

Prioritized Research, Development, Deployment and Demonstration (RDD&D) Needs:

Marine and Other Hydrokinetic Renewable Energy

Final Report, December 2008

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PRODUCT DESCRIPTION

Results and Findings

Through engaging a national set of stakeholders, EPRI identified and prioritized research, development, deployment and demonstration (RDD&D) needs for the emerging marine and other hydrokinetic renewable (MHK) energy technology sector. Eighteen (18) topical RDD&D needs areas were identified. The prioritization resulted in the following top three topics:

- #1 – Testing (development including experimental through pilot demonstration)
- #2 – Environmental Issues (which will require device testing and deployed projects)
- #3 – Standards

Challenges and Objectives

This document is aimed at technology developers, project developers, policy makers, the U.S. Department of Energy, State Energy Agencies, National Laboratories, investors (public and private), the supply chain, consultants, regulators and academics to aid in understanding the prioritized RDD&D needs for MHK sector progression towards commercialization.

Marine and other hydrokinetic (MHK) energy may be among the last of the large natural resources for which the electricity generation potential in the United States has not yet been determined. There are five types of MHK energy: wave, tidal currents, ocean currents, free flowing river currents and ocean temperature differentials.

The United States faces many challenges as it prepares to meet its energy needs of the future. A convergence of forces is coming together at this time in history and may result in a new economy; one that is built on sustainable energy. These forces include economic crises of the old economy, awareness of global climate change, awareness of the need for a greater degree of national energy independence and state renewable portfolio requirements. Supply disruptions, rising and volatile energy prices, the domestic supply infrastructure and vulnerability to foreign supply are all concerns. Many (including EPRI) believe that we need a balanced and diversified mix of energy supply options in our national portfolio. We as a nation have investigated all known large sources of energy from fossil fuel, nuclear and many forms of renewable supplies such as conventional hydropower, solar, wind, biomass and geothermal. One large source that we have just begun to investigate is the use of the MHK energy; the energy in our ocean waves, our tidal, ocean and river currents and in the temperature differences in our oceans. This

investigation is responsive to the public interest and mandate to develop, deploy, demonstrate and implement new renewable energy technology.

Applications, Values, and Use

Numerous project and device developers have initiated wave power plant projects off the shores of many countries. European governments (particularly in the UK, Ireland, Portugal, Spain, Norway and Denmark) as well as those in Japan, New Zealand, and Australia, support MHK RDD&D technology and are now providing incentives to stimulate a commercial market.

The U.S. DOE initiated a Waterpower R&D Program in FY 2008 with a congressionally mandated \$10 million. The Senate and House mark up appropriation bills for FY 2009 are between \$30 and \$40 million. The DOE FY 2009 budget is currently under a continuing resolution.

Technology development and early commercialization projects, including multi-megawatt “wave farms” will be realized over the next decade in Europe and Australia (and in the U.S. if funding is appropriated and if barriers to development are overcome).

EPRI Perspective

EPRI believes that a reliable and robust electrical system in our nation requires a diversified and balanced portfolio of energy supply alternatives. There is a need to develop, deploy, demonstrate and implement new sources of environmentally responsible renewable energy. One of these new renewable energy sources is marine and other hydrokinetic (MHK) technologies.

Approach

The goals of the report were reached by engaging a large number of MHK stakeholders, both in a workshop setting and through contacts prior to the workshop, to identify the RDD&D needs and to prioritize those needs.

Keywords

Marine energy

Water power

Wave energy

Ocean current energy

Ocean thermal energy

Ocean energy

Hydrokinetic energy

Tidal energy

River current energy

ABSTRACT

A workshop was held to identify and prioritize the research, development, deployment and demonstration (RDD&D) needs of the marine and other hydrokinetic (MHK) energy industry. A broad set of participants included representatives from Federal and State government, national laboratories, non governmental organizations, academia and private industry. Eighteen (18) RDD&D topical areas were identified and prioritized. Five MHK types were covered: 1) wave energy, 2) tidal in-stream energy, 3) ocean current energy, 4) free flowing river in-stream energy and 5) ocean thermal energy. Each topical area consists of multiple subtopics. The three highest prioritized topical areas were:

- 1). Testing (development including experimental through pilot demonstration)
- 2) Environmental Issues (which will require device testing and deployed projects)
- 3) Standards

A topic that generated significant discussion in the workshop was the need for an additional workshop as soon as possible to reach an industry-wide vision, goal, objective and roadmap for developing and deploying MHK technology in the United States. The consensus recommendation from this workshop is that such a vision would provide a rationale for a funded program (public and/or private program). Once funding is available, specific programs and projects for high priority topics identified in this workshop should be developed and implemented.

Relative to the specific, measurable, achievable, realistic and time lined (SMART) objectives, the consensus opinion expressed in the workshop is that the industry should set the bar (i.e., the vision, goals and objectives) as high as realistically achievable. The bar statement might be one similar to the UK bar, a specified installed capacity by a specified year. This bar along with the RDD&D needs and the timelines would help to define the funding requirements. Setting the bar and setting the prioritized RDD&D needs is an iterative process. Therefore, caution should be taken when considering the current list of prioritized needs which were defined and prioritized before setting the bar.

Once funding is available, specific programs and projects for high priority topics identified in this workshop should be developed and implemented.

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1. INTRODUCTION

The United States faces many challenges as it prepares to meet its energy needs of the future. A convergence of forces is coming together and may result in a new economy; one that is built on sustainable energy. These forces include the current economic crises, awareness of global climate change, awareness of the need for a greater degree of national energy independence and state renewable portfolio requirements. Supply disruptions, rising and volatile energy prices, the domestic supply infrastructure and vulnerability to foreign supply are all concerns. Many believe that we need a balanced and diversified mix of energy supply options in our national portfolio. We as a nation have investigated all known large sources of energy from fossil fuel, nuclear and many forms of renewable supplies such as conventional hydroelectricity, solar, wind, biomass and geothermal. One large source that we have just begun to investigate is the use of marine and other hydrokinetic (MHK) energy; the energy in our ocean waves, our tidal, ocean and river currents and in the temperature differences in our oceans. These are renewable energy resources that can be converted to electricity without green house gas emissions. Given proper care in design, deployment and operation, MHK energy has so far demonstrated the potential to be an environmentally benign source of electricity generation.

The oceans are public resources held in trust and accommodating multiple uses including fishing and recreation as illustrated in Figure 1-1. The ocean is also home to marine mammals and fish. The question our country needs to answer is how much MHK energy can reasonably be extracted without significant environmental effects, what would it take to do so and what are the impacts in terms of funding required and conflicts with other uses of the sea space?



UWVEBOB

Figure 1-1
The Oceans Accommodate Multiple Uses

Marine and other hydrokinetic energy may be among the last of the large natural resources not yet investigated with significant electricity generation potential for the United States. The oceans

cover approximately 70% of the Earth's surface and are our largest collector of solar energy. The U.S. has significant MHK energy resources. The technologies to convert these resources to electricity, albeit, in their infancy, have now been developed and many commercial projects are expected to be deployed in the next 5 to 10 years.

The Electric Power Research Institute (EPRI) led a national-level multiple-stakeholder workshop in October 2008 for the purpose of a identifying and prioritizing research, development, deployment and demonstration (RDD&D) needs of the emerging Marine and other Hydro Kinetic (MHK) industry

This document is aimed at technology developers, project developers, policy makers, the U.S. Department of Energy, State Energy Agencies, National Laboratories, investors (public and private), the supply chain, consultants, regulators and academics to aid in an understanding the prioritized MHK RDD&D needs.

1.1. Background

The Marine Renewable Energy Act of 2007 passed by the US Congress defined the term “marine and other hydrokinetic renewable energy” as meaning energy from:

- ✓ Waves, tides and currents in oceans, estuaries and tidal areas;
- ✓ Free flowing water in rivers, lakes and streams;
- ✓ Free flowing water in man made channels, including projects that utilize non-mechanical structures to accelerate the flow of water for power production purposes; and
- ✓ Differentials in ocean temperature (ocean thermal energy conversion).

Furthermore, the Act specifies that the definition of MHK shall not include energy from any source that uses a dam, diversionary structure, or impoundment for power production purposes.

The US Marine Hydrokinetic Energy Resource

Whereas we have a good understanding of the available wave energy resource, our understanding of how much of that resource can be used to generate electricity is poor. Our understanding of the other ocean energy forms is also poor as described in Table 1-1.

**Table 1-1
Summary of Current Understanding of MHK Energy Resources**

	Wave	Tidal	Ocean Current	River	Ocean Thermal
Primary Resource Potential	Good	Fair	Poor	Poor	Poor
Technical Extractable Limit	Fair	Poor	Poor	Poor	Poor
Practical Extractable Limit	Poor	Poor	Poor	Poor	Poor

Wave Energy Resource

The wave power density $(P/L)_{\text{wave}}$ of a given sea state, in kilowatts per meter of wave crest width, is given by the following equation:

$$(P/L)_{\text{wave}} = k H_s^2 T_z \text{ [kW/m]}$$

where H_s^2 is the significant wave height in meters squared, T_z is the mean or zero-crossing wave period in seconds and k is a constant usually ranging from 0.4 to 0.6 depending on the relative amounts of energy in the short-period wind driven component and the longer-period swell component of a given sea state.

EPRI has estimated the U.S. wave energy resource from decades of wave height and period measurements by NOAA and Scripps data buoys. The analysis used the methodology described in EPRI Report WP-001 [Ref 1]. The available wave energy resource is about 2,100 TWh/yr (for all state coastlines with an average annual wave power flux > 10 kW/m). This energy is divided regionally as follows:

- New England and Mid-Atlantic States = 100 TWh/yr
- Northern California, Oregon and Washington = 440 TWh/yr
- Alaska (Pacific coastline only) = 1,250 TWh/yr
- Hawaii and Midway Islands (northern EEZ border)= 330 TWh/yr

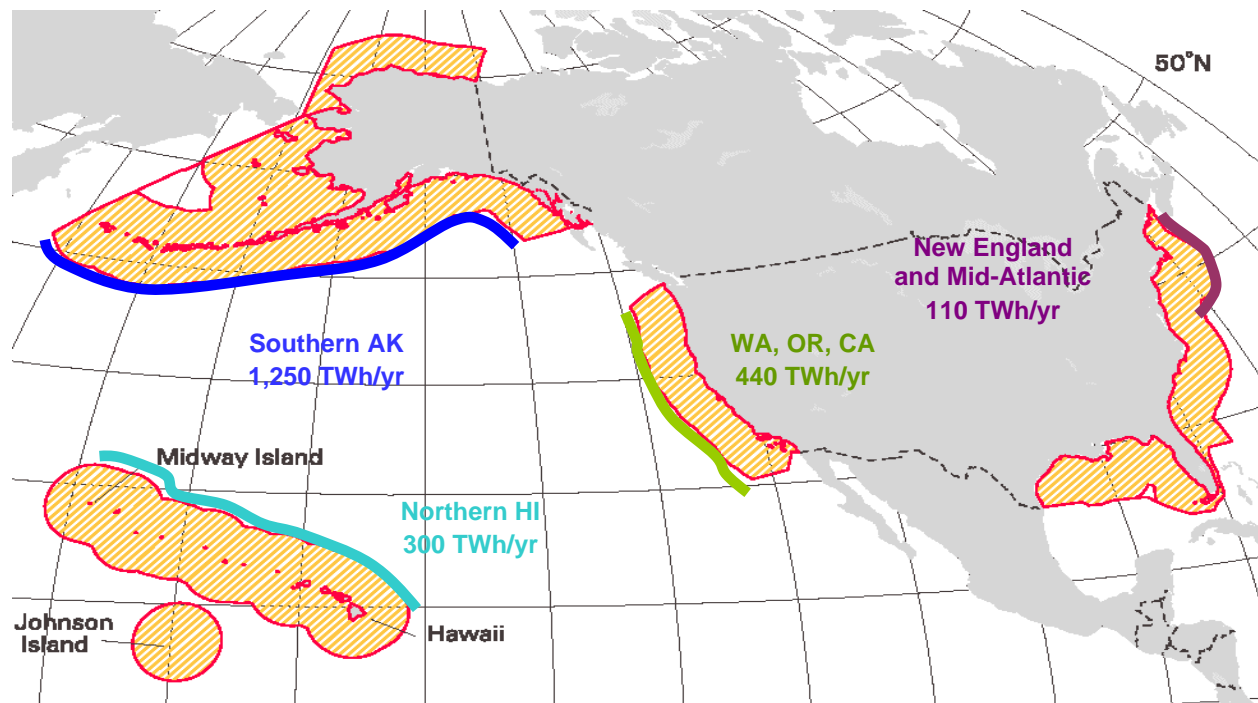


Figure 1-2
US Ocean Wave Energy Resources

Tidal, Ocean and River Current Energy Resources

The in-stream hydrokinetic power density $(P/A)_{\text{tidal}}$ at a given tidal, ocean current or river speed in watts per meter squared of turbine rotor swept area, is given by the following equation:

$$(P/A)_{\text{tidal}} = \frac{1}{2} \rho U^3 \left[\text{W/m}^2 \right]$$

where ρ is the density of fresh water (1,000 kg/m³) or seawater (1024 kg/m³), and U^3 is the speed of the tidal, ocean or river current (m/s) cubed. Annual depth-averaged power densities for commercially interesting sites in the United States range from about 1 to 5 kW/m².

