrays of devices, has been driving many data asks for single, short-term device deployments. The general feeling was that the MHK industry was being held to different standards for similar potential impacts (e.g., EMF emissions, acoustic noise) than established industries.

The MHK industry has a strong desire for regulatory agencies to collectively identify which perceived risks are the most important and to articulate a methodology or research process to address them. This would include articulating the remaining risks associated with single or small arrays of MHK devices, what definitive studies are needed to address lingering questions around different potential impact areas, and the expected conclusions or defined criteria to determine whether the studies are successful. The industry is interested in working with state, regional, and national regulatory organizations to ensure that the findings of studies that have addressed identified risks are reported and, if additional risks have been identified, what additional studies are required.

3.3.5 Themes from Industry: Data Sources

Questions persist regarding the use of previously completed studies and data applicability across the MHK industry. For example, understanding how to effectively use relevant existing data is another strong industry desire, including ensuring that global observations and relevant data from other industries are being utilized in assessing U.S. project risk.

Additional topics that are being discussed include what is appropriate for modeling based on external or point measurements (e.g., how acceptable are encounter probability models and how such models can be validated, especially when observational data can be hard to obtain). Because MHK technology deployment is still new, additional data- and study-related questions remain, such as accepted protocols/best practices and measurement technologies to ensure, to the extent possible, consistent and accepted study results across technologies, species, geographies, and also between agencies.

3.3.6 Themes from Industry: Monitoring Requirements

Overall, the industry representatives interviewed believe that the present level of required monitoring for single devices, especially for short-term deployments that are typical of testing for technology development, is not aligned with the associated risks nor with what can be learned based on the proposed activities. The industry's objective would be adaptive management and monitoring around remaining risks with thresholds for contingency action.

3.3.7 Themes from Industry: Pre-Permitted Test Centers

There is a strong desire to establish pre-permitted test centers to make it efficient for MHK technologies to begin operating and collecting data, enabling them to mature in reliability and performance in as environmentally benign a manner as possible. These test centers could also be leveraged to better understand/retire some single-device and small array risks.

3.4 Adaptive Management Case Studies

Adaptive management is not a new concept; the practice of studying something and making changes to address identified problems is a powerful tool applied in many permitting schemes.

Definitions of adaptive management are diverse and varied, including:

- "A systematic approach for improving resource management by learning from outcomes" (Williams, Szaro, and Shapiro 2009, p. 1)
- "[A]n iterative approach to managing ecosystems, where the methods of achieving the desired objectives are unknown or uncertain" (California Coastal Commission 1995)
- A process for "evaluating the performance of new management approaches and changing practices over time as experience is gained" (West Coast Environmental Law Glossary 2016).

3.4.1 Green-Versus-Green Regulatory Challenge

From the MHK development community's perspective, some of the environmental policies and processes that drive renewable energy development and those that protect the environment are not well aligned. Climate mitigation is one of the drivers for expanded renewable energy development, which can reduce or offset larger environmental impacts, but then renewable energy projects face substantial barriers from natural resources protection regulation. Balancing the priorities of allowing MHK technology development with its longer-term, positive environmental impacts while honoring the regulatory agencies' different drivers and defined roles continues to be a challenge. Adaptive planning and management strategies and practices have the potential to be one tool that can reconcile these discrepancies, supplementing and enhancing the precautionary principle in wildlife planning for green energy (Koppel et al. 2014).

3.4.2 Perspectives in Adaptive Management in MHK

The perspectives on adaptive management in MHK by the regulatory agencies and the industry are an important contextual element for the development of effective adaptive management programs going forward. Until the risks to the marine environment from MHK projects are better understood, regulatory agencies must take a conservative approach to protection of listed species and their habitats. Ideally, information gained from small-scale projects will also be useful for understanding potential effects as projects scale up while allowing for the development of alternative design approaches that may reduce or eliminate impactful design elements. However, the challenges to studying small-scale projects need to be considered from a basic cost and technology development timeline perspective. The role of and process for adaptive management must be clearly defined and focused. Industry should focus on known high-probability, higher-risk impacts for which successful, targeted monitoring methodologies are available to assess and evaluate minimization and mitigations. Impacts for which the risks or impact severity are relatively unknown, monitoring approaches are experimental or untested, and other more challenging topics should be addressed through defined, co-funded research projects incorporating the organizations most likely to allow successful and scientifically valid conclusions.

