Proceedings

of the

Hydrokinetic and Wave Energy Technologies

Technical and Environmental Issues

Workshop

Sponsored by:

U.S. Department of Energy
OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY
Wind and Hydropower Technologies Program

March 24, 2006

To access this document and presentations made at the

Hydrokinetic and Wave Energy Technologies
Technical and Environmental Issues
Workshop

visit*: http://hydropower.inl.gov/hydrokinetic_wave/*

The production of this document was supported by the National Renewable Energy Laboratory under the subcontract YAM-4-33-217-01. Financial support by the National Renewable Energy Laboratory and the Department of Energy does not constitute an endorsement by these institutions of the views expressed in this document.

Abstract

Renewable energy technologies offer the promise of non-polluting alternatives to fossil and nuclear-fueled power plants to meet growing demand for electrical energy. Two emerging categories of renewable energy technologies, *hydrokinetic* and *wave energy conversion devices*, offer ways to tap the energy of moving water without impoundment (dams) or diversion required by many conventional hydroelectric facilities. These technologies include devices designed for deployment in natural streams, tidal estuaries, ocean currents, and constructed waterways, as well as devices designed to capture the energy of ocean waves.

On 26-28 October 2005, 54 representatives from government, non-governmental organizations, and private business met to:

- Identify the varieties of hydrokinetic energy and wave technology devices, their stages of development, and the projected cost to bring each to market;
- Identify where these technologies can best operate;
- Identify the potential environmental issues associated with these technologies and possible mitigation measures;
- Develop a list of research needs and/or practical solutions to address unresolved environmental issues.

These Workshop Proceedings include detailed summaries of the presentations made and the discussions that followed.

Suggested Citation Format:

Proceedings of the Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop. Washington, DC. October 26-28, 2005. Prepared by RESOLVE, Inc., Washington, D.C., Susan Savitt Schwartz, ed. March 2006.

Proceedings (including slide presentations) may be downloaded from: http://hydropower.inl.gov/

Acknowledgments

Direct and in-kind support for the Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop and Proceedings was provided by:

U.S. Department of Energy Wind and Hydropower Technologies Program

Planning Committee Members:

Edward Abrams, *Federal Energy Regulatory Commission*

James Ahlgrimm, *U.S. Department of Energy*

Fred Ayer, *Low Impact Hydropower Institute*

Michael Bahleda, *Bahleda Management and Consulting, LLC*

Tom Bigford, *National Marine Fisheries Service*

Glenn Cada, *Oak Ridge National Laboratory*

Linda Church Ciocci, *National Hydropower Association*

Stefanie Damiani Stavrakas, *U.S. Fish and Wildlife Service*

Douglas Hall, *Idaho National Laboratory*

Russell Moursund, *Pacific Northwest National Laboratory*

Richard Roos-Collins, *Natural Heritage Institute*

Facilitation team: Abby Arnold, Brad Spangler, Jennifer Peyser, *RESOLVE, Inc.*

Table of Contents

Abstract i
Acknowledgments iii
Table of Contents v
Preface ix
Glossary of Acronyms xii

EXECUTIVE SUMMARY XIIII

Overview of the Technologies and Environmental Resources xiiii
Research Needed to Evaluate the Potential Environmental Impacts Associated with Hydrokinetic and Wave Technologies xv
Strategies for Addressing Environmental Research Needs xvii

INTRODUCTION 1

Welcome from Planning Committee Representatives 1
Review of Workshop Purpose, Objectives & Agenda 3
Workshop Participants 4
Meeting Proceedings 4

PRESENTATIONS OF HYDROKINETIC AND WAVE ENERGY TECHNOLOGIES 5

Overview of Technology Classes and Key Terminology [1. R. Bedard_Day 1 Overview of Techs.pdf] 5
Axial Flow Machines [2. T.Taylor Presentation_Day 1.pdf] 8
Open Center Turbine [3. H.Williams Tech Presentation.pdf] 12
Ducted Turbine [4. S.Meade Tech Presentation.pdf] 13
Turbine Matrix / Hydromatrix® [5. A.Bihlmayer Tech Pres-1.pdf] 16
"Cross Flow" / (Helical) Turbine [6. A. Gorlov Presentation.pdf] 18
Venturi Devices 19
Heave Wave Devices [7. A.Weinstein Presentation.pdf] 20
[8. G.Taylor Presentation-revised.pdf]
Heave-Surge Wave Devices [9. M.Carcas Tech Presentation.pdf] 25
Overtopping Wave Devices [10. Erik F-M Tech Presentation.pdf] 28
Oscillating Water Column [*This presentation was made without slides.*] 30