Tidal Currents

Good hydrokinetic tidal energy sites typically occur in narrow passageways between oceans and large estuaries or bays. The in-stream power on a transect of that passageway is the product of the annual average kinetic power density and the cross-sectional area of the transect. The kinetic power density varies vertically from the surface to the bottom as well as across the width. As a first order estimate of the available energy across a given transect, single-point current predictions and bathymetric data from the National Oceanographic and Atmospheric Administration (NOAA) may be used, but, this generally requires extrapolation of stream speeds vertically and horizontally from the reference point. The methodology for estimating the tidal power on a single transect is described in EPRI Report TP 001 [Ref 2]

EPRI has studied many, but not all, potential U.S. tidal energy sites. The tidal energy at all sites evaluated by EPRI to date is estimated to be 115 TWh/yr with 6 TWh/yr at sites in the continental U.S. and the remaining 109 TWh/yr in Alaska as shown in Figure 1-3. Large high power density sites exist in Southeast Alaska, Cook Inlet, and the Aleutian Islands. Tidal hydrokinetic energy resources may be a locally important resources for the following regions in the lower 48 states; Maine, New York, San Francisco and Washington's Puget Sound. The 115 TWh/yr estimate excludes sites with annual average power densities less than 1 kW/m². If in-stream energy conversion device technology is economical at power densities less than 1 kW/m, then the available resource in the lower 48 states could be much greater.

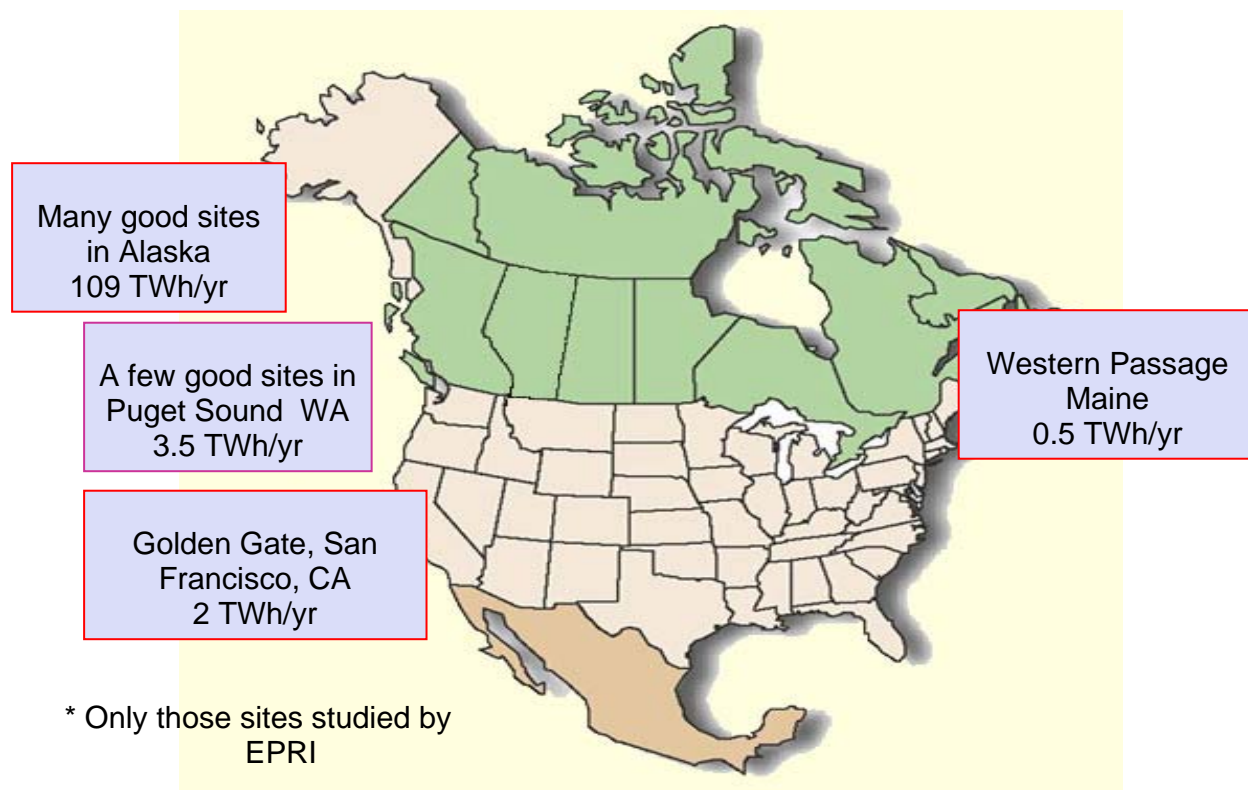


Figure 1-3
US Tidal Current Energy Resources

Ocean Currents

The primary ocean current resource available to the U.S. is located about 30 km off the shores of Southern Florida as shown in Figure 1-4. The total available resource is not known, however, both AeroViroment [Ref 3] in the 1970s and recently Florida Atlantic University [Ref 4] have estimated an extractable energy of 50 TWh/yr and an average annual power of about 10 GW (a capacity factor of 57%).

1.
Introduction

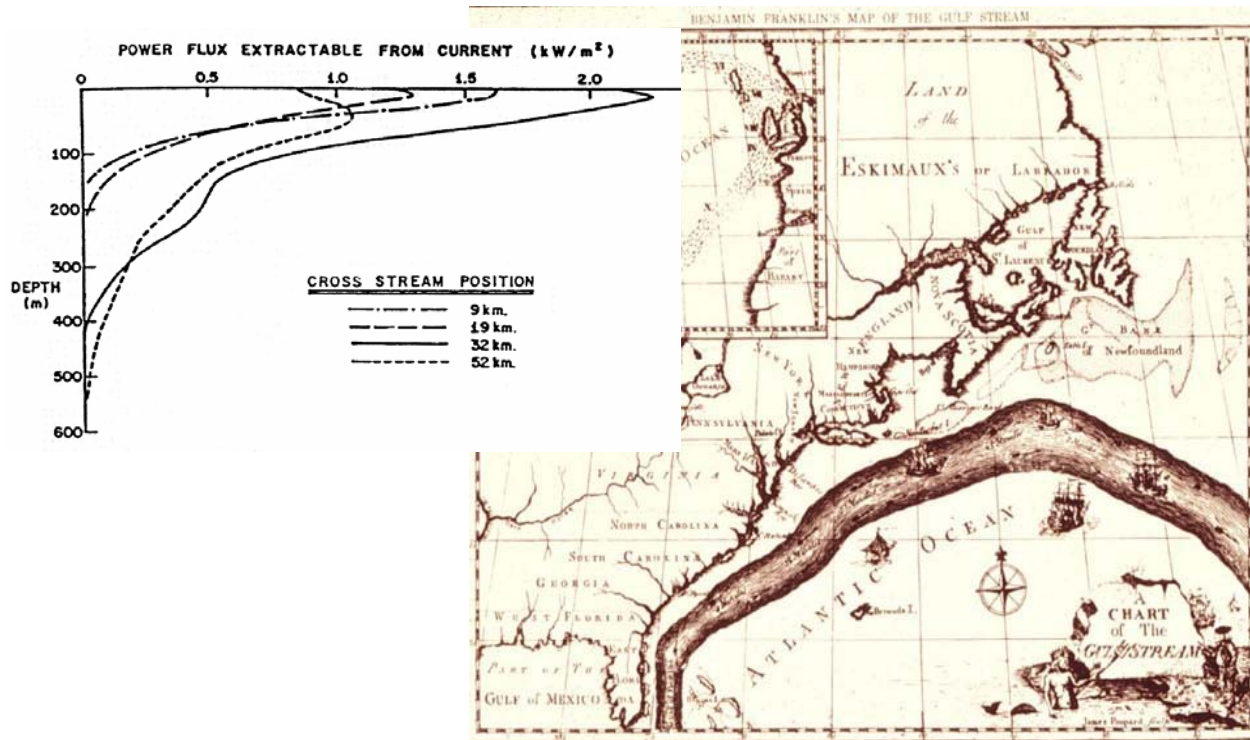


Figure 1-4
Ocean Current Energy Resources

River Currents

The overall hydrokinetic power potential of U.S. Rivers was studied by New York University in 1986 and estimated at 12,500 MW using conservative assumptions of turbine array deployment and for rivers with discharge rates greater than 113 m³/s and velocities greater than 1.3 m/s. The primary river current resource available to the U.S. is in Alaska and the Pacific Northwest. Depending on whether the conversion technology is economical at low power densities, every state could have a river hydro-kinetic resource.

EPRI evaluated the available resource at six (6) specific off-grid sites in Alaska. The total yearly energy for those sites was 78 GWh and the average annual power was 8.9 MW. The extractable resource due to societal, physical and/or environmental limits is not known. These applications are not only relevant to Alaskan villages, but also to many remote sites in third world countries. Maybe one of the applications of MHK technology will be to skip the need for large-scale transmission systems into remote areas with small populations. Also, development of MHK technology for these regions may be a stepping stone to large-scale development, and may provide valuable info on the performance and environmental impacts.

The North American rivers with the largest discharges are shown in Figure 1-5. Note that the Columbia River, in particular, has significant traditional hydroelectric generation.

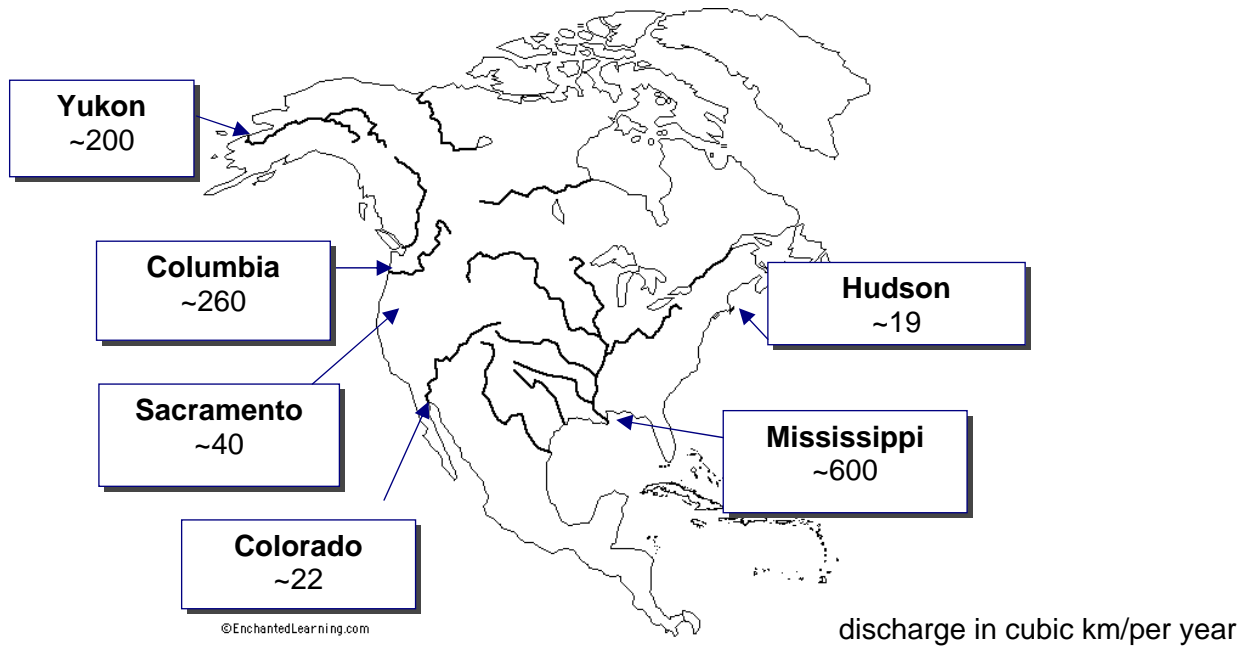


Figure 1-5
River Current Energy Resources

Ocean Temperature Differential Energy Resources

Ocean thermal energy conversion (OTEC) requires a difference in surface and sub sea temperature of about 20°C with a depth of no greater than around 1,000 meters to be economically viable. The world's ocean's surface temperature differentials are shown in Figure 1-6. The equatorial zones are the primary locations for OTEC resources and in the US states, only the southern part of Florida and Hawaii are suitable candidate locations.

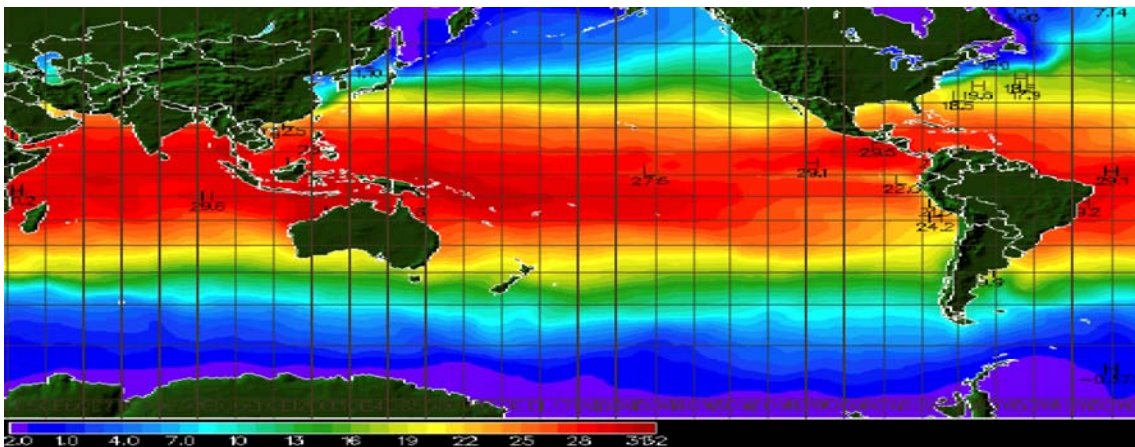


Figure 1-6
Ocean Thermal Energy Resources

Marine and Other Hydrokinetic Technology Status

In the 1970s, the U.K. regarded wave power as an alternative to nuclear generation and had the most aggressive RDD&D program for wave energy in the world. Although the program contributed to important research on optimal control and tuning of wave power conversion devices, it ultimately stalled as oil prices dropped and government incentives vanished.