Although there is an inherent desire to use the deployment experience from single or small-scale deployments to inform potential larger-scale deployments, the industry feels strongly that knowledge gaps of potential impacts of large-scale array deployment cannot be filled substantively by information collected for short-term, single-device, or small-scale deployments. Participants noted that the flexibility inherent in adaptive management helps in the permitting process but can challenge project financing if not well defined and bounded because it can add significant uncertainty.

3.4.3 Ocean Renewable Power Company Case Study

ORPC presented a brief case study of adaptive management utilization on its Cobscook Bay Tidal Energy Project, which included the deployment of a single TidGen® device. ORPC's regulatory concerns included the Endangered Species Act, the Magnuson Stevens Act, and the Marine Mammal Protection Act. A broadly represented and knowledgeable adaptive management team used best science-based data collection and analysis, and frequent and transparent communication to develop and implement an adaptive management plan. This resulted in such actions as the removal of seasonal restrictions for pile driving based on mitigation methods and measured acoustic levels and a reduction in frequency or elimination of specific monitoring surveys based on increased knowledge of species presence and environmental effects.

3.4.4 Verdant Power Case Study

Verdant Power's Roosevelt Island Tidal Energy (RITE) Project is a multi-year pilot MHK tidal development, deployment, and educational process with 26 agencies and more than 50 non-governmental organizations involved and more than $4 million in environmental studies and a committed $2.3 million in future RITE Project Monitoring of Environmental Effects plans (Verdant Power 2016).

Verdant's project case study was the staged development of up to 30 turbines in the East River in New York City. Regulatory agencies perceived the primary risks to be the effects of multiple turbines and the behavioral aspects of species movement and migration over years. The adaptive management objectives of the RITE project were to relate risk, cost, and knowledge obtained to the size and scale of the project. The monitoring plan, which was established during developer/agency negotiations at the draft license application phase, expands as the number of machines increases. This plan results in refining ongoing monitoring, and where findings substantiate, eliminating future monitoring. In January 2012, FERC issued a pilot commercial license (FERC No. P-12611) for the installation of up to 30 turbines, although to date no turbines have been installed.

Verdant's adaptive management philosophy has the following components:

- **Monitor operations:** Apply best known techniques
- **Adjust monitoring:** Interactive discussion of data with all relevant regulatory parties leading to adjustment of monitoring parameters and technology as needed
- **Adjust operations:** Understanding that the ultimate purpose of the project is to generate electricity and adapt operations when necessary based on measured impacts and discussion with relevant regulatory organizations
- **Stop/remove:** Again based on monitored observations and discussion with relevant regulatory organizations, remove the equipment if mitigation or minimization strategies cannot be identified.

Verdant's current perspective is that a Catch 22 exists: How can you understand the effects if you don't test, and how can you permit testing if you don't know the effects? The applied adaptive management strategy should help address this paradox.

To enable successful MHK deployments, Verdant staff suggests establishing a small, knowledgeable working group of geographic diversity regulatory agencies to address larger questions of appropriate regulation. They recommend matching prioritized natural resource issues to monitoring scales and developing monitoring methods and protocols to answer these specific uncertainties. Verdant recommended that adaptive management be implemented in a staged but defined manner. Based on their experience, Verdant staff believes that the MHK regulatory process is streamlined by the FERC pilot regulatory process but felt that bilateral (both agencies and the developer) awareness and participation during pilot operation is essential. The company's representatives also support the parallel funding of long-term macro studies by academia and DOE labs to support implementation of a U.S. industry.