DAY ONE WRAP-UP DISCUSSION SUMMARY 32

FACILITATED DISCUSSION WITH TECHNOLOGY PRESENTERS 36

RESOURCE AREAS FOR DEPLOYMENT OF HYDROKINETIC AND WAVE ENERGY AND ASSOCIATED ENVIRONMENTAL QUESTIONS/CONCERNS 42

Resource Concerns Associated with Natural Streams [1. Cada and Meyer - Natural Streams.pdf] 42
Resource Concerns Associated with Estuaries [2. T. Swanson - Estuaries.pdf] 45
Resource Concerns Associated with Near-Shore Environments [3. J.Gibson - Near Shore.pdf] 49
Resource Concerns Associated with the Off-shore Environment [4. J.Ogden - Offshore (Bigford).pdf] 51
Canals and Other Engineered Waterways [No slide presentation] 54

KNOWN AND POTENTIAL ENVIRONMENTAL QUESTIONS/CONCERNS RAISED IN CONNECTION WITH HYDROKINETIC TECHNOLOGIES 55

I. Rotating Machines 55
Resource Questions Associated with Axial-Flow Turbine Arrays in Existing Structures 55
[1. A. Bihlmayer Hydromatrix Envr Info.pdf]
Resource Questions Associated with Free-flow Axial Turbines 57
[2. J.Gibson - Free Flow Axial Turbines Envr Info.pdf]
Resource Questions Associated with Cross-Axis (Helical) Devices 59
[See earlier slides: 6. A. Gorlov Presentation.pdf]
II. Wave Energy Devices 60
Resource Questions Associated with a Heave-Surge Device 60
[3. M.Carcas - Pelamis Envr Concerns.pdf]
Resource Questions Associated with Heave (Point-Absorber) Devices 62
[4. G.Taylor - OPT Envr Concerns.pdf]
[Weinstein-051027_DOE_HW_workshop_ea.pdf]
III. Oscillating Water Column Devices 64
Resource Questions Associated with an Oscillating Water Column 64
[No slides with this presentation]

DISCUSSION SUMMARIES 65

Preliminary Thoughts on Environmental Questions Posed by Development of Hydrokinetic and Wave Technologies 65
Summary List of Research Topics for Hydrokinetic and Wave Technologies 72
Strategies for Addressing Environmental Research Needs 74

RESEARCH APPROACHES AND MODELS FOR COLLABORATION 77

Electric Power Research Institute (EPRI)'s Ocean Energy Research Program 77

[1. R.Bedard EPRI Future.pdf]
European Marine Energy Centre (EMEC) 80
[2. J.Griffiths EMEC Overview.pdf], [PO4-037-002 Final EMEC EIA procedure.pdf]
Proposal for a US Marine Energy Center 84
[3. K.Rhinefrank - Oregon St Activities.pdf]
Possible Models for Collaboration 86
[Presentation made without slides]

CONCLUDING THOUGHTS AND OBSERVATIONS 89

APPENDIX A: GROUPING OF WORKSHOP PARTICIPANTS' RESEARCH QUESTIONS/CONCERNS 90

APPENDIX B: ALPHABETICAL LISTING OF PLANNING COMMITTEE MEMBERS, PRESENTERS, AND WORKSHOP PARTICIPANTS WITH CONTACT INFORMATION 100

APPENDIX C: WORKSHOP AGENDA 106

APPENDIX D: LIST OF SLIDE PRESENTATIONS 110

Preface

The *Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop* was funded by the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy's Wind & Hydropower Technologies Program. DOE contracted RESOLVE Inc. as a neutral third-party facilitator to assist with the convening and facilitation of the workshop. RESOLVE, in consultation with DOE staff, organized a Planning Committee. Comprised of individuals representing federal agencies, the hydropower industry, the environmental community, and an independent consultant (see Planning Committee Roster, included in Appendix B), the Planning Committee worked closely with RESOLVE to collaboratively develop the objectives, agenda and invitation list for the workshop.

The *Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop* was held in Washington, DC on October 26-28, 2005. These proceedings provide an overview of the range of hydrokinetic and wave energy technologies, of the various water resources in which these technologies are designed to be sited, and of the types of technical and environmental research questions which will need to be answered to facilitate the commercial development of these technologies.

The organizers of the Workshop hope this publication will provide a useful starting point for further efforts to promote the environmentally sound deployment of hydrokinetic and wave energy technologies.