Over the last decade, research in wave-powered, tidal-powered and other types of MHK generation and advances in the offshore industry have led to new designs, some of which have been tested at sea and connected to the grid. Today, a number of small companies backed by government organizations, private industry, utilities, and venture capital are leading the commercialization of technologies to generate electricity from marine energy resources.

While it is clear that MHK devices can be made to work; it is not been demonstrated that they can be made to work in an environmentally benign and acceptable manner with economically attractive prices for the energy generated.

There are many technology developers with many different MHK energy conversion technologies and devices and those devices are at various stages of development as shown in Figure 1-7., which is 2006 data from the Carbon Trust [Ref 7] and shows the various stages of development of the various wave and tidal device concepts under development. One model of the MHK technology status is illustrated with the pyramid of Figure 1-8. There are thousands of concepts and patents for which the technology has never been developed. There are hundreds which are at the subscale laboratory level of development. There are even fewer that have made in out of the laboratory and have reached short-term subscale testing in natural waters. Lastly, there are only a few that have achieved long-term (>1 year) testing of full scale devices in natural waters. The time period for ocean wave and in-stream technologies to progress from a conceptual level to deployment of a long-term full-scale prototype tested in natural waters is on the order of 5 to 10 years (with wave energy tending to the 10 year time period and in-stream technologies tending to the 5 year time period). The technology is still in its emerging stage. It is too early to know which technology will turn out to be most cost-effective, reliable, and environmentally sound.

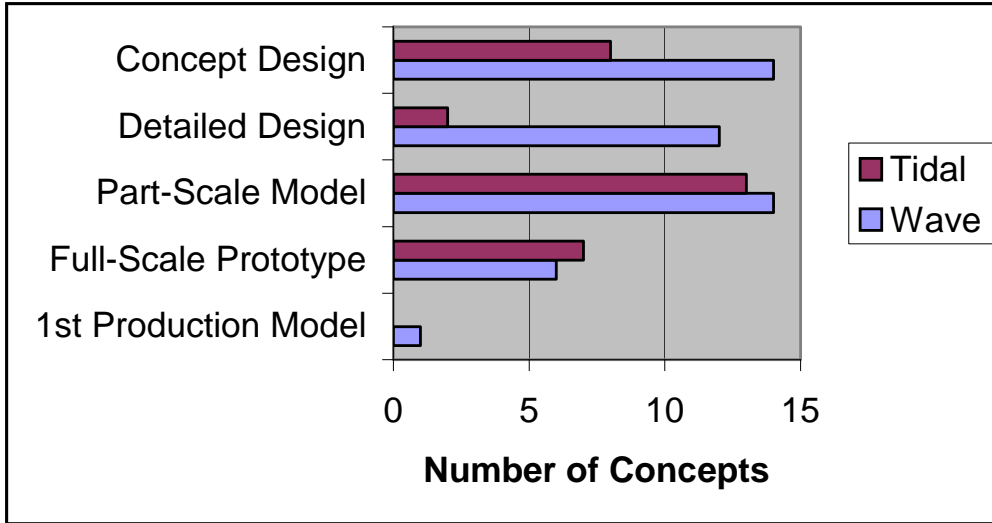


Figure 1-7
Development Status of Wave and Tidal Technology

It typically takes 5 to 10 years for a technology to progress from concept-only to deployment of a long-term prototype

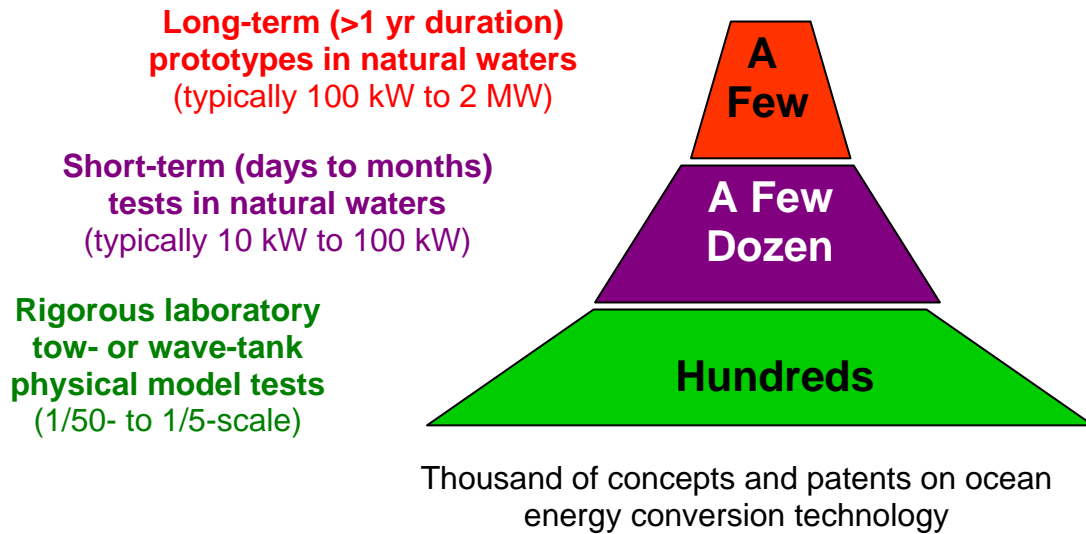


Figure 1-8
Technology Development Status

The installed wave energy conversion (WEC) capacity to date is about 4 MW worldwide. Most of the deployed devices are engineering or commercial prototypes. The first shore-based grid-connected wave power unit was the 500 kW WaveGen oscillating water column (OWC) system built into the coastline of the Island of Islay in Scotland in 2000. In 2003, a subscale WaveDragon was the first offshore grid-connected wave power unit and was deployed in a protected bay due to its subscale nature. In 2004, a 750 kW Pelamis was the first offshore full-scale grid-connected wave power unit and was deployed in open seas at the European Marine Energy Center (EMEC) in Scotland. Based on the successful Pelamis EMEC testing, the first commercial sale of an offshore wave power plant was announced in May 2005 and the first phase of that plant, three Pelamis units, were deployed off the coast of Portugal and were commissioned in August 2008. In addition, a number of other demonstration projects are ongoing or planned in the U.K., Ireland, Spain, Portugal, China, Japan, Australia, Canada, and the United States. If these early demonstration projects prove successful, medium-size wave farms of up to 20-100 MW in capacity could be deployed within the next five to eight years.

The U.S. Department of Energy's Marine and Hydrokinetic Technology Database has up-to-date information on marine and hydrokinetic renewable energy, both in the U.S. and around the world at <http://www1.eere.energy.gov/windandhydro/hydrokinetic/default.aspx>. The database includes wave, tidal, current, and ocean thermal energy, and contains information on the various energy conversion technologies, companies active in the field, and development of projects in the water. Depending on the needs of the user, the database can present a snapshot of projects in a given region, assess the progress of a certain technology type, or provide a comprehensive view of the entire marine and hydrokinetic energy industry.

A partial list of WEC developers and photos of devices from each of the three classes of WEC devices is shown in Figure 1-9. The three classes are point absorbers, terminators and attenuators.

Installed tidal in-stream energy conversion (TISEC) capacity to date is about 2 MW worldwide. Most of the devices are engineering or commercial prototypes. The Marine Current Turbine (MCT) 300 kW experimental SeaFlow unit was installed in May 2003 and was the world's first TISEC system of significant size to be installed in a genuinely offshore location. The site is 1 km off the coast of North Devon, U.K. In 2008, MCT deployed the world's largest TISEC device, the 1.2 MW dual 16 meter diameter rotor SeaGen turbine at Strangfold Narrows in Northern Ireland. Open Hydro installed an experimental TISEC device at EMEC in late 2006 and in 2008 deployed a commercial prototype at EMEC. Clean Currents of Canada deployed a 40 kW turbine at Race Rocks in British Columbia in late 2007. In the United States, Verdant Power installed an array of six 35-kW grid-connected water turbines in the East River (a tidal river) in New York in early 2007. In addition, a number of in-stream tidal demonstration projects are ongoing and planned in the U.K., Italy, Korea, Canada, and the United States. If these early demonstration schemes prove successful, arrays up to 1-10 MW in capacity could be deployed within the next five to eight years. A partial list of TISEC developers and photos of devices is shown in Figure 1-10.

There are no Ocean Current or Ocean Thermal Energy Conversion devices deployed at this time.

- Finavera (AquaEnergy) - AquaBuOY
- AWS Energy - Archimedes Wave Swing
- Ecofys - Wave Rotor
- OceanLinx (Energetech) - Uiscebeathe
- Independent Natural Resources Inc - SeaDog™
- Pelamis Wave Power - Pelamis
- Ocean Power Technologies - PowerBuoy®
- Ocean Energy – OEBuoy
- Oregon State University – Direct Drive Point Absorbers
- Cylindrical Energy Transfer Oscillator (CETO)
- Wavebob Ltd - Wavebob WEC
- Wave Dragon Ltd - Wave Dragon

Pelamis Linear Attenuator



Ocean Power Technologies Point Absorber



Wave Dragon Terminator



Figure 1-9
Example Wave Energy Conversion Technology

- Clean Current (horizontal-axis, shrouded rotor)
- GCK (vertical-axis, Gorlov helical rotor)
- Lunar Energy (horizontal-axis, shrouded rotor)
- Marine Current Turbines (horizontal -axis, open rotor)
- Open Hydro (horizontal-axis, shrouded open rotor)
- Ocean Renewable Power Corp (crossflow- axis)
- Ponte de Archimeda (vertical-axis)
- UEK (horizontal-axis, shrouded rotor)
- Verdant Power (horizontal-axis, open rotor)

Figure 1-10
Example Tidal Current Energy Conversion Technology

1.2. Approach

EPRI, with support from the U.S. Department of Energy's Office (DOE) of Energy Efficiency and Renewable Energy, Wind and Hydropower Technologies Program, sponsored a workshop for the water power industry (marine and other hydrokinetic- tidal and river currents, energy and conventional hydropower and pumped storage) in October 2008. The purpose of the workshop was to identify and prioritize research, development, deployment and demonstration (RDD&D) needs which will further the deployment of conventional hydro/pumped storage and emerging MHK technologies and increase domestic, low-carbon energy production. The priorities identified may be used to shape EPRI's research agenda and DOE's research agenda and will support R&D initiatives throughout both the public and private sectors.

The remainder of this report will discuss MHK only. A companion report describes the prioritized RDD&D needs of conventional hydro and pumped storage technology.

The objective of the workshop was to reach industry consensus on the prioritized MHK RD&D needs. In order to meet this objective, EPRI formed a steering committee and used that committee to decide on a list of RDD&D themes, select speakers for the workshop to address the needs within those themes, select a prioritization approach and to vote on the prioritization of those themes. The full set of MHK workshop participants also voted on the prioritization of those topics.

Form and Engage Steering Committee

In order to structure and plan a comprehensive and successful workshop and one engaging the largest number of MHK stakeholders possible, EPRI organized a balanced public-private Steering Committee with representatives knowledgeable of the technical issues faced by developers in each waterpower technology area. The objectives of this Committee were to:

1. Identify the topics or subject areas to be discussed at the forum;
2. Identify the speakers to be invited to address the topics identified for discussion;
3. Establish a location and date for the forum including associated meeting logistics; and
4. Review & comment on final forum reports

The seven (7) Steering Committee members for the MHK part of the workshop and their constituencies were as follows:

1. Roger Bedard, EPRI Ocean Energy Leader rbedard@epri.com 650-855-2131
2. Sean O'Neill, President, Ocean Renewable Energy Coalition (represents the ocean energy industry) sonnell@symmetrix.biz, (301) 869-3790; Sean designated Carolyn Elefant as his alternate

3. Federal Government – Dr. Robert Thresher – National Wind Tech Center. NREL (representing the National Laboratories) Robert_Thresher@nrel.gov 303-384-6922; Bob designated Walt Musial as his alternate.
4. State Government – David Lockard – Alaska Energy Authority (representing State Government; Alaska being the U.S. state with the majority of the nation’s wave, tidal and river hydrokinetic resources) dlockard@aidea.org 907-771-3602
5. Wave Energy Researcher – Justin Klure of Pacific Ventures (representing university research in wave energy). Justin designated Dr. Robert Paasch of Oregon State University as his alternate.
6. Tidal Energy Researcher –Professor Dr Phil Malte - Univ of Washington, (representing university research in tidal and river current resources) Malte@u.washington.edu, 206.685.2171. Phil designated Brian Polagye as his alternate.
7. MMS –Lori D’Angelo – Mineral Management Service Lori.D’Angelo@mms.gov 703.787.1300. Lori designated Matthew Quinney as her alternate.