4 Research Needs and Knowledge Gaps Discussion Summary

The workshop presentations and discussions provided background for discussion of research needs and knowledge gaps. As part of this dialog, a synthesis of the earlier presentations provided guidance for the group; several themes emerged, including:

- There should be a distinction between research needs and knowledge gaps that should be addressed as a permit requirement. Monitoring and adaptive management should be conducted where uncertainties and risk are high. Research should be conducted collaboratively between researchers, agencies and industry, but ultimately there should be an open discussion about who should bear the responsibility to address and fund research versus knowledge gaps that can affect permitting.

- The need for extensive baseline and effects monitoring and studies when project effects are likely to be negligible or indiscernible is likely not warranted.

- Topic areas in which environmental effects are already reasonably understood need not undergo extensive monitoring.

- The role of modeling or simulations to provide reasonable bounds for uncertainty should be readily applied as an initial approach to addressing potential impacts.

In all of these cases, any required monitoring should apply the concept of proportionality, in which the potential risks are linked to the baseline information needed and monitoring, followed by adaptive management, is applied commensurate to the risks.

Table 2 provides an overview of the resulting discussion in relation to the four areas addressed as part of the workshop.

4.1 Collaborative Interchange of Project Permitting and Research

There is a need to be cognizant of these knowledge gaps given the realities of what we:

- Must know for obtaining project permits

- Would like to know because of uncertainties and scientific interest (e.g., research)

- Can actually feasibly evaluate giving consideration to the cost, the risks to resources, size and scale of potential effect given natural variability, and feasibility of getting sufficient information to adequately address hypotheses and objectives.

The overarching issue is that the monitoring cost is high, including the equipment, implementation, upkeep, and information processing. The relevance of the information gained being applied to the resolution of high-risk issues associated with a project under permit should lead the need for monitoring and how monitoring is funded.

Table 2. Recommendations for Monitoring and Research from Workshop Presentations and Discussions

	Monitoring for Single Devices/Demonstration-Scale Projects	Research for Single-Device/Demonstration-Scale or Commercial-Scale Projects
Operational Noise	• Information collected to date indicates that operational devices are typically less noisy than other anthropogenic sources. • Monitoring is generally not warranted as significant acoustic impacts are unlikely and difficult to distinguish from background noise.	• Data collection at demonstration scales may be appropriate, if detectable, to inform modeling for larger-scale arrays. • Research on biological and behavioral implications of sound and particle motion would be helpful.
Electromagnetic Fields	• No significant effects to organisms have been observed to date. • Monitoring is generally not warranted since EMFs are likely to be low intensity and approach background levels within a few meters from the source.	• EMF emissions are relatively scalable as power and voltages increase but the responses of any receptive animals are not; thus research on single devices or small-scale arrays may not be directly transferable to larger-scale projects. • Existing energy subsea cables can be utilized to assess EMF levels and animal behavioral responses.
Physical Interactions (Strike)	• No physical interactions have been observed in the field. Lab experiments have found that fish can easily detect and avoid or swim around turbines and have very high survival rates when forced to pass through turbines. • Any required monitoring should be based on risk posed at the project of interest and should consider that strike events are likely to be rare, difficult to detect, and very costly to monitor.	• Research to better understand the risk of strike and development of predictive models (e.g., location in the water column relative to the device, avoidance and evasion behaviors) and identification of potential mitigation actions would be helpful.
Impacts on Physical Systems	• Numerical modeling consistently predicts that arrays <10 devices will have minimal impact on wave heights, flow patterns, and sediment transport. • Monitoring is generally not warranted as impacts from a single device or small arrays will likely be minimal.	• Impacts of larger arrays are unknown and will require more research. Data from eventual large arrays are needed to validate predictive models.
For the purposes of the workshop and this table, “monitoring” was defined as activities required of the developer by federal, state, or local entities to assess project impacts during operations and to fulfill legal regulatory obligations. The level of monitoring should be based on the level of assessed risk/potential project impact posed by the project in question and should be directed to address specific objectives. “Research” is performed to fill gaps in understanding and answer questions beyond those required to meet fundamental legal or regulatory mandates. Research is typically performed by academia or government agencies.		