Glossary of Acronyms

BPA	Bonneville Power Authority
cfs	cubic feet per second
EIA	Environmental impact assessment
EMEC	European Marine Energy Centre
EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
FONSI	Finding of No Significant Impact
INL	Idaho National Laboratory
kW	Kilowatt
LIPA	Long Island Power Authority
LNG	Liquid natural gas
MMS	Minerals Management Service
MTC	Massachusetts Technology Collaborative
MW	Megawatt
NHA	National Hydropower Association
NIMBY	"Not In My Backyard"
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRDC	National Resources Defense Council
NYSERDA	New York State Energy Research and Development Authority
OEP	Ocean Energy Program (DOE Program authorized by the 2005 Energy Bill)
OREC	Ocean Renewable Energy Coalition
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
RPS	Renewables Portfolio Standard
SEPA	State Environmental Policy Act
SMUD	Sacramento Municipal Utility District
USDOE	United States Department of Energy
USFWS	United States Fish and Wildlife Service

EXECUTIVE SUMMARY

Two emerging categories of renewable energy technologies, hydrokinetic and wave energy conversion devices, offer ways to tap water energy without impoundment or diversion. On 26-28 October, 2005, 54 representatives from government, non-governmental organizations, and private business took part in the *Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop*. Participants shared information about the technologies and identified potential environmental issues associated with deploying them, and outlined a list of research needs and possible approaches to addressing those issues.

Overview of the Technologies and Environmental Resources

Hydrokinetic and Wave Energy Conversion Technologies

- ***Hydrokinetic energy conversion devices*** are designed to be deployed in a stream or current, capturing kinetic energy from the flow of water across or through the rotor (which may take various forms) to power a generator without impounding or diverting the flow of the water resource. Conceptually, this is similar to the way wind energy conversion devices work.
- ***Wave energy conversion devices*** create a system of reacting forces, in which two or more bodies move relative to each other, while at least one body interacts with the waves. The body moved by the waves is called the *displacer*, while the body that reacts to the displacer is called the *reactor*. There are many ways that such a system may be configured, including: oscillating water columns (OWC), point-absorbers, attenuators, and overtopping devices.

The ***market potential*** for hydrokinetic and wave energy is vast, ranging from small-scale distributed generation applications to large-scale power plants.

- Given that hydrokinetic devices can be deployed in any water resource having sufficient velocity to drive them, their energy generation potential is gargantuan. Water resources that could be harnessed include: natural streams, tidal estuaries, ocean currents, and constructed waterways such as aqueducts and various types of effluent streams. None of these resources have been comprehensively assessed to determine their potential for hydrokinetic energy generation.
- The Electric Power Research Institute (EPRI) calculates the annual average incident wave energy at a 60 m depth off the US coastline as equal to 2100 Terawatt hours per year. Harnessing 20% of that total at 50% capacity factor would generate almost as much electricity as conventional hydropower provides (currently 7% of total US electricity consumption).

The main ***obstacles to development*** result from these being relatively new technologies, unfamiliar to licensing and resource agencies, and as yet largely unproven from the point of view of investors. Developers are small and undercapitalized. Many of the environmental impact questions that must be addressed in order to permit even a demonstration project cannot be answered without deploying the devices and monitoring the impacts. Although the technologies themselves appear to have fewer impacts than more conventional energy technologies, the prospect of deploying these devices in already-stressed environments requires strict scrutiny from the point of view of resource managers. This concern is magnified by the difficulty of extrapolating impacts from individual pilot projects to those associated with full-scale build-out.

Water Resource Areas for Deployment and Associated Environmental Considerations

Wave energy conversion devices are designed for use in either the open ocean or near-shore environments. The various hydrokinetic rotating devices are more varied in their applications; water resource settings may include natural streams, tidal estuaries, ocean currents, and constructed waterways. Each of these settings raises its own set of environmental considerations.

Natural streams. Important features of natural streams that are relevant to impacts from hydrokinetic technologies include highly variable flows and turbulence, shallow depths, and the frequent occurrence of multiple, competing uses. As with conventional turbines, deployment of rotating machines in natural streams raises questions about fish strike. Other concerns include impacts on the physical and chemical characteristics of the water and the substrate.

Tidal Estuaries are highly complex, diverse systems, providing a wide variety of rich and for the most part productive habitat. Each is unique, and many are designated as research reserves, or as being of "national importance." Possible impacts have to be considered in the context of existing anthropogenic modifications, with the cumulative impact of ecological stresses taken into account when evaluating the impact of a given project.

Near-shore environments may be distinguished from "off-shore" as the vegetative or photic zone, an area where the substrate and influence of sunlight support a productive food web for a wide range of plants and animals. Other near-shore functions include: wave and current buffering, water quality protection, floodwater attenuation, and ecological buffer zone.

Off-shore. Although the oceans are huge, a relatively small fraction of the continental shelf area is environmentally and economically feasible for deployment of hydrokinetic or wave technologies.