Preliminary Selection of RD&D Themes

As a starting point for selection of RDD&D topics, the Steering Committee decided to use the twelve (12) RDD&D topics from the UK Marine Energy Roadmap [Ref 8] and add other U.S. stakeholder RDD&D needs from other sources, including the workshop itself. These topics are generic and apply, for the most part, to each of the five types of MHK energy. The lists of twelve (12) topics identified in the UK Roadmap were developed to meet a goal of 2 GW of MHK energy by 2020.

Engage National Marine Energy Stakeholders on RDD&D Needs

The Ocean Renewable Energy Coalition (OREC) and the National Hydropower Association (NHA) contacted their members to assist in identifying the MHK RDD&D need topics. The results are presented in the next section.

Select Speakers for the Forum

Based on a preliminary set of twelve (12) RDD&D topic sand other considerations, the Steering Committee developed a list of potential speakers deemed to best address the topics and subtopics within those topics. The workshop agenda provided two-half day sessions for those presentations. Each presentation was about 10 minutes long, allowing 5 minutes for questions and answers and discussions following the presentation. The list of presentations and presenters were:

**Table 1-2
MHK Workshop Presentations and Presenters**

EPRI Overview and Roadmapping	Roger Bedard, EPRI
Resource Assessments: Wave Energy	Roger Bedard, EPRI on behalf of George Hagerman, Virginia Tech
Resource Assessments: Tidal Current	Brian Polagye, University of Washington
Resource Assessments: River Current	Mirko Previsic, Re-Vision
Resource Assessments: Ocean Current	Sue Skemp, Florida Atlantic University
Resource Assessments: Ocean Thermal	Richard Meyers, Ocean Energy Council
Hawaii Specific R&D Needs	Rick Rocheleau, University of Hawaii
Device Modeling and System Simulation	Bob Thresher, NREL
Experimental and System Testing	Bob Paasch, Oregon State University (OSU)
Moorings and Sea Bed Attachments	Tom Hudon, PCCI Inc.
Electrical Infrastructure	Tom Key, EPRI
Power Take Off and Control	Bob Paasch, OSU
Engineering Design*	Mirko Previsic, Re-Vision
Life Cycle and Manufacturing	Chris Retzler, Pelamis Wavepower
Installation and O&M	Chris Retzler, Pelamis Wavepower
Standards	Walt Musial, NREL
Ocean Renewable Energy Coalition Perspectives	Sean O'Neill, Ocean Renewable Energy Coalition
National Hydropower Association Perspectives	Mike Murphy, NHA
Alaska Specific R&D Needs	Roger Bedard on behalf of David Lockard, Alaska Energy Authority
Environmental	Glenn Cada, ORNL
Storage	Patrick Sullivan, NREL
System Configuration	Mirko Previsic, Re-Vision

* The Materials topic was primarily covered under the Engineering Design presentation but was also embedded in many other topical presentations.

Select Prioritization Approach

The Steering Committee considered two generic approaches to the workshop structure in terms of identifying RDD&D needs and prioritization:

- 1) Listen to as many RDD&D need presentations as possible within the time allocated for the workshop and predefine a simple approach to prioritization that can be implemented in minimum time at the workshop.
- 2) Go into the workshop with the RDD&D needs essentially predefined and minimize the RDD&D needs presentations and use the time allocated for the workshop on developing a prioritization approach

The Steering Committee chose the former approach. The prioritization approach chosen was to simply rank the topics as either; 1) high priority, 2) medium priority or 3) low priority. In order to assure that the results would be meaningful (as opposed to everyone voting that all topics were of high priority), the steering committee requested that the voters approximately allocate their votes into a standard distribution with about 16% of the topics being high priority and 16% of the topics being low priority and the remaining 68% being medium priority.

Prioritize RD&D Topics

The steering committee decided that two votes would be taken. The first vote would consist of the entire MHK population (approximately 40 people as the venue was limited to 80 attendees with that being approximately split between those primarily interested in MHK technologies and the other half being primarily interested in conventional hydro/pumped storage technology). The second vote to be taken was of the MHK steering committee.

2. MHK RDD&D NEEDS

The RDD&D Workshop began with a brief plenary session with three MHK speakers

Robert Thresher, National Renewable Energy Laboratory Senior Research Fellow and previous Director of the National Wind Technology Center presented ten lessons learned from the development of the wind energy industry development and an admonition that those who do not know history are doomed to repeat it:

1. Continue to Develop First Principle Theories to Bound Performance and Guide Designs
2. Perform Rigors Testing
3. Model the Important Physics and Validate the Models with Test Data
4. Expect Prototypes Machines to Fail and Learn from the Failures
5. Develop Comprehensive Standards for Ocean Energy Systems at an Early Stage
6. Build Prototypes at a Practical Size and Make Them Work, Then Scale for Economy
7. Develop and Verify Energy Loss Models for Arrays and Complex Flow Situations
8. Develop and Verify Economics Models
9. Perform Environmental Studies at Proposed Sites
10. Focus On Technology Innovation, Scale, and Reliability to Reduce Cost

Chris Retzler from Pelamis WavePower delivered a briefing on the RDD&D history about what his company went through to get to where they are today with the recent deployment of the world's first commercial wave power plant off the coast of Portugal.....

Henry Jeffrey from the UK Engineering Research Center (UKERC) at the University of Edinburgh briefed the process and results of the UK Marine Energy Technology Roadmapping Project. The UKERC [Ref 8] developed a list 12 themes referred to as Technology Working Areas (TWA) which represent the technology development chain in marine renewable devices. The US RDD&D Needs Workshop used these 12 topics as the starting point for developing the US technology needs.

- 1) Resource Modeling
- 2) Device modeling
- 3) Experimental Testing
- 4) Moorings & Sea bed attachments
- 5) Electrical Infrastructure
- 6) Power Take Off and Control
- 7) Engineering Design
- 8) Lifecycle & Manufacturing

MHK RDD&D needs

- 9) Installation, O&M
- 10) Environmental
- 11) Standards
- 12) System Simulation

Four other topics identified by the Steering Committee prior to the workshop which are not on UK Roadmap list are as follows:

- 1) Materials – low cost, corrosion and biofouling
- 2) Storage
- 3) System configuration evaluations
- 4) Vision, Goals, Objectives and Roadmap

Two other topics identified by the participants of the workshop during the workshop were:

- 1) Master Generation and Transmission Plan
- 2) Education

The following paragraphs drill down into the eighteen (18) topics listed above and summarize the presentations given at the MHK workshop.

2.1. Resource Modeling

Why RDD&D in this topic is needed:

- Resource modeling is important for technical and economic reasons.
- The size of the resource is important to understanding the potential contribution that harnessing that resource can make to the nation's energy portfolio needs.
- The location of the resource is important for siting decisions
- Knowledge of extreme events will impact the engineering design of energy conversion devices and their ability to survive, which in turn has economic implications.
- A better knowledge of the near shore resource will inform the design of devices and the economic exploitation of such sites
- Knowledge of the combined impact of waves and currents on devices is important in those applications with combined waves and currents
- Existing river measurements are not suitable to characterize river in-stream hydrokinetic resources
- Measurement and calibration data does exist for a limited number of river in-stream sites (i.e., only those sites co located with a USGS measurement station)
- Tidal and river resource characteristics are highly localized

The RDD&D needs are:

- Modeling that captures the fundamental physics is required in order to improve the accuracy and detail of the existing knowledge of the available and extractable resource estimates. These models should be calibrated against actual measurements. Modeling of large-scale kinetic energy extraction effects is also required and like wave, these models

should be calibrated with actual measurements as the first hydro-kinetic plants are built out.

- Modeling is required to understand the effects of energy extraction on environmental dynamics. This modeling should be done in parallel with measurements as the first power plants are built out.
- Further evaluations of potential sites are required to more fully understand the magnitude of the available U.S. resource.
- Since the resource is geographically based, archiving the resource information in a Geographical Information System (GIS) database should be explored.

- Wave Energy
 - Refine resource analysis
 - More complete spatial coverage including shallow water
 - Higher resolution understanding
 - Data and models to identify “hot spots” for both wave energy in shallow water and tidal, river and ocean currents
 - Better wave forecasting ability, including extreme events
 - Effects of extraction on resource
 - Limits on extraction
 - Display in a geographic database

- Tidal In-Stream Energy
 - Strategy for comprehensive resource prediction
 - Standardized resource assessment methodology
 - Effect of extraction on resource - Realistic comparison between regions
 - Optimized array packing - Wake persistence and propagation
 - Ecological implications of changes to tidal regime
 - Models to study environmental effects of tidal energy extraction
 - Optimal array packing - Numerical modeling - Field measurements
 - Modular instrumentation package - site and device characterization
Maximize data capture

- River In-Stream Energy
 - Characterize a significant number of potential sites that may be representative of other sites to understand the resource characteristics better using a combination of modeling and measurement.
 - Based on these results some generalization of the resource characteristic may be possible and applied to a broader number of sites.
 - Based on results, device manufacturers will be able to refine and optimize their devices

Note that the workshop included many presentations on generic RDD&D topics (moorings, electrical, etc) by individuals involved in wave and tidal energy development. Ocean currents and ocean thermal energy was represented in only one individual attendee and one presentation each. Therefore, these two individuals (Sue Skemp/FAU on ocean current and Richard Meyer/OEC on ocean thermal) were requested to encompass the full breadth of these two MHK application areas.

- Ocean Currents
 - Numerical tools and software for system design and optimization
 - Materials, composites, corrosion, and anti-fouling
 - Environmental and ecological interaction and standardized assessment
 - Integrated system resource modeling and assessment
 - Installation and maintenance
 - Health monitoring, diagnostics, and prognostics
 - Underwater power conditioning and transmission
 - Detection, control and avoidance
 - Grid connection
 - Life cycle analysis
 - Cumulative effects – arrays, etc.
 - Permitting and rule development
 - Industry standards
 - Public outreach and awareness
 - Workforce development and education
- Ocean Thermal
 - Resource assessment for all U.S. state or territory potential OTEC sites
 - Environmental studies needed for EIS preparation
 - Assessment of long term impacts of large numbers of OTEC plants
 - Studies of CWP (cold water pipe) deployment techniques
 - Near scale and large scale circulation effects from OTEC operations
 - Adaption of heat exchanger designs specific for OTEC applications
 - Wave tank testing for large platforms: floating, land-based or semi-submersible
 - Improved OTEC turbine design
 - Extend Gerard Nihous' study on total exploitable resource to assess possible environmental impact near shore as well as in the open ocean
 - Support large scale testing
 - Extending connectivity into the ocean to allow easier hookups with wind, wave, thermal, etc.
 - Develop a resources assessment and technology based on OTEC systems to extract 10% or more electrical energy from thermal power plants (coal and nuclear) using their warm water effluents.
 - Develop coastal-cooling systems resource assessment and technology: cold sea water air conditioning

2.2. Device Modeling

Why RDD&D in this topic is needed:

- Traditionally the development process involves a number of stages in wave tanks at different scales and can take between 5-10 years before reaching a scale suitable for sea trials. The number of development stages could be reduced by combining tank tests with more accurate device models that can be used with confidence.
- Modeling of devices in arrays is vital for large volume deployment of devices in arrays

- There are close links with resource modeling, experimental testing, moorings, electrical infrastructure, power take off and control and system modeling.

The RDD&D needs are:

- Models to enable a better understanding of hydrodynamic and primary power conversion and the effect of diffusers in tidal, river and ocean current applications
- Models to enable a better understanding of array effects (modeling multiple devices). Physical data from smaller arrays should be used to verify array modeling work.
- Evaluate adapting the NREL Wind Energy Device Simulation Codes for the unique aspects of wave and in-stream hydrokinetic applications and the new physics needed for hydrokinetic rotors and buoys

Rotors:

- Water turbines \neq wind turbines with $1000\times$ the fluid density
- New inflow:
 - Wave kinematics
 - Unique turbulence models for sea current, tidal flow, and rivers
- New blade loads:
 - Inertia loading from decelerating inflow (diffraction)
 - Added mass & damping (radiation)
 - Buoyancy
- Blockage of wake due to seabed and free surface
- Prediction of onset of cavitation

Buoys:

- New power take-off degrees of freedom
- Mooring system dynamics (including drag & inertia)

2.3. Testing

Why RDD&D in this topic is needed:

- Design and performance issues can only be uncovered by testing
- Environmental impacts of in-water systems require in-water testing.
- Access to scale test tanks provides an economic method of assessing new concepts, which when combined with accurate device models has the potential to reduce the number of development stages.
- Tank test facilities provide a controlled and repeatable environment for device development.
- Test facilities are important for the verification of resource and device models.
- The major gap in controllable and repeatable wet test facilities is for tidal current systems. At present developers tend to use river sites for scale testing at say $1/15^{\text{th}}$ scale and then jump to full scale for sea-trials, which has considerable risk associated with it.
- Towing tanks have been used in the past, but these do not adequately represent the interaction of a stationary energy extraction device in moving water.
- There is currently no facility for investigating the combination of current and waves – if all sites are to be exploited there will be a need for such a facility.