The group discussed four key questions, concluding:

The need for an umbrella collaborative or organization to serve as a central clearinghouse for global research and monitoring needs within the MHK industry. The collaboration among industry, scientists, agencies, and environmental groups can set the stage to resolve remaining environmental issues by researching technology innovations, providing science to support policy and decision-making, and providing for information exchange to decrease uncertainties.

- A spectrum of collaboration could be considered, ranging from the collection of research projects (as demonstrated by the Tethys Knowledge Base); coordination of international research (such as the OES Annex IV); coordination and collaboration, including the development of research roadmaps (as has been conducted by the American Wind Wildlife Institute); or an organization that consolidates and then funds research (exemplified by the Bats and Wind Energy Cooperative).

- As some experts indicated, there is a need to share information gathered at specific projects with the research community so that models and their predictive capabilities can be improved upon to allow application to address environmental uncertainty for future projects and project build-out scenarios.

- The idea of a public-private partnership, in which industry can provide data for specific topic areas to researchers, should also be considered. Also by pooling expertise and funding, it may be possible to support research projects to address larger questions that affect multiple projects.

- There are significant differences among regions regarding the level of monitoring and obligation of industry. In addition, the onus on industry to evaluate potential environmental effects seems out of proportion to the environmental risks. Understanding the continuum of risk, including the potential for impact and the effects of those impacts, could be a role that a collaborative group could address.

Because natural variability in marine environments is high and events/interactions of concern are likely to be rare, the ability to detect effects using traditional monitoring tools is very low. Monitoring approaches and technologies, especially those that need to detect relatively rare events, are under development but are not yet readily available.

- There is a need to develop monitoring technologies that can be deployed in harsh ocean conditions over long time periods, can perform reliability at all time periods (e.g., some effects may only occur at night where light levels are low or only during high sea states), and can provide that information in a timely manner.

- The development, demonstration, and validation of new monitoring devices should be performed in a collaborative research setting, with biologists, engineers, and others working to develop the technologies and approaches for data gathering, data storage and analysis, and interpretation. Permitting authorities should consider this issue when determining monitoring needs for a specific project. Some questions cannot be adequately addressed through methods and instrumentation that are currently available without tremendous effort and cost.

A NEPA database could provide a useful source of information for future project permitting. NEPA is a requirement for project permitting; therefore, a focused impact study is conducted on every project. As more projects get permitted, the environmental analyses should become increasingly informative and uncertainties should decrease (either because no or minimal impacts are found or because adaptive management enables ways to identify impacts and avoid, minimize, or mitigate impacts).

Addressing research needs and knowledge gaps through studies and monitoring can be very costly, so it is necessary to consider how the available limited funding could help inform 1) improvements to models/simulations to increase certainty and predictability, 2) future/new projects, and 3) scale issues (e.g., commercialization from small-scale to larger arrays).

- The group felt that the issue of EMF emissions is sufficiently complex and has far too many uncertainties (especially understanding the ability of animals to detect project-generated EMFs and their behavioral responses at the power levels of current MHK devices) and that it belongs in the research realm using a collaborative approach, rather than evaluating effects on a project-by-project basis. In addition, studies on animal detection and behavior are best done in laboratory and experimental field settings where factors can be controlled for.
- Sound generation was another area where baseline information is important because sound will be site-specific due to background anthropogenic sources, seabed composition, bathymetry, and other factors. However, the collection of baseline information is likely only necessary when trying to understand how the acoustic condition for a site has changed, based on deployment. It is not anticipated that this will be necessary for small-scale and/or temporary installations. Such baseline studies may be helpful to advance modeling efforts and improve predictive capability for future projects or commercialization. To put sound into context, there needs to be an understanding of the potential impact at different sound levels, risks to species of concern, and how to determine mitigation actions when sound becomes a concern.