Constructed Waterways. This includes irrigation canals, aqueducts, water supply or effluent streams.

Research Needed to Evaluate the Potential Environmental Impacts Associated with Hydrokinetic and Wave Technologies

Workshop participants identified several areas where research and development is needed to evaluate potential environmental impacts that may be associated with the various hydrokinetic and wave energy technologies. **The discussion emphasized a need for Federal support for technology development, long-term research on environmental effects and mitigation measures, and well-designed operational monitoring.** (See Appendix A for complete, detailed list of research needs. Note that the product of this Workshop discussion does not reflect a consensus or prioritized list.)

Evaluate the environmental impacts of various technology-resource site combinations using standardized measures, looking at the cumulative and synergistic effects of multiple installations. Coordination/collaboration is the key to getting beyond the present “shotgun” approach to examining environmental issues. Research would be better accepted if done by independent organizations or consortia rather than developers. A testing facility that uses standardized approaches in a common testing environment would be valuable.

Identify gaps in our understanding of environmental effects. A high-level, programmatic EIS could compare impacts of different sites and technologies using similar metrics. These assessments should evaluate cumulative and synergistic effects of multiple installations, employ models to extrapolate effects from pilot projects to full scale projects, consider all possible resources that might be impacted (including aesthetics and recreation), consider future freshwater flow/sea level conditions, and suggest appropriate mitigation and monitoring. In addition to routine installation and operation, the consequences of accidents and equipment failure should be assessed. Information from previous work on conventional hydropower projects should be applied to new technologies where possible.

Identify the location and power potential of feasibly developable water energy resources. Resource assessments are needed to develop estimates of the amount of energy that can be extracted, especially from marine and estuarine systems. These would include (1) ascertaining locations of applicable resources and estimation of their gross power potential, and (2) evaluating the feasibility of development and estimation of their true power potential.

Evaluate the long term reliability and susceptibility to damage of the various technologies within various resource settings. More work needs to be done on the long term reliability of these technologies and their susceptibility to accidents/damage within various resource settings.

Evaluate the effect of power generating equipment and their mooring systems on stream beds, sea floor (including impact on benthic habitat), and on shoreline and shallow water processes. Cables, mooring structures, and the motions of hydrokinetic machines in shallow water could alter sediments. Research is needed to address possible effects including resuspension of sediments and contaminants and resettlement elsewhere, increased turbidity, long-term scour from slack lines, alteration of shoreline and shallow water processes, and alteration of benthic habitats and the consequent effects on bottom-dwelling animals.

Estimate the effects of technologies (individual units and mass deployment) on resource hydraulics and the resulting impacts to open water habitats. Research is needed on the impacts these technologies would have on local hydraulics (small-scale effects) and current patterns and other hydrological regimes (large-scale effects). Hydraulic impacts could alter sediment dynamics and degrade habitats for aquatic organisms. Modeling may help extrapolate effects from a few units to a large energy production facility.

Measure the electromagnetic fields produced by these new technologies and their impacts to migratory and resident aquatic organisms. Research is needed to quantify the electromagnetic fields produced by these new technologies as well as the impacts to migratory and resident aquatic organisms.

Research the toxicity of paints, hydraulic fluids, and chemicals used to control biofouling. Information should be developed on the toxicity of paints, hydraulic fluids, and chemicals that will be used to control biofouling.

Evaluate the risk and consequences of strike by moving structures and impingement on screens for aquatic organisms and diving birds and mammals. Research is needed to determine the risk and consequences of aquatic organisms and birds striking moving structures associated with these technologies. If screens are employed to protect aquatic biota, there may be a risk of impingement injury and mortality. Information developed from conventional hydropower plants may be useful for making initial predictions of impacts and for guiding future research.

Evaluate the noise impacts of technologies. Research is needed on both the noise made by these new technologies (frequencies, sound levels, and areal extent) and the effects of noise on aquatic organisms (damaging or attractive).

Research impacts on drifting and actively migrating fish, benthic fish and invertebrates, aquatic mammals and turtles, diving birds, shore birds, and aquatic vegetation. Research is needed on the impacts of construction and operation of these technologies to aquatic organisms. Potential impacts to aquatic organisms include strike by moving structures, impingement on screens used to protect organisms or structures, creation of damaging pressures and shear, creation of physical barriers to movement/migration, attraction to structures, degradation of open water and benthic habitats, entanglement in cables, electromagnetic fields, and chemical toxicity. Potentially affected organisms include drifting and actively migrating fish, benthic fish and invertebrates, aquatic mammals and turtles, diving birds, shore birds, and aquatic vegetation.

Strategies for Addressing Environmental Research Needs

Workshop participants also discussed how to address the various environmental research needs they had identified. Participants emphasized the need for leadership, for synthesis of existing knowledge, and for collaboration.