MHK RDD&D needs

- Component testing will contribute to a better understanding of reliability, but must be performed under realistic conditions.
- Alongside resource and device modeling, experimental testing is integral to the engineering design and deployment of devices at all levels from new concepts to large arrays.
- Improved understanding of WEC system performance and interactions for optimization opportunities

The RDD&D needs are:

- Development of the necessary infrastructure to test and deploy WEC systems.
- Test facilities, from laboratory to the ocean, from subscale to full scale
- Turbulence testing of water turbines
- Testing standards are required to ensure consistency between test facilities.
- Effects from construction/deployment/service of cables
 - Impact on invertebrates or seafloor structure from placement of anchors and power lines.
 - The most destructive aspect of laying natural gas lines is during the deployment of lines; the seafloor with its inhabitants is altered as the line is laid with large machinery. Similar effects could be expected with laying of electric cables if similar methods are used.
 - Impact on invertebrates or seafloor structure from placement of anchors and power lines.
 - Creation of a sediment plume and resulting impacts on fish/invertebrates.
- Effects of the physical structure of the buoy field.
 - Entanglement of marine mammals
 - Changes in whale migration pathways.
 - Effects of using antifouling agents: introduction of toxics
- Monitoring needs to be scale appropriate.
 - Impacts from small scale may not be scalable to large energy generation farms.
 - Monitoring program needs to be adaptive in design to respond to evolving impacts.
 - Monitoring needs to compare manipulated and un-manipulated areas.
- Effects of Electromagnetic Fields:
 - Marine mammal attraction or repulsion.
 - Change in larval dispersion.
 - Change in fish use of area, fish migration or fish reproductive success.

2.4. Moorings and Seabed Attachments

Why RDD&D in this topic is needed:

- Moorings and seabed attachments are integral to the successful deployment and operation of floating wave and tidal current devices.
- There is a significant benefit to development of technologies to eliminate need the for large deployment vessels
- Knowledge gained from early deployments must be used to finalize design tools for large volume deployment.
- There is a close interaction with resource modeling, device modeling, experimental testing, engineering design, environment, and installation O&M.
- Generic R&D Needs:
 - Long term fatigue of lines and connections
 - Standard designs for quick connect & release
 - Series of mooring studies for generic types of devices
 - Numerical modeling improvements for arrays

The RDD&D needs are:

- Validation of design tools for mooring of device arrays
- Development of “standard” mooring arrangements for generic device arrays in shallow and deeper water depths to develop realistic costs , to establish array motion prediction and interaction for permitting and to investigate effects of individual buoy removal or broken legs
- Investigation of mooring response at dominant wave frequency and affect on fatigue life of components
- Removal procedures for servicing of individual buoys in array mooring system and design of quick connect and release
- Low cost mooring (both part costs and installation cost)
- Better understanding of fatigue in mooring lines
- Need to validate design tools using scale and at-sea test facilities

2.5. Electrical

Why RDD&D in this topic is needed:

- Upgrading is likely to be both onshore and offshore – the two have to be combined in such a way to minimize potential delays brought on by planning and environmental issues.
- Provide the highest value to the grid as possible; i.e. grid integration
- Electrical connection of devices, cable laying, and connection within and between arrays link in with installation and O&M.
- Future upgrading of the electrical grid infrastructure is critical

The RDD&D needs are:

For Electrical Infrastructure

- Low cost flexible submerged electrical cables and connectors
- Low cost installation of submerged cables (including interface with land based cables)
- Conversion of the mechanical energy into electrical energy using direct drive provides a potentially more robust and efficient solution compared to say hydraulics or gearboxes driving a conventional rotary generator, but deployments are required to demonstrate the potential advantages if direct drive is to make a significant contribution to large volume deployment
- Power electronic converters are required to interface to the electrical grid, but once again, deployments are required to gain more knowledge of performance and reliability in particular.
- Condition monitoring systems will play a role in O&M of devices, and should be intelligent such that the power take off can be controlled to modify performance ensuring continued operation even during a fault condition.
- Physical data collected from small scale deployments should be used to modify designs for large volume array deployments

For Grid Integration

- Development of real time forecasting
- Development of unified interconnection standards
- Increase in transmission and distribution capacity (this is not R&D except for technologies which provide additional capacity over the same wires)
- Development of short term energy storage to reduce the effect of high frequency resource variability
- Future development of load balancing at high penetration; maybe be sooner for remote Alaska grids.

2.6. Power Take Off and Control

Why RDD&D in this topic is needed:

- Wave energy typically demands high forces and low velocities. Hydraulics and pneumatics fit this requirement, is mature, off-the-shelf, naturally provide some energy storage but can be maintenance intensive
- High reliability, direct drive technologies (electric generator without a gearbox) are attractive, but building electric generators to handle the large torque and low speed requirements in a cost effective manner is challenging. The experience of the wind industry in direct drive generators may help launch similar ideas in wave energy
- High part load efficiency and effective control systems in power take off mechanisms such as hydraulics or air-turbines affect the technical performance and the economics of the system.

The RDD&D needs are:

- Critical, fundamental research is needed on direct drive generators for marine energy applications

- In particular, research geared toward systems that address survivability and maintainability of marine energy conversion systems is needed
- There will be close links with resource and device modeling, electrical infrastructure, experimental testing, moorings, engineering design, markets and economics.
- Control systems and methods for optimum performance (while ensuring survivability)
- Energy control theory has been established, but there is much applied work to be done
- There is a tremendous opportunity to conduct control research on optimizing energy production while also protecting the wave energy converter against large velocities and forces
- In addition, fundamental control theory and applied control techniques may be significantly different between the major wave energy technological paradigms: point absorber, overtopping, oscillating water column, and attenuator
- There is also a large opportunity for fundamental research in wave park array control to make use of buoy-buoy interaction

2.7. Engineering Design (which is closely coupled with Standards – see 2.11)

Why RDD&D in this topic is needed:

- Engineering design is critical to successful large volume deployment.
- Survivability is the most important aspect of the development of any new device, which requires advances in new structural materials, a better understanding of failure modes and component reliability, and the ability to forecast extreme events.
- There are close links with resource modeling in terms of extreme events, device modeling, moorings, electrical infrastructure, power take off and control, manufacturing and environment.

The RDD&D needs are:

- Low friction bearings with high load capability, long life and high tolerance of poor geometry
- Mechanical shaft seals with long life in sea water
- Establish component reliability database
- Better understanding of biofouling (a MMS study is currently ongoing and may provide assistance in the understanding of biofouling. see www.mms.gov/tarprojects/622.htm)
- Low cost materials
- Standard design codes should be developed so that they can be applied to any new concept to reduce the development stages and reduce cost.
- Standards and best practices development for all stages of product design.
- Improving modeling capabilities, incorporating data from measurements on part-scale and full-scale systems.
- Development of standard computational models for different device types and subsystems.
- Subsea collector system.
- In-Stream specific: Optimized rotor blade geometry

- Wave-specific: Short-term wave prediction
- Operational considerations
- Design for manufacturability
- Mooring system dynamic modeling.
- Alternative materials (concrete, ferrocement, composites).

2.8. Lifecycle and Manufacturing

Why RDD&D in this topic is needed:

- Economic attractiveness require manufacturing infrastructure for high volume deployment. High volume manufacture will require device designs to have matured and been finalized.

The RDD&D needs are:

- Scaling and the economics need to be assessed to determine the optimum production unit, which should be finalized for high volume deployment.
- During testing of small to medium arrays device/array performance should be appraised so that more confidence is gained for operation and costing for larger arrays.
- A generic component database including reliability and cost data will be a useful tool for developers.
- Low cost manufacturing
- Development of volume production techniques
- Ultra high reliability components (for minimum maintenance cost)
- Life time extension

2.9. Installation and O&M

Why RDD&D in this topic is needed:

- In order to achieve economically attractive high volume deployments, the community needs to have dedicated installation vessels so that they do not compete with other sectors of the offshore industry.
- Deployment of the small to medium sized arrays will provide experience of installation methods and O&M procedures, particularly in various weather conditions.

The RDD&D needs are:

- Safe, reliable, quick, easy and low cost installation
- Autonomous operations
- Low operation and maintenance costs
- Safety procedures need to be established before even small scale deployments.
- Ultra high reliability components (for minimum maintenance cost)
- Installation methods should be part of an integrated design procedure forming part of the design optimization.
- Throughout the deployment phases, physical data detailing performance and reliability should be collected for verifying modeling and design tools.

- Intelligent condition monitoring methods need to be demonstrated to assist in O&M.
- Conditioned based maintenance Ultra high reliability components (for minimum maintenance cost)

2.10. Environmental

Why RDD&D in this topic is needed:

- The US needs to learn whether the use of large scale MHK technologies can be done in such a manner as to be environmentally acceptable to our society. “The environment” includes not only marine life, but also the marine geography, recreation, cultural resources and public safety
- To gain public acceptance and reduce uncertainties about effects on marine environment by assessing impacts, determining what is known and unknown and identify rigorous scientific studies to address and resolve the concerns

The RDD&D needs are:

Receptor Information Needs

- Physical Environment – Pilot projects to understand and model wave reduction effects
- Pelagic habitat – evaluate effects of electro magnetic forces (EMF), entanglement, and meroplankton settlement
- Marine birds – Determine spatial and temporal abundance, activity at night, areas of bird activity that should be avoided, important migration patterns, and effects on food web.
- Marine mammals – Baseline data on mammal biology, presence/absence, species diversity, and prey availability. Immediate monitoring to determine interactions with wave or marine hydrokinetic energy facilities.

Stressor Information Needs

- Siting – Develop and make available information on sensitive habitats early
- Chemical effects – develop information on nature of toxic chemicals, potential amounts that may be released, responses of receptors, and contaminant fate
- New hard structures – develop information on how they will alter benthic and pelagic habitats and food webs
- Acoustics – measure noise levels and compare to ambient noise; model effects of additional units in full build out; anticipate synchrony of noise from multiple units; compare noise levels to audiograms of sensitive species; determine if devices could constitute a sound barrier
- EMF – Before and after baseline assessment of local magnetic fields is needed. Controlled experiments difficult and easily confounded by other factors. Access EMF research on technologies analogous to MHK technologies.
- System View/Cumulative Effects – Establish thresholds of effect. Develop new risk end points as needed during scale up. Consider displacement of other activities (fishing, altered migration paths).
- Adaptive management critical to addressing long-term effects.

Overall

- The impact of the devices (installation, operation and decommissioning phases) on the environment and vice versa needs to be monitored throughout the deployment of small to medium arrays.
- Physical data collected during the monitoring process will be used to verify environmental modeling, assess the impact of new devices and assist in the planning process for larger volume deployments.
- Environmental monitoring and post-processing of the results is important to solve potential environmental barriers to deployment. This will require close collaboration between the marine environment and marine energy communities.

2.11. Standards

Why RDD&D in this topic is needed:

- Having to meet standards gives device and project developers, policy makers and potential investors more confidence in the capabilities of the technology.
- Standardization will accelerate the maturity of the industry by incorporating collective industry experience.

The RDD&D needs are:

- Provide an overarching certification strategy and recommendations
- Terminology standard
- Resource assessment standard
- Performance testing and measurement standard for wave and tidal MHK technologies
- Guidelines and best practice should be established before prescriptive binding standards to ensure that new concepts are not disadvantaged.
- Results from all deployments – single prototypes to arrays – should be used to establish guidelines. Continued deployment will enable these guidelines to be verified leading to the establishment of standards.
- Standards should be reviewed and revised at regular intervals to take into account advances in the technology and new knowledge of the environment.

2.12. System Simulation

Why RDD&D in this topic is needed:

- System simulation models the entire marine energy plant (RDD&D need #2 device modeling describes the need to simulate a single energy conversion module or unit)
- In order to understand the operation and performance of an entire marine energy power plant, full system simulation is required

The RDD&D needs are:

- Mathematical and physical modeling of arrays of devices (especially non linear and real fluid effects) and the balance of plant
- Mathematical valuation of the system effects of diffusers (i.e., ducted water turbines)

2.13. Materials

Why RDD&D in this topic is needed:

- Alternative materials such as, concrete, composites and ferrocement could provide significant cost savings in commercial machines. However many device developers are staying away from using such materials because few or no design codes exist for these structures.
- Providing a wider range of material alternatives will allow for lower device cost and in many cases better mechanical and chemical properties. It will also reduce uncertainties associated with reliance on a single raw material. Diversification is a good thing in a world of limited resources.

The RDD&D needs are:

- The demonstration of the application of alternative low cost materials (Concrete, Ferrocement, Composites).
- Corrosion and biofouling mitigation

2.14. Storage

Why RDD&D in this topic is needed:

- Economical storage technologies would ease the path to higher penetration of renewables
- Economical storage allows for a cheaper overall system & less expensive electricity

The RDD&D needs are:

- Develop economical storage that works with marine energy technologies
- Wave and tidal power, being variable resources, would also be likely to benefit from economical storage options.
- Energy storage systems and alternative energy vectors is a long term issue, but needs to be investigated for non-electricity markets and further developments.

2.15. System Configuration Evaluation

Why RDD&D in this topic is needed:

- System configuration evaluations (which are best under what circumstances) and (which are best under what circumstances) and module size versus cost of electricity sensitivity requires a methodology for systematically identifying and evaluation the most promising MHK devices so that Gov't decision makers know which technologies to cofund.