4.2 Needs for Site Characterization and Environmental Baseline Assessment

As part of project permitting, there are requirements for site characterization and environmental baselines from which to evaluate potential project effects. Many of the presenters indicated that for small-scale MHK projects (e.g., <10 devices), many of the potential environmental effects (e.g., entanglement, behavior/use, reefing, benthos, EMFs) are likely either negligible and/or predictable at this scale. The group discussed three follow-up questions:

Do we know enough about some topics to be able to permit/license sites without baseline assessments?

- Workshop participants discussed issues at the small project scale that would require baseline studies. For smaller or temporary projects, there was consensus that we have sufficient information on the potential effects/levels of EMFs, benthic disturbance, and effects to seabirds at tidal turbines to not warrant baseline monitoring at this scale. However, some site characterization and baseline monitoring will be important for addressing potential for certain project effects, including ambient acoustic measurements, identification of species that might be susceptible to tidal turbine blade strike (e.g., which species/life stages and probability/timing of presence) to inform strike risk models, and characterization of benthic environment to inform physical model/simulations.

- In addition, participants recognized that BOEM is conducting baseline biological monitoring of the outer continental shelf that should be helpful for characterizing specific biota (e.g., seabirds, benthos), which should decrease the amount of additional baseline monitoring for a project at a given site. BOEM- and DOE-supported syntheses will also be helpful for providing the state of the science, which should inform additional needs for baseline monitoring.

What thresholds are there to indicate that a baseline assessment is insufficient for permitting and additional field studies should be undertaken?

- Acoustic thresholds have been suggested for some animal groups, and baseline monitoring should inform pre-project levels of sound to put thresholds and project effects into context.

- However, for other baseline needs there are no available thresholds for permitting or identifying needs for continued or additional field studies. The regulatory agencies and developers should work together with scientists to develop realistic monitoring objectives considering the level of effort needed to document an effect (e.g., is baseline monitoring being conducted to evaluate effects after project installation, and if so, are the methods and monitoring technology appropriate to detect changes?). It is important to address these objectives such that once monitoring results indicate environmental effects are within an acceptable range, monitoring can cease or be scaled back appropriately.

- Furthermore, monitoring objectives should focus on environmental effects that are likely to have high uncertainty and a high risk to resources. Monitoring should focus on times or seasons, or locations, when/where risks are greatest. An adaptive management process would be a good means for implementing monitoring and evaluation of results.

How many years of baseline information are needed?

- The number of years of baseline observation will depend on the objectives of the baseline effort. If the objective is to provide site characterization information, less than 1 year may be sufficient depending on what is known about the location in question. However, if the purpose is to provide baseline for a before-after-control-impact study, then several years may be necessary. For example, evaluating whether species avoid a project area after implementation may require more than 1 year establishing pre-project use of the project area. The length and goals of the expected deployment should also be considered, however. Conducting extensive pre-project deployment to understand current use is unnecessary if the deployment is limited in size and scale such that avoidance would be difficult or impossible to detect.

4.3 Role of Modeling and Simulation to Address Uncertainties

For many potential project effects, modeling and simulation can help address or bound uncertainties. For example, what effects can be modeled or simulated with sufficient robustness (e.g., EMFs, acoustics, strike, physical environment)? Can such modeling substitute for baseline and effects monitoring for informing environmental impact assessment and ESA consultation? Understanding that model validation requires observational data, are we at a stage for model development in which further investment of research funding would be better spent in developing and validating models as compared to conducting more field measurement (i.e., should we focus on the sensitivity of specific model parameters that affect model predictions for effects that are well understood compared to the collection of additional field data from more geographic locations)?

- Strike and collision modeling should be able to characterize the risk for small or large projects, using simple baseline information such as species, probability of presence, and project location in the water column, similar to what has been done for wind projects. One consideration is that models could be parameterized collaboratively by researchers, industry, and regulators so that there is agreement on the ranges of model parameters, allowing a stronger focus on the sensitivity of parameters that have the greatest effect on model results.

- Although it is likely that small-scale projects will have minor impacts to the physical environment, collecting information at projects would be useful to improve relevant models, especially for application toward commercial development. However, extreme care must be taken from a regulatory perspective in differentiating between data that should be collected as part of the regulatory monitoring requirements and data that could be collected opportunistically when deployments occur that will help advance the industry as a whole. Since opportunistic data collection would go beyond the needs of the permitting of specific projects, this is a good example of research/industry collaboration for addressing knowledge gaps by providing project-specific information and pooling resources.