There is a need for leadership.

Historically, energy technologies have developed because the national government has made them a priority, and established policies and invested resources for an expected return. Absent leadership at the national level, developers and resource agencies face several obstacles:

- Better estimates of the size of the feasibly developable energy resource are needed to support appropriate levels of investment and technical R&D.
- Developers face a poorly-defined regulatory structure.
- Research and development priorities are not clear.
- Developers are small and under-capitalized; investors want to see projects in the water before they make any commitments.
- R&D funding for hydrokinetic energy technologies has to include a budget that enables under-funded and under-staffed resource agencies to participate.

There is a need for synthesis, for a common language

A lot of the data and knowledge relevant to developing hydrokinetic and wave energy resources and addressing potential environmental impacts already exists. However, synthesizing this information requires a framework and a common language.

- Given the diversity of hydrokinetic and wave technologies, we need to identify generic questions and a set of common terms when asking/answering those questions about specific technologies.
- As we gather data, we should be building a base of knowledge, so that we can begin to identify which among these technologies has the least environmental impacts.
- Communication and collaboration are important not only for the industry and for researchers, but also for regulators and resource agencies. The more we can learn what we need to know together, the better we can avoid confusion and redundancy in the permitting process.

Collaboration is critical

Participants emphasized the importance of collaborating, not only to identify research priorities but also to lobby for funding and to continue to educate each other as stakeholders. Several specific points were made.

- DOE is not going to have R&D capacity in the short term; bringing stakeholders together is the first step in forming coalitions that can get funding for R&D.

- Much of the money for research comes from the states, from non-profits. Again, getting the money to do the research requires working together to come up with a concrete list of research priorities.
- One approach is to create a coalition to address the big-picture questions, such as:
  - What is the size of the resource and its development potential? (This may be key to getting public funds.)
  - In an underwater axial turbine, what is the zone of influence?
  - How do you scale up the evaluation of environmental impacts from individual devices to those of commercial-scale projects and the cumulative impact of multiple projects?
- An alternative to funding the national labs to do research is the "bottom up" approach: funding individual projects and trying to extrapolate the information, involving resource agencies and NGOs in the research plans.
- It may be necessary to pursue both approaches: 1) fund and gather information on individual demonstration projects; and 2) develop support for synthesizing what we learn from those projects, pulling the information together to see what larger questions we can answer, what other work is needed to fill in the gaps.

How do we organize to move forward?

- The best licensing in traditional hydropower has come out of collaborative efforts to educate people about the impacts of these technologies; we should work together to determine what research needs to be done.
- Adaptive management is essential: a phased approach to testing, monitoring, and adapting individual projects can yield information that will be useful to a lot of other companies.
- Hydrokinetic and wave technologies are small and under-capitalized, much as wind was 10-15 years ago. Collaboration on a national level was important for wind.
- This industry might benefit collaborating with other new industries (such as aquaculture) that are working in the same environment, dealing with many of the same environmental impact questions.
- We should continue to foster international collaboration as well.

Participants considered various possible models for collaboration, including the European Marine Energy Centre located at Orkney (UK); a somewhat analogous facility being developed in Oregon, the Electric Power Research Institute's Ocean Energy Program, and opportunities for tapping support from the state and non-governmental sectors.

INTRODUCTION

Renewable energy technologies offer the promise of non-polluting alternatives to fossil and nuclear-fueled power plants to meet growing demand for electrical energy. Two emerging categories of renewable energy technologies, hydrokinetic and wave energy conversion devices, offer ways to tap the energy of moving water without impoundment (dams) or diversion required by many conventional hydropower facilities. These technologies include devices designed for deployment in natural streams, tidal estuaries, ocean currents, and constructed waterways as well as devices designed to capture the energy of ocean waves.

Because these technologies are so new, so numerous, and so diverse, they raise many questions for the agencies that manage the natural resources in which these devices would be deployed. Neither the agencies nor environmental organizations – nor, to a large extent, the developers of hydrokinetic and wave energy conversion devices – know what impact these technologies might have on their environments. Developers and environmental stakeholders alike seek answers, yet many of these devices (and their environmental impacts) cannot be tested fully without actually deploying them – creating an obstacle to commercial development.

To address the opportunities and questions raised by these new categories of renewables, the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy's Wind & Hydropower Technologies Program sponsored the *Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop*. On 26-28 October 2005, 54 representatives from government, non-governmental organizations, and private business met to share their perspectives on:

- The available classes of hydrokinetic energy and wave technologies
- The water resource areas where these technologies can best operate
- The potential environmental issues associated with deploying these technologies
- Research needs and/or practical solutions to address unresolved environmental issues

Welcome from Planning Committee Representatives

Several members of the Planning Committee welcomed participants and outlined their expectations for the Workshop.