- Many of the generic issues and RDD&D needs are manifested differently in different devices and across the ocean energy types; so that generic RDD&D value maybe limited. This implies that public program funds specific types and designs within a type. It also places a critical importance on consistent, reliable and robust assessment methodologies to help funding decision makers select the most promising types and designs
- Development of non power applications

The RDD&D needs are:

- Answer key questions such as
 - What type/size will yield optimal economics?
 - Will the installed cost of wave energy conversion devices realize its potential of being less expensive than solar or wind?
 - Will the one- to two-day forecast-ability of wave power earn a capacity credit for its dispatch ability?
 - Will the performance, cost, and reliability projections be realized in practice once wave energy devices are deployed and operated?

2.16. Master Generation and Transmission Plan

Why RDD&D in this topic is needed:

- Marine energy generation will limited to those locations with good energy resources and are not in conflict with other uses (fishing, navigation, etc). The availability of coastal transmission and distribution as well as the transmission to move the power to the load centers is an important consideration. A master plan is needed to help guide the evolution of both generation and transmission in a way that cost effectively meets the societies needs of our society

The RDD&D needs are:

- Develop a geographical database of marine energy resources (being done under the FY08 DOE wave and tidal energy resource assessment projects)
- Develop a geographical database of T&D infrastructure, capacity limits, contracted capacity and remaining capacity
- Develop the software to analyze the effects of addition of new ocean energy generation at a given location on the existing T&D network (how much can be transmitted and to where) and the effects of adding new T&D capacity (including the cost of that capacity)

2.17. Education

Why RDD&D in this topic is needed:

- The electricity industry workforce is getting old and replacement with the best and the brightest is needed.
- Only a few universities have an MHK engineering curriculum
- The public has very little knowledge of MHK energy
- University education and public outreach are two totally distinct endeavors and should be separated out as two topics in the future

The RDD&D needs are:

- Develop undergraduate level engineering curriculum
- Train university professors to give the courses
- Develop a public outreach program
- Implement a public outreach program

2.18. Vision, Goals, Objectives and Roadmap

Why RDD&D in this topic is needed:

- There is a need for the MHK industry to clearly announce its vision, goals and objectives and there is a need for the Federal Government to delineate a Strategic Energy Plan which includes the addition of MHK energy. A common vision, goal, objective and roadmap is expected to help the industry go forward and help the Federal Government to shape the necessary political will to make it happen.

The RDD&D needs are:

- Develop industry-wide MHK vision, goals, objectives and technology roadmap

2.19. Ocean Renewable Energy Coalition (OREC) Perspective

The Ocean Renewable Energy Coalition surveyed their MHK members prior to the workshop. Fourteen (14) members responded to each of the topics below with a “3” for the topic being a high need, a “2” for medium need and a “1” for a low need. They were:

Pacific Gas and Electric (PG&E), Utility and renewable energy project developer
Florida Atlantic University (FAU), Ocean current and ocean thermal R&D
WaveBob, Ocean wave energy developer
Verdant, Power, Tidal and river hydrokinetic energy developer
Long Island Power Association (LIPA), Utility and renewable energy project developer
Millbank, Law Firm
Tacoma Power, Utility and tidal project developer
Strategic Marketing Initiatives, Inc., Marketing and consulting firm
Alden, Conventional and hydrokinetic turbine developer and services provider
Florida Power and Light (FP&L), Utility and renewable energy project developer
Lockheed Martin, Ocean wave and thermal energy conversion developer
Resolute Energy, Ocean wave energy developer
Pierce Atwood, Law firm
Oregon State University, (OSU), wave energy R&D

The results of the survey for all fourteen (14) members are shown in the first column and the results grouped by type of members are shown in columns 2 through 5 in Table 2-1.

Table 2-1
OREC Member RDD&D Needs Survey Results

<u>Topic Title</u>	<u>All OREC</u>	<u>Equip. Dev</u>	<u>Services & Law</u>	<u>Utility Rank</u>	<u>University Rank</u>
Regulatory Reform	38	13	7	12	5
System Performance	37	11	8	9	6
System testing	37	12	8	8	6
Environment	35	13	8	6	5
Standards	35	12	8	7	5
Safety	35	10	9	9	5
Experimental Testing	34	9	8	8	6
Resource Modeling	33	11	8	6	5
Electrical Infrastructure	32	11	7	8	4
Installation, O&M	32	10	9	7	4
Outreach & Education	32	11	6	9	5
Funding for individual projects	32	11	7	8	5
Engineering Design and Materials	31	10	5	7	6
RTO Integration	31	11	6	7	6
Wave Forecasting	31	10	8	6	4
Moorings & Attachments	30	10	6	7	5
Best Management Practices	30	8	8	9	4
Device Modelling and Simulation	29	8	8	5	5
Power Take Off and Control	28	9	7	5	4
Roadmapping	27	7	7	6	5
System Configuration Issues	27	8	6	8	5
Renewable Energy Zones	27	9	5	7	5
Lifecycle & Manufacturing	26	8	6	6	5
Storage	26	9	7	5	4
WEC Maintenance Practices	25	8	6	8	2
Hawaii Specific RDD&D Needs	24	9	7	4	2
Alaska Specific RDD&D Needs	22	7	7	4	2

2.20. National Hydropower Association Member RDD&D Perspective

The National Hydropower Association (NHA) surveyed their MHK members prior to the workshop. Thirteen (13) members responded. They were:

Hydro Green Energy, Instream hydrokinetic developer
 Puget Sound Energy, Utility and renewable energy project developer
 Tacoma Power, Utility and renewable energy project developer
 Verdant Power, Tidal power developer
 Free Flow Power, Instream hydrokinetic developer
 Snohomish Public Utility District, Utility and renewable energy project developer
 Grant County Public Utility District, researching instream hydrokinetic and conduit power
 Pacific Gas & Electric, Utility and renewable energy project developer

Voith Siemens Hydro Generation, wave energy equipment provider
Alden Research Laboratories, wave energy equipment provider
Devine Tarbell & Associates, environmental and hydrokinetic consulting
Bahleda Management & Consulting, hydrokinetic consulting
Xcel Energy, Utility and renewable energy project developer and purchasing power generated from Hydro Green Energy's Hastings project

Unlike OREC, NHA asked its members to identify without scoring the priority of the RDD&D needs. The list identified by NHA MHK members were:

Environment - Natural resources

- Coastal morphology and dynamics
- Current alterations
- Energy extraction models

Environment - Marine life

- Moorings, cables
- Fish attractions
- Avian interactions

Regulatory reform

- Regulatory process/impact
- Environmental regulations

Engineering - Turbine research

- Field tests (inc. ocean, in-river, irrigation canals)
- Fish passage studies

Infrastructure

- Offshore grid interconnection
- RTO integration

Other

- Public education
- Resource assessments – more complete picture of all technologies
- Economic analysis

3.

MHK RDD&D PRIORITIZATION APPROACH

As described in section 1.2., the Steering Committee considered two generic approaches to the workshop structure in terms of identifying RDD&D needs and prioritization:

- 1) Listen to as many RDD&D need presentations as possible within the time allocated for the workshop and predefine a simple approach to prioritization that can be implemented in minimum time at the workshop.
- 2) Go into the workshop with the RDD&D needs essentially predefined and minimize the RDD&D needs presentations and use the time allocated for the workshop on developing a prioritization approach

The Steering Committee chose the former approach. The prioritization approach chosen was to simply rank the topics as either; 1) high priority, 2) medium priority or 3) low priority. In order to assure that the results would be meaningful (as opposed to everyone voting that all topics were of high priority), the steering committee requested that the voters approximately allocate their votes into a standard distribution with about 16% of the topics being high priority and 16% of the topics being low priority and the remaining 68% being medium priority

There were two other principles that were decided by the steering committee; namely:

1. We ought not to try to prioritize among the five (5) marine energy types. Wave energy developers, with few exceptions are not also developing tidal energy or ocean thermal energy. Information about each marine type will be provided to allow a RD&D funder the ability to make that decision, information such as 1) size of extractable resource in the U.S., 2) location of resource, 3) connection of resource to electrical grid, 4) variability, 5) forecast ability and 6) economic potential
2. Priority voting should be done with anonymity

There are many ways to forecast, such as 1) rank order, 2) high, medium vs low and 3) near term vs short term, 3) high cost vs low cost, 4) high payoff vs low payoff and 5) high internal rate of return vs low internal rate of return. The simplest approach, high, medium or low, was felt to be the best approach for this first prioritization. Other and more complex schemas could be used in the future as the technology matures.

4.

MHK RDD&D PRIORITIZATION RESULTS

The eighteen (18) marine and other hydrokinetic RDD&D need topics described in Section 2 were prioritized using the procedure described in section 3. (either high, medium or low). Two groups voted: 1) the full set of MHK participants who attended the workshop (approximately 40 individuals) and 2) the MHK steering committee (see section 1.2). The full group was asked to strive for a normal or standard distribution in their voting, i.e., each voter should have about 16% of topics as high, 68% as medium and 16% as low. The steering committee was not provided with this guidance. The results of both voting processes are described in this section.

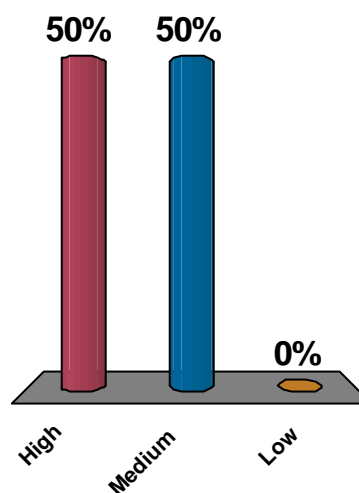
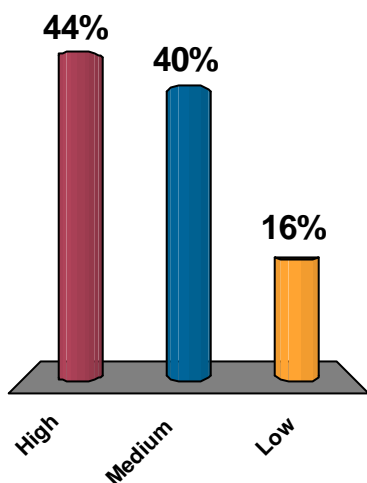
The two highest priority RDD&D topics were clearly 1) Testing and 2) Environmental. There is a natural linkage between the top two priority topics in that the resolution of environmental needs must be accomplished through testing of deployed projects in the water. The prioritization results of the full group of MHK workshop participants are shown on the left and the results for just the steering committee are shown on the right of the following bar charts.

RDD&D Need Topic

Full Group

Steering Committee

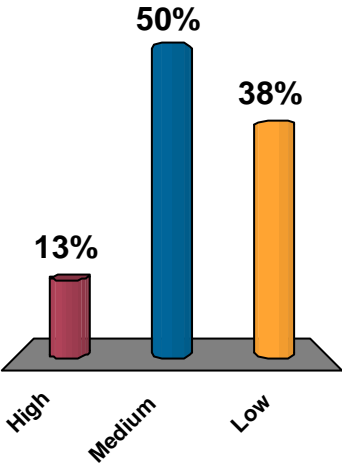
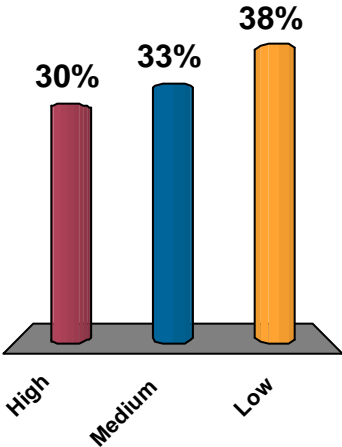
1. Resource Modeling



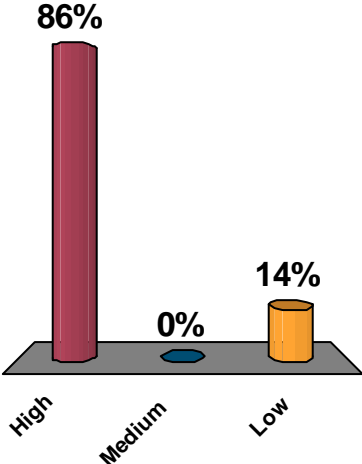
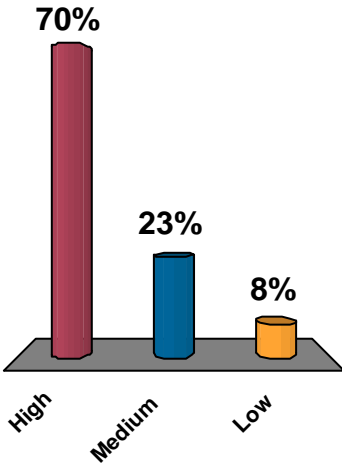
Full Group

Steering Committee

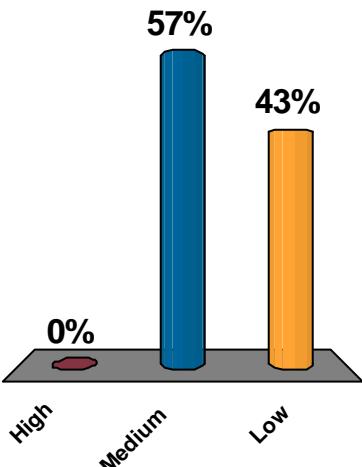
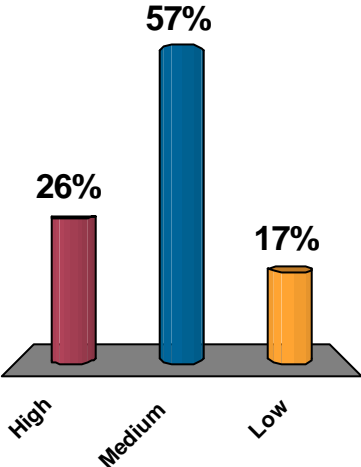
2. Device Modeling