- EMF modeling (generation of EMF by a project) has the potential to support or replace the use of measurement data, but models have to be validated first; current information indicates that models are reasonably accurate. It would be helpful to conduct opportunistic project-specific monitoring to address uncertainty around existing measurement and modeling options. However, the uncertainty is greater with interpreting model outputs (e.g., the effects of differing levels of EMFs on organisms), which would require research in laboratory settings and focused field efforts.

5 Conclusion

The workshop provided a good opportunity for regulators to hear directly from leading researchers and learn what is known and unknown regarding the deployment of MHK technologies. The ability for members of the regulatory community to engage in dialog with the researchers also helped expand their understanding of important topics, and collaborative discussion provided insight that can empower regulators to determine the appropriate level of regulation for the MHK industry.

The general conclusion was that early device deployment baseline and monitoring requirements were not necessarily commensurate with the uncertainties and potential risks of specific small-scale deployments and that in some instances, too much emphasis has been placed on studying potential effects of large-scale array deployment as compared to assessing observable and likely impacts given the current deployment of single devices and small-scale arrays. At the same time, given the early stage of the technology's development, the group discussed the need for continued research by government and academia to gain further understanding of potential project impacts at larger commercial scales.

Given the current understanding of risk levels associated with small and temporary project development, assessments of perceived risk and monitoring needs, combined with actionable adaptive management strategies so that any issues that are identified can be rectified or mitigated, should be applied. Without such an approach, the ability of MHK technologies to develop through a process of single-device and small-scale serial deployment, leading to a low-cost and low-impact technology that can be deployed at commercial scale, will be very difficult.

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Appendix A: Annotated Agenda

Following is a brief summary of each workshop session.

Regulatory Introduction: Roles and Responsibilities within the Permitting Process

Speaker: Anna West, Kearns & West

Purpose: to provide a broad overview of the state and federal regulatory process. Topics explored included identifying the agencies involved in the permitting process and clarifying their roles and responsibilities, legal jurisdiction, focus areas, inputs to consider, and challenges they face in the application process. The presentation also reviewed the project permitting and licensing process.

MHK Technology Overview

Speaker: Ryan Sun Chee Fore, U.S. Department of Energy

Purpose: to provide an overview of the primary MHK technologies and systems that are being developed to capture wave, tidal, ocean, and river current energy resources. The presentation focused on key operational concepts and impacts, as well as recent and existing demonstration projects and testing sites. Although no large MHK arrays have been deployed, Sun Chee Fore discussed contemporary research and the availability of wind research that could be leveraged.

Introduction and Overview of Environmental Issues and Processes

Speaker: Sharon Kramer, H.T. Harvey & Associates

Purpose: to discuss the environmental issues and processes relevant to MHK energy generation and project implementation. This session explored current research and case studies on potential environmental effects, what has been measured and observed during the course of research, and processes for evaluating potential effects.

Physical Interactions with MHK Devices

Speaker: Jocelyn Brown-Saracino, U.S. Department of Energy

Purpose: to present the current state of understanding of risks and issues associated with direct and indirect physical interactions among MHK devices and systems, moorings, electrical interconnections, and marine species. This session looked at the probability, consequences, and effects of strike events as well as survival rates and avoidance behavior in fish and mammal populations.

Acoustic Output from MHK Devices

Speaker: Chris Bassett, Woods Hole Oceanographic Institute

Purpose: to address the acoustic impact of MHK deployment and operation on ocean ecosystems and marine systems, providing a better understanding of sound variables and the measurement and assessment methodologies used to determine this impact. Areas with additional data needs and continued study were identified.