Jim Ahlgrimm, U.S. Department of Energy (USDOE). It is exciting to see everyone here in one room. This workshop has gathered quite a collection of brainpower; it should be good experience.

Peter Goldman, US DOE (Manager of Hydropower Program, supported by ORNL, INL, PNNL, NREL). For the last ten years, DOE has been working on large "fish friendly" turbines. We will be completing the Advanced Hydropower Turbine System Program in FY2006, so last year we asked RESOLVE to help organize a collaborative effort patterned on the National Wind

Coordinating Committee – a consensus-based forum for the development and pursuit of research agenda. We found that there was interest, that there was not necessarily enough time/resources to commit to a full-blown Collaborative, but enough for a workshop on hydrokinetic technologies. With the Hydropower Program ending, DOE would be interested in laying the foundation for planning for development and deployment of these new technologies – what issues need to be addressed, what research? At the end of the meeting, we will talk about next steps, how we can work together to address research questions.

Linda Church Ciocci, National Hydropower Association. NHA extends its appreciation to the DOE, RESOLVE, and the planning committee for their support of this important workshop. We support these new technologies. We are very interested in seeing their full deployment. We recognize the important role research plays in fulfilling the promise of these technologies. We know, first-hand, from the Advanced Hydropower Turbine Program that technological improvements enable us as energy planners to strike an appropriate balance between the delivery of clean energy and the minimization of impact on fish/aquatic life. Based on full scale tests of the advanced hydro turbine conducted last spring on the Columbia River, many years of difficult and concerted research in the design of this new turbine has lead to major success. In fact, we have succeeded our goals for fish survival, and produced more energy with less water. That program has clearly shown the importance of a concerted national effort to further new advanced technologies through cooperative R&D.

Advances in tidal, wave, ocean and hydrokinetic technologies create tremendous opportunity to produce clean energy to meet growing energy demand. The potential growth in these areas is tremendous, but will we realize that promise?

Through R&D we could. Some of these technologies are better understood than others. We need to fully understand all the options. We need to have a better understanding of where the various technologies would best be deployed and how they might fit within utility planning. We need to have a workable regulatory process and that, in turn, requires a willingness among regulators and stakeholders to accept them. Shining more light on the potential, both in terms of technology resource and impacts, is a critical step toward gaining acceptance and reaching full deployment. It will take industry, the federal government, state government and all stakeholders, working together, to see the promise fulfilled. It is our hope that this workshop can shine more light and help us toward reaching consensus on next steps.

Robbin Marks, American Rivers. Thanks to DOE for involving us in the Planning Committee. We have 45,000 members in every state, have worked on hydropower licensing. I chair the Hydropower Reform Coalition – a consortium of 132 organizations dedicated to preserving rivers through FERC relicensing process. We support strong science R&D to avoid environmental impacts and inform licensing decisions.

We are here to learn about the technology and its potential, what environmental impacts are or may be. While it may appear that the impacts are smaller than for traditional hydro (or other energy) technologies, we can't assume that impacts are trivial either; we have to assess them comprehensively and on site-by site basis. We support a strong federal role in:

1) assessing potential of hydro to bring most efficient technologies to marketplace;
2) R&D of technology and robust analysis of impacts through involvement of stakeholders and resource agencies; and
3) ensuring environmental impacts are identified and mitigated as the technology moves to the marketplace.

Questions we want answered:

1. What is the state of knowledge about environmental impacts?
2. What is the government role – not only DOE in R&D and deployment, but also states, resource agencies, collaboration with industry?
3. What's the economic potential for this technology?
4. What is the anticipated scale of deployment?
5. What will the regulatory structure look like?

Richard Roos-Collins (NHI) could not be here today, but expressed interest in how workshop participants may want to work together to move the process (begun here) forward.

Tom Bigford, National Oceanic and Atmospheric Administration. It is not often we have an opportunity to sit down with energy sectors so early in development of an emerging technology – usually environmental issues don't get considered until relatively late in the process. Hopefully this is a chance to make sure things proceed more smoothly, not slow the process down later on. We're always trying to avoid impacts, sector by sector. Most cost-effective to think about this before projects start being deployed, rather than after impacts start occurring.

About five years ago, American Fisheries Society hosted a meeting to take steps forward in identifying and addressing environmental issues with hydropower. Talking generally about the industry and the technologies, and specifically about some of the projects, is a great way to discuss some of the environmental impacts we're concerned with.