3. Testing



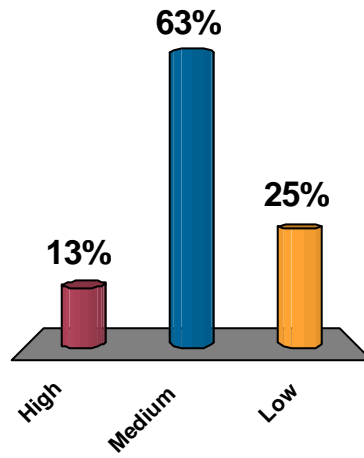
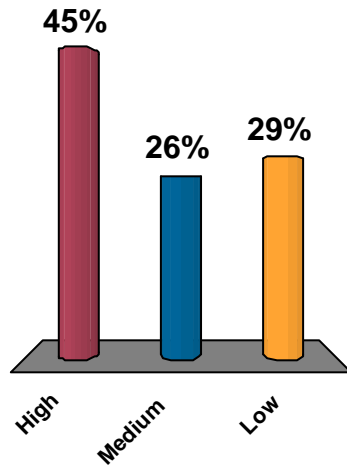
4. Moorings and Seabed Attachments



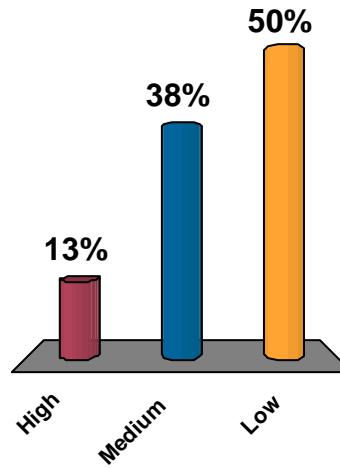
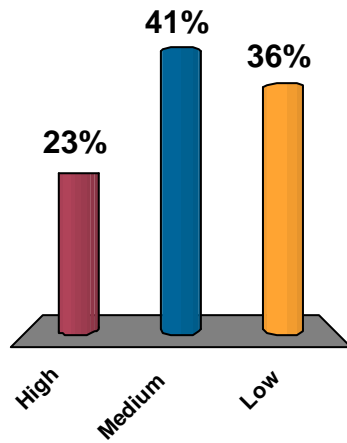
Full Group

Steering Committee

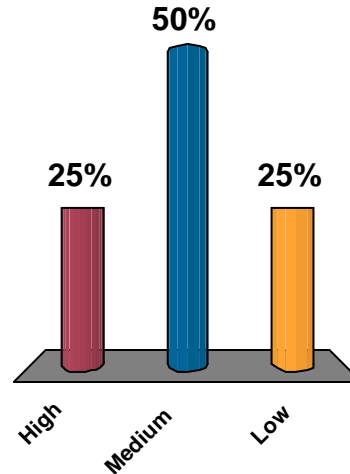
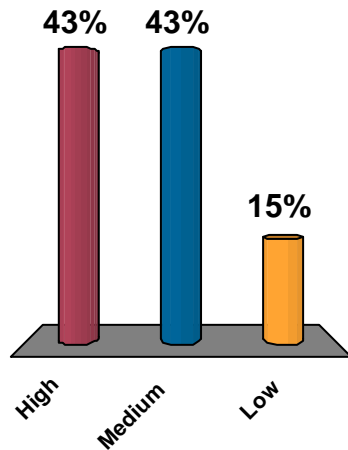
5. Electrical



6. Power Take Off and Control



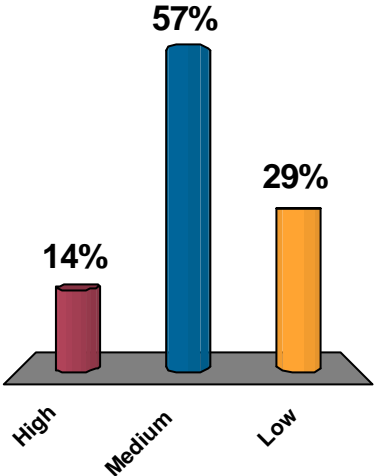
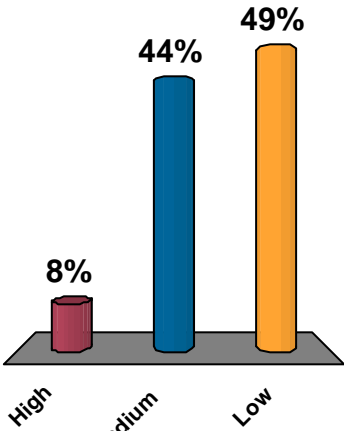
7. Engineering Design



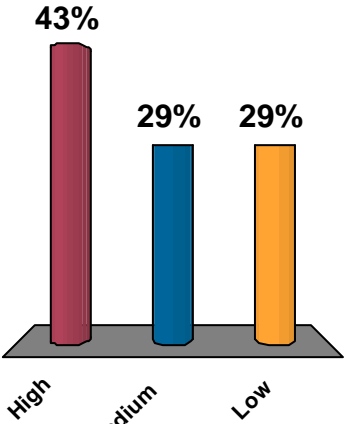
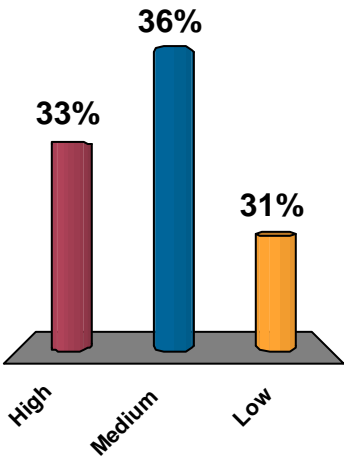
Full Group

Steering Committee

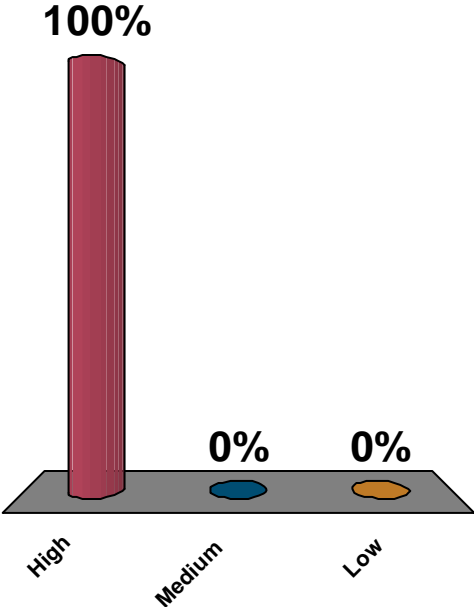
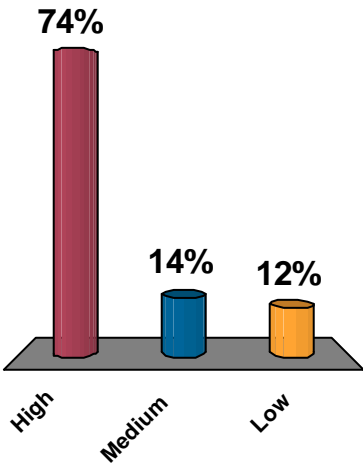
8. Lifecycle and Manufacturing



9. Installation and O&M



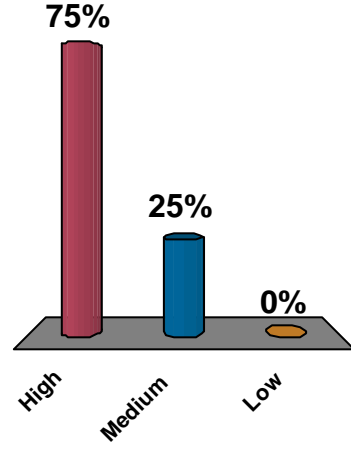
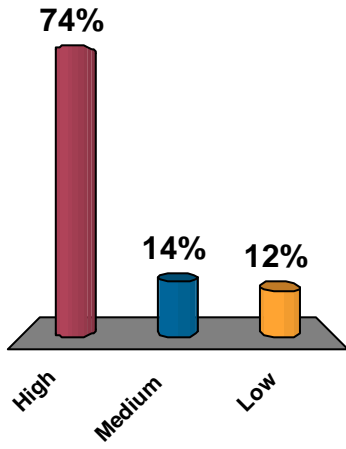
10. Environment



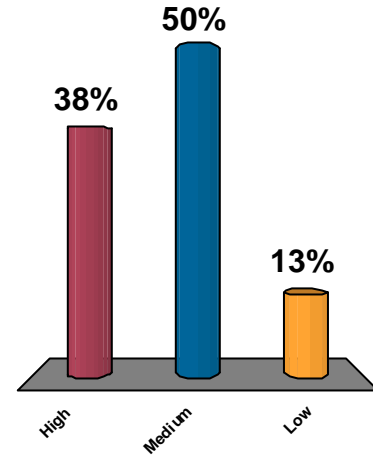
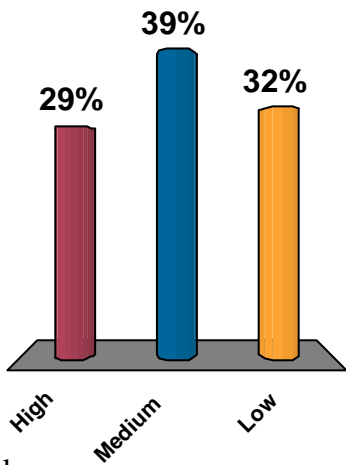
Full Group

Steering Committee

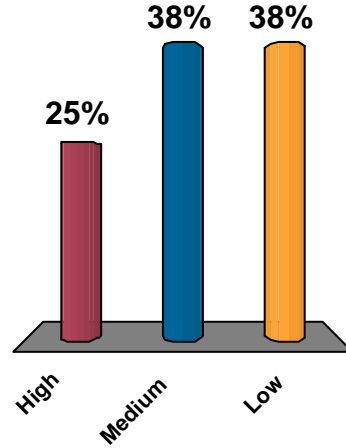
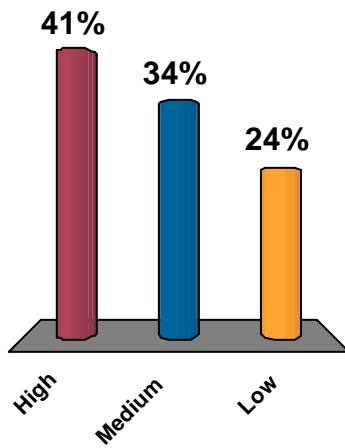
11. Standards