Effects of MHK Development on Physical Systems

Speaker: Jesse Roberts, Sandia National Laboratories, and Craig Jones, Integral Consulting

Purpose: to present the environmental effects of marine energy development on physical systems within the ocean space, including the change of local ocean ecosystems due to the installation of new MHK devices. Roberts and Jones discussed how the physical environment is changed, whether the changes are significant and cause for concern, and whether effective mitigation strategies exist.

IEA Annex IV and Tethys Database Demonstration

Speaker: Hoyt Battey, U.S. Department of Energy

Purpose: to provide an overview of IEA Annex IV's ongoing research activities on the environmental effects of marine energy devices and introduce the Tethys Knowledge Base of information on environmental effects of MHK and offshore wind development.

Electromagnetic Force from Tidal and Wave Systems and its Impact on Marine Animals

Speaker: Andrew Gill, Cranfield University

Purpose: to discuss undersea power networks and EMF emissions from undersea AC and DC cables and present the current state of knowledge regarding the effects of emitted EMFs from marine renewable energy cables on marine organisms. Field data and case studies from around the world helped establish an understanding of the interaction between EMF and a variety of species, as well as identified remaining questions requiring further research and measurement campaigns.

Lessons Learned from the Wind Industry

Speaker: Ian Baring-Gould, National Renewable Energy Laboratory

Purpose: to review the growth of the wind industry and how lessons learned have altered site selection, regulation, and the application of adaptive management processes. Comparisons between the marine energy industry and the path of the wind industry were made and potential relevance of lessons learned were identified.

Federal and State Agency Roundtable: Perspectives on the Permitting Process

Moderator: Anna West, Kearns & West

Panelists: Casey Reeves, Bureau of Ocean Energy Management; Stephen Bowler, Federal Energy Regulatory Commission; Joshua Gange, Jeff Murphy, National Ocean and Atmospheric Administration; Jim Beyer, Maine Department of Environmental Protection

Purpose: to allow regulators to obtain a perspective from other regulators, supporting better collaboration and coordination between organizations at the state and federal levels. Representatives discussed current challenges and recommendations, baseline information, data gathering and monitoring requirements, as well as ways that both regulators and industry can approach a project to best navigate the process.

Information and Perspectives from Industry

Speaker: Al LiVecchi, National Renewable Energy Laboratory

Purpose: to discuss experiences with the regulatory process and monitoring requirements from the developer perspective. Questions and experiences related to inter- and intra-agency coordination, risk-based approaches, data sources, measurement protocols, and measurement and monitoring requirements were posed as participants explored what has and has not worked well in the past and what could be done differently in future projects.

Adaptive Management Case Studies Roundtable

Moderator: Al LiVecchi, National Renewable Energy Laboratory

Panelists: Nate Johnson, Ocean Renewable Power Company; Jim Beyer, Maine Department of Environmental Protection; Ron Smith and Mary Ann Adonizio, Verdant Power Inc.

Purpose: to define adaptive management, explore how it has been applied in other industries, and highlight the challenges of implementation through the framework of recent MHK case studies. Participants and panelists also discussed recommendations for effective implementation of adaptive management and the role of project scope and scale in designing adaptive project approaches.

Breakout Discussions: Knowledge Gaps and Research Needs

Moderator: Sharon Kramer, H.T. Harvey & Associates

Purpose: to consider the information presented during the workshop and identify remaining knowledge gaps and additional information needed to make regulatory decisions regarding MHK technology deployments. Participants discussed near-term and future regulatory information needs, how project scale influences potential impact and monitoring requirements, and how the burden of greater research needs should be addressed through efforts from government laboratories, agencies, and educational institutions.

Appendix B: Additional Session Information

Applicable Laws and Executive Orders

Section 1.3 referenced a list of more than 22 applicable laws and executive orders that are relevant to permitting and licensing MHK projects in the United States. The following list identifies those laws and executive orders:

- National Environmental Policy Act
- Endangered Species Act
- Marine Mammal Protection Act
- Magnuson-Stevens Fishery
- Conservation and Management Act
- Marine Protection, Research and Sanctuaries Act
- National Marine Sanctuaries Act
- E.O. 13186 (Migratory Birds)
- Coastal Zone Management Act
- Clean Air Act
- Clean Water Act
- E.O. 13547 (Stewardship of Oceans, Our Coasts and the Great Lakes)
- Ports and Waterways Safety Act
- Rivers and Harbors Appropriations Act
- Resource Conservation and Recovery Act
- National Historic Preservation Act
- Archaeological and Historical Preservation Act
- American Indian Religious Freedom Act
- Federal Aviation Act
- Federal Power Act
- E.O. 13007 (Indian Sacred Sites)

- Marking of Obstructions.

Knowledge Gaps and Research Needs: Summary Table

During the Knowledge Gaps and Research Needs session, participants and topical experts identified major topic areas and discussed whether the burden of filling current knowledge gaps lies with industry or with public entities such as government research laboratories and agencies, regulating entities, or educational institutions. For the majority of topic areas and for smaller, temporary projects, participants concluded that the responsibility for filling the knowledge gap and meeting research needs was with public entities. A few areas required additional baseline data-gathering campaigns for site-specific information. Given the current state of technology deployment, knowledge gaps and research needs were not discussed for multi-device arrays. Table 2 summarizes this discussion.

IEA Annex IV and Tethys Knowledge Base

IEA Annex IV is an international collaborative project established by the International Energy Association's Ocean Energy Systems,[24] with 13 member nations involved as of February 2016. The goal of Annex IV is to examine environmental effects of marine energy devices and environmental research studies from around the world, making existing information available and accessible to marine energy researchers, regulators, developers, and stakeholders.

One of the outcomes of the initial IEA Annex IV work to compile and disseminate information was the development of the Tethys[25] Knowledge Base. The database is a knowledge management system that gathers, organizes, and disseminates information on the environmental effects of MHK and offshore wind energy development. The information provided is not limited to literature and media; it includes project information and a map viewer and provides a collaborative research space for the exchange of technical information on the effects of wind and marine renewable energy devices and their components.

[24] https://www.ocean-energy-systems.org/oes-projects/task-4-assessment-of-environmental-effects-and-monitoring-efforts-for-ocean-wave-tidal-and-current-energy-systems/
[25] http://tethys.pnnl.gov/

Appendix C: Key Contacts

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Appendix D: Organizational Participant List

Organizations that participated in the 2015 MHK Workshop:

- Cranfield University
- Bureau of Ocean Energy Management (BOEM)
- Bureau of Safety and Environmental Enforcement (BSEE)
- Federal Energy Regulatory Commission (FERC)
- H.T. Harvey & Associates
- Kearns & West
- Maine Department of Environmental Protection
- National Oceanic and Atmospheric Administration (NOAA)
- National Renewable Energy Laboratory (NREL)
- Naval Facilities Engineering Command (NAVFAC)
- New West Technologies, LLC
- NOAA National Marine Fisheries Service (NMFS)
- Ocean Renewable Power Company (ORPC)
- Sandia National Laboratories (SNL)
- State of Maine Department of Marine Resources
- U.S. Coast Guard
- U.S. Department of Energy (DOE)
- U.S. Marine Corps
- U.S. Navy
- Verdant Power Inc.
- Woods Hole Oceanographic Institution (WHOI).

Appendix E: Industry Input

Questions regarding the regulatory process posed by the MHK deployment community collected as part of an industry interview process completed by NREL staff prior to the workshop:

- Describe your experience with deploying MHK device(s) in the water and collaborating with regulatory agencies. What has worked well? What has not worked well? What are key lessons learned to date? What opportunities exist to make these collaborative efforts more efficient and effective?
- Have any (perceived) risks been retired and, if so, is there widespread regulatory awareness of these? What key studies are still needed to retire key perceived risks?
- How are data generated by project developers viewed differently than data provided by third parties (industry contractors)?
- What types of data and information have been transferable between sites? Between different projects at similar sites (e.g., nearby activities/structures)?
- What measurement protocols/best practices and technologies/sensors exist, and how is the acceptability of these being captured and shared within and between agencies?
- Describe your experience with developing and implementing adaptive management approaches.