Review of Workshop Purpose, Objectives & Agenda

The purpose of this Workshop is to provide a forum for discussion among experts in the fields of hydrokinetic and wave technologies and marine and riverine habitat and ecology. Specific objectives of the Workshop were to:

- Identify the varieties of hydrokinetic energy and wave technology devices, their stages of development, and the projected cost to bring each to market;
- Identify where these technologies can best operate (i.e., natural streams, tidal areas, ocean currents, waves, canals and other engineered facilities);
- Identify the potential environmental issues associated with these technologies, attempted or conceptual mitigation measures, and the effectiveness of those measures where implemented;
- Develop a list of research needs and/or practical solutions to address unresolved environmental issues.

The workshop was designed to facilitate information exchange. In addition to the discussions that followed each series of presentations, two sessions were devoted to brainstorming existing research gaps/needs and ways for the group to move forward toward the goal of understanding these new energy technologies' potential impacts on marine and riverine resources, and mitigating/minimizing them as development continues. (See Appendix A for a list of Research Topics proposed by workshop participants.) Although the group brainstormed research and action ideas collectively, a consensus process was not employed to develop the lists of research topics, nor were the lists prioritized.

The first day of the workshop consisted primarily of ten-minute presentations about the various types of hydrokinetic and wave technologies, followed by a facilitated discussion in which participants had a chance to ask questions of the panel members who had made presentations. The second day included a second opportunity for participants to discuss what they had heard on Day 1, followed by a series of presentations on the various water resource areas where the hydrokinetic/wave energy technologies might be deployed. Subsequent sessions addressed known and potential environmental questions/concerns from the developers' perspectives, a chance for workshop participants to reflect as a group on these and other questions and possible mitigation strategies. The third part of the workshop was devoted to open floor, facilitated discussion of what studies or research are needed to assess known or potential environmental questions, concerns, and mitigation strategies. (See Appendix C for complete meeting agenda.)

Workshop Participants

A list of the people who took part in the Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop, along with their organizational affiliations and contact information, appears in Appendix B. Participants were invited based on their representation of the hydrokinetic or wave energy technology industry, federal and state regulatory agencies, or environmental conservation and renewable energy non-governmental organizations. Speakers were selected by the Planning Committee.

Meeting Proceedings

A proceedings narrative was compiled and edited by Susan Savitt Schwartz, based on the presentations and discussion at the meeting. Draft Proceedings were reviewed by the organizers, presenters, and participants, and were finalized taking their comments into account. In addition to this narrative summary, the proceedings package includes pdf versions of each presenter's slide presentations. (See Appendix D for a list of the slide presentations and file names.)

Presentations of Hydrokinetic and Wave Energy Technologies

This session consisted of an overview followed by ten presentations intended to provide an introduction to hydrokinetic and wave energy technologies, from the industry's perspective. Roger Bedard of the Electric Power Research Institute (EPRI) offered an overview of key concepts and terms used to define and describe hydrokinetic energy technologies. Representatives of companies developing hydrokinetic and wave energy devices then gave brief presentations explaining the type of technology, its potential market, and current obstacles to its development and commercialization.

While some questions were taken from the floor following individual presentations, this session was followed by a facilitated discussion period during which participants had an opportunity to ask questions of any or all the technology presenters. A summary of this discussion follows the presentation summaries.

Overview of Technology Classes and Key Terminology

[1. R. Bedard_Day 1 Overview of Techs.pdf]

Roger Bedard, EPRI

Roger Bedard is Ocean Energy Leader at the Electric Power Research Institute (EPRI), an independent, non-profit center for energy and environmental research supported by the electric utility industry. In 2003, EPRI initiated a collaborative wave energy conversion technology feasibility study with state energy agencies and utilities in Maine, Massachusetts, Northern California, Oregon, Washington, and Hawaii. Mr. Bedard is currently leading a feasibility study of in-stream tidal energy technology in collaboration with state energy agencies and utilities in New Brunswick, Nova Scotia, Maine, Massachusetts, Alaska, and Washington.

This presentation started with definitions of several key terms and concepts which will be used throughout this workshop. In most cases, the terms we will be using are defined in the UK Carbon Trust's Marine Glossary.[1] One term, however, is not included in this glossary:

Hydrokinetic energy = energy possessed by a body of water because of its motion[2]

Conventional hydropower, by contrast, captures *hydrostatic energy*, that is, the potential energy (PE) possessed by a body of water because of its position location at an elevation or height above a reference or datum (in engineering terms, this is commonly referred to as "head").[3] Examples

---

[1] Marine Energy Glossary. Compiled by Entec, UK Ltd. under contract to the Carbon Trust, an independent company set up by the U.K. government to help the U.K. meet its climate change obligations under the Kyoto Protocol. July 2005. [http://www.thecarbontrust.co.uk/ctmarine3/res/MarineEnergyGlossary.pdf]

[2] The formula for kinetic energy (KE) is $KE = \frac{1}{2} mv^2$, where m=mass and v=velocity

[3] The formula for potential energy (PE) is PE = mgh, where m=mass, g=gravitational force, and h=height

of hydrostatic power include conventional hydroelectric power plants with storage (such as Grand Coulee Dam); run-of-river projects without storage (such as the Wailuku River project, Island of Hawaii); and tidal hydro plants (LaRance, France; Nova Scotia; Annapolis, Maryland).

Broadly speaking, the term *hydrokinetic energy* refers to energy that can be captured either from flowing water, such as occurs in a river or ocean current. US DOE includes tidal in-stream, river in-stream, ocean current, and constructed waterways under the heading of hydrokinetic energy resources. EPRI's Ocean Energy Program includes all of these as well as offshore wind and hybrid ocean wave and wind energy devices.

Classification of Hydrokinetic Energy Conversion Devices

For the purposes of this workshop, hydrokinetic energy conversion devices will be considered in two broad categories: *rotating machines* and *wave energy conversion devices*. Rotating machines are designed to be deployed within a stream or current, capturing energy from the flow of water across or through the turbine (which may take various forms) to power a generator without impounding or diverting the flow of the water resource. Conceptually, this is similar to the way wind energy conversion devices work.

Primary types of wave energy conversion devices. Wave energy conversion devices create a system of reacting forces, in which two or more bodies move relative to each other, while at least one body interacts with the waves. The body moved by the waves is called the *displacer*, while the body that reacts to the displacer is called the *reactor*. There are many ways that such a system may be configured. The best-known wave energy conversion device concepts are described below:

Terminator – A terminator is any structure that extends perpendicular to the predominant wave direction. One example of a terminator is a breakwater – essentially, a wall. However, a breakwater merely reflects or diverts the energy of oncoming waves without capturing any of that energy. Some form of displacement-reaction must be employed to capture the power that would otherwise be reflected or absorbed by the terminator. An oscillating water column is one example of a device designed to convert the energy captured by a terminator into electricity.

Oscillating Water Column – An oscillating water column (OWC) consists of a partially submerged structure (the collector) which is open to the sea below the water surface so that it contains a column of water with air trapped above it. As waves enter and exit the collector, the water column moves up and down and acts like a piston, pushing the air back and forth. The air is channeled towards a turbine and forces it to turn, generating electricity. (Example shown: Energetech's *Oscillating Water Column*.)

Point-absorber – Whereas a terminator is designed to absorb energy coming predominantly from one direction, a point absorber is a floating structure that absorbs energy from all directions by virtue of its movements at or near the surface of the water. The amount of power available for capture may be maximized by designing the device to resonate by moving with larger amplitudes than the waves themselves. (Example given: Aqua Energy's *AquaBuOY*.)

Attenuator – Like a terminator, an attenuator is a long floating structure. However, unlike a terminator, an attenuator is oriented parallel to the predominant direction of travel of the waves. It rides the waves like a ship, extracting energy by virtue of restraints at the device's bow and along its length. (Example: Ocean Power Delivery's *Pelamis*.)

Overtopping Devices – An overtopping device is essentially a floating reservoir, a partially-submerged structure consisting of walls over which waves topple, filling the reservoir and creating a head of water which turns hydro turbines at the bottom of the reservoir as the water is released back into the ocean. (Example: *Wave Dragon*.)

Apart from their conceptual design and configuration, wave energy conversion devices may be characterized in terms of their *placement* or location. Wave power may be captured either at the shoreline, near to shore, or offshore. The distinction between "near shore" and "offshore" is not rigidly defined. It may be a function of distance from the shoreline, depth of water, or both. Devices typically are optimized for operation within a particular depth range. Both water depth and the energy content of the waves tend to increase with distance from shore. Distance from shore also affects accessibility (for deployment, retrieval, operation, and maintenance) and visual impact; at any given site the distance from shore will also determine what aspects of the marine resource may be affected. Another characteristic distinguishing different types of wave energy conversion devices is the method of *fixing* the device to the site. Bottom-mounted devices are fixed to the seabed by a static member. Floating devices are anchor moored to the sea bed.

Primary types of in-stream tidal flow energy conversion devices (TISECs). *Rotating devices may be classified as one of two primary types:*

Horizontal axis – This model most closely resembles a modern wind turbine in design, with rotor blades rotating in a plane perpendicular to the axis, which is oriented into the direction of the flow or tidal current. Examples include SeaGen's Marine Current turbines and Verdant's pilot demonstration