12. System Simulation



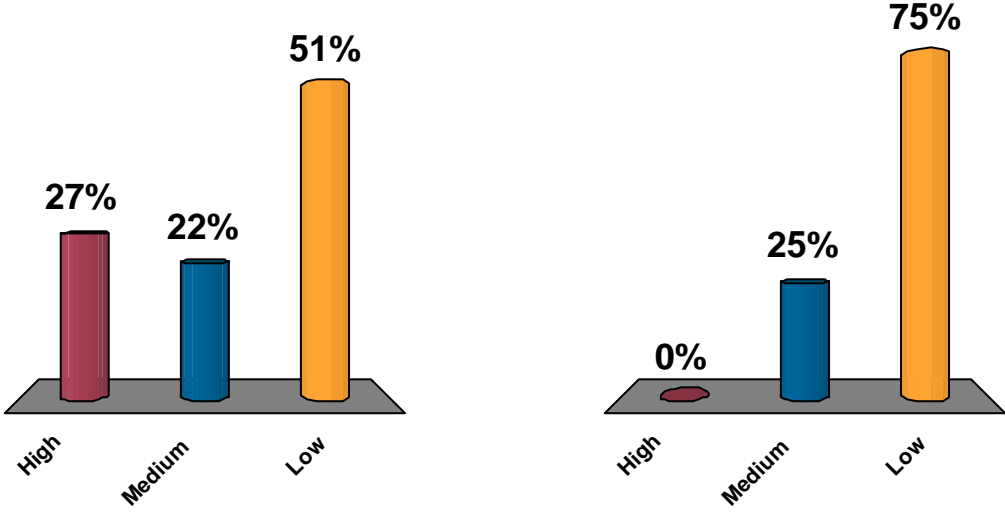
13. Materials



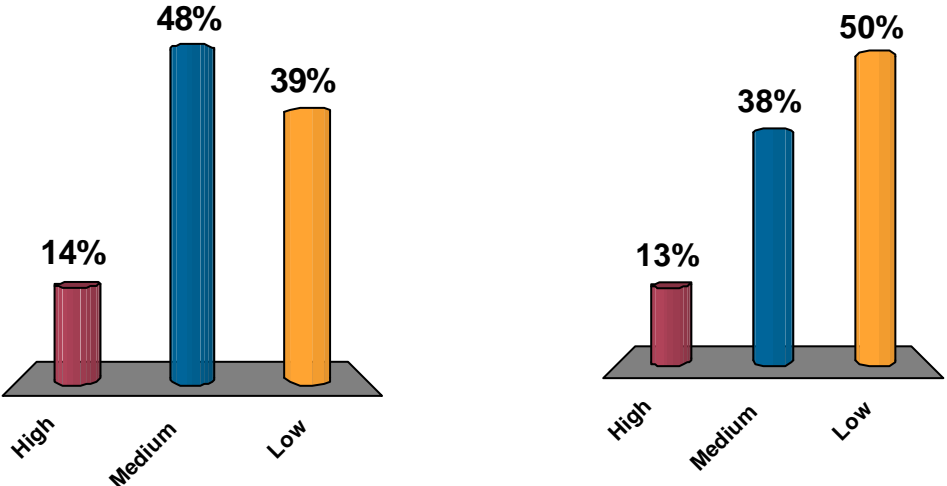
Full Group

Steering Committee

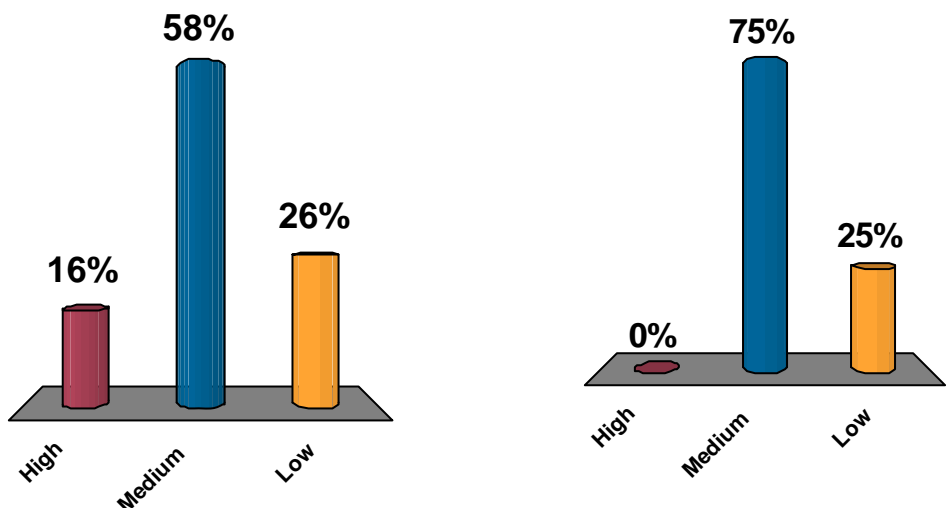
14. Storage



15. System Configuration Evaluations



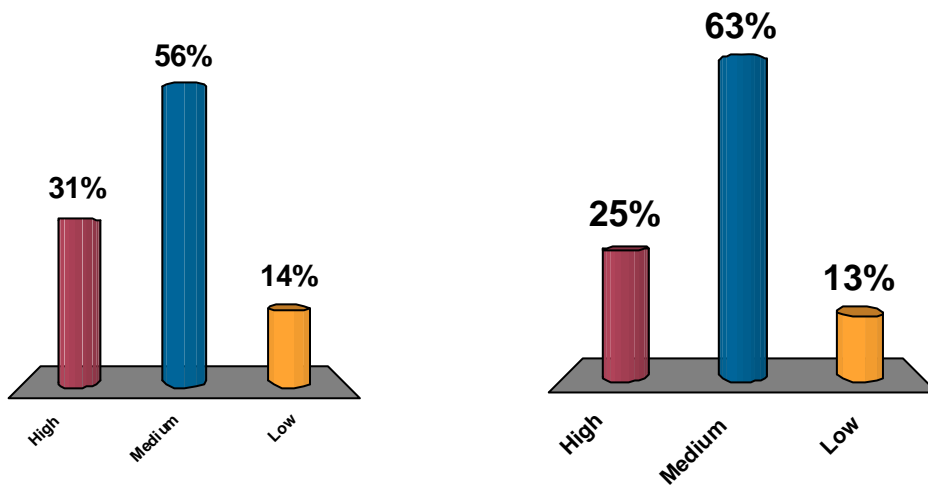
16. Master Generation/Transmission Plan



Full Group

Steering Committee

17. Education



18. Technology Roadmap

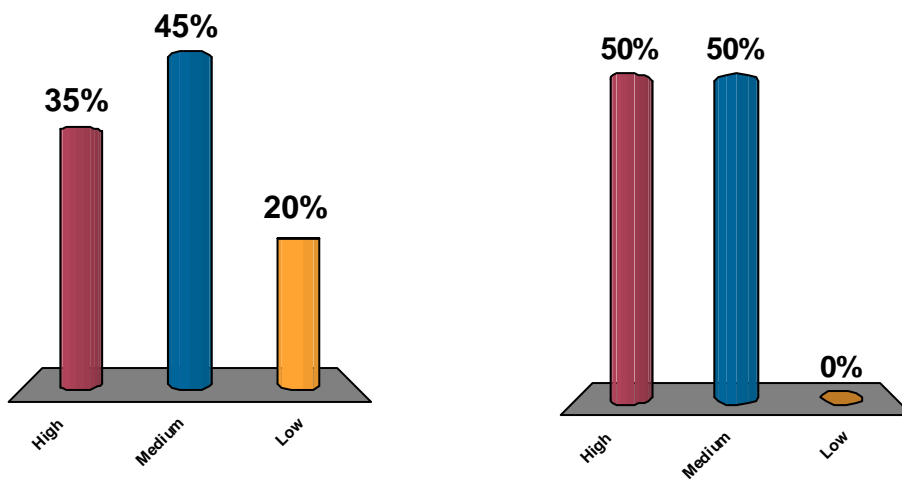


Table 3-1 shows the list of topics in prioritized order as scored by all workshop attendees and Tale 3-2 shows the list as scored by the steering committee. Numerical values were assigned as follows: High = 10; Medium = 5 and Low = 0

Table 4-1
Prioritized list if RDD&D Topics – All Workshop Attendees

Topic	Scoring by All Workshop Attendees			Rank by All
	% High	% Medium	% Low	
3. Testing	70	23	8	8.15
10. Environmental	74	14	12	8.1
11. Standards	74	14	12	8.1
7. Engineering Design	43	43	15	6.45
1. Resource Modeling	44	40	16	6.4
17. Education	31	56	14	5.9
5. Electrical	45	26	29	5.8
13. Materials	41	34	24	5.8
18. Technology Roadmap	35	45	20	5.75
4. Mooring and Sea Bed Attachment	26	57	17	5.45
9. Installation and O&M	33	36	31	5.1
12. System Simulation	29	39	32	4.85
2. Device Modeling	30	33	38	4.65
16. Master Generation/Transmission Plan	16	58	26	4.5
6. Power Take-off and Control	23	41	36	4.35
14. Storage	27	22	51	3.8
15. System Configuration Evaluation	14	48	39	3.8
8. Lifecycle and Manufacturing	8	44	49	3

Table 4-2
Prioritized list if RDD&D Topics – Steering Committee Only

Topic	Scoring By the Steering Committee			Steering Rank
	% High	% Medium	% Low	
10. Environmental	100	0	0	10
11. Standards	75	25	0	8.75
3. Testing	86	0	14	8.6
1. Resource Modeling	50	50	0	7.5
18. Technology Roadmap	50	50	0	7.5
13. Materials	38	50	13	6.3
12. System Simulation	38	50	13	6.3
9. Installation and O&M	43	29	29	5.75
17. Education	25	63	13	5.65
7. Engineering Design	25	50	25	5
5. Electrical	13	63	25	4.45
8. Lifecycle and Manufacturing	14	57	29	4.25
2. Device Modeling	13	50	38	3.8
16. Master Generation/Transmission Plan	0	75	25	3.75
6. Power Take-off and Control	13	38	50	3.2
15. System Configuration Evaluation	13	38	50	3.2
4. Mooring and Sea Bed Attachment	0	57	43	2.85
14. Storage	0	25	75	1.25

5.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

A workshop was held to identify and prioritize the research, development, deployment and demonstration (RDD&D) needs of the marine and other hydrokinetic (MHK) energy industry. The broad set of participants included representatives from Federal and State government, national laboratories, non governmental organizations, academia and private industry. Eighteen (18) RDD&D topical areas were identified and prioritized and encompassed, for the most part, the five MHK types: 1) wave energy, 2) tidal in-stream energy, 3) ocean current energy, 4) free flowing river in-stream energy and 5) ocean thermal energy. Each thematic area consists of multiple topics and subtopics. The three highest prioritized topical areas were

- 1). Testing (development including experimental through pilot demonstration)
- 2) Environmental (which will require device testing and deployed projects)
- 3) Standards

As shown in Tables 4-1 and 4-2, it is clear that the topics Testing, Environmental and Standards are the top three priorities. They were ranked in the top three by both the all attendees group and the Steering Committee. However after these top three topics, the agreement on priorities between the two groups varies considerably. Considering the variation in priority ranking for each topic, the steering committee was generally much closer to consensus than the workshop attendees. A definition of consensus is when the votes tend to cluster at high, medium or low. For example, for the “Environmental” topic the steering committee reached complete consensus, which is illustrated by the fact that all of the steering committee ranked the topic high, giving that topic a score of 10. Thus there was complete consensus by the steering committee on the ranking for the Environmental topic. As a counter example, the all workshop attendees group scored “Installation and O&M” as 33% High, 36% Medium and 31% Low, which gave it a score of 5.1 out of 10. That would seem to indicate that it was half as important as the “Environmental” topic. However, maybe not! If the voting had been 100% in the medium category giving it a 5, then would have been consensus. With the voting split about one-third in each priority category, high, medium and low, we conclude that the attendee group was not in agreement on how this category should be ranked. Note also that the Steering committee was similarly conflicted on this topic with a voting of 43% high, 29% medium, and 29% low. Possibly, the topic was too broad and people voted based on different aspects as they individually interpreted the question. Possibly, everybody was confused about what was included in the category, but it is clear that they did not agree on the ranking. For that reason, it is difficult

to decide exactly how to rank this topic. This is an important outcome. In addition, many of the topics ranked by the all attendees group that scored as a medium priority lack a clear consensus.

In reviewing the scoring, it seems that the steering committee was much closer to consensus than the all workshop attendees group, particularly at the high end of the priorities and the low end. This is not unexpected, because the steering committee members were selected based on their background and knowledge about the ocean energy research. In addition, they discussed the workshop topics and developed the agenda in weekly steering committee telephone calls over a two month period. For this reason, the steering committee's research priority rankings show a higher degree of consensus among the members. This is important, because there is a tendency to take the ranking of topics at face value, and that could be a mistake. This may mean that there was confusion about the contents of some topics, and perhaps some group members had insufficient information about some topics to be able to decide priorities.

Finally, even the topics that were rated low priority need some investment in research. The topics that the steering committee used as a starting basis were vetted in Europe as important for ocean energy development. The Europeans plan to address all of these topics, because they feel they are important based on their experience. So even the lower ranked research topics warrant some RDD&D investment. Perhaps, these topics could be addressed through overall systems studies, and specific device designs and development work done by machine manufacturers.

Recommendations

Once funding is available, specific programs and projects for high priority topics identified in this workshop should be developed and implemented.

Clearly, the RDD&D topics of "Environmental", "Standards" and "Testing" need to be addressed in a comprehensive fashion. Also, these topics may warrant further consideration in follow-on meetings to be explored in more detail with knowledgeable experts in the field. In addition, a smaller group could formulate RDD&D questions that need to be addressed by research. This type of expert meeting has worked very well for formulating and focusing research for the Bats and Wind Cooperative. See for example <http://www.batsandwind.org/pdf/finalbatpro2004.pdf>

Topics falling below the high priority ranking with less consensus are still important, and need to be addressed, but are not as urgent, and probably do not need individually targeted workshops. Perhaps, these topics could be grouped together in closely related topical workshops to develop more in-depth research agendas. For example, the topics of Materials, System Simulation, Engineering Design, and Device Modeling could be rolled into a single meeting. The October 2008 workshop did not provide enough time or depth of discussion to come to consensus on many of the topics that were rated as medium priority and a more in-depth research agenda is needed to guide a well articulated, prudent goal driven research program.

A topic that generated much discussion in the workshop was the need for an additional workshop as soon as possible to reach an industry-wide vision, goal, objectives and a roadmap for developing and deploying MHK technology in the United States. The consensus recommendation from this workshop is that such a vision, goal and objective would go a long way towards achieving a funded program. Relative to the specific, measurable, achievable, realistic and time lined (SMART) objectives, the consensus opinion is that the industry should set the bar as high as realistically achievable. The bar statement might be one similar to the UK bar, a specified installed capacity by a specific year. This bar along with the RDD&D needs and the timelines would define the funding requirements.

Lastly, the workshop would be valuable to see more info on how MHK technology will be viewed and valued by utilities. Wind energy provides a fine example of the polarized views and perspectives that divides many wind energy advocates and many utilities. We recommend that consideration be given to a workshop that would address:

- MHK impacts on utility reliability and price
- The capacity value of MHK
- How the variability and capacity factor of marine energy reduces the value of the power
- What generation resources would match well with MHK (storage hydro, diesel, etc?)
- Low vs. high penetration impacts on utility operations

6.

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All EPRI WP, TP and RP series reports are available at www.epri.com/oceanenergy/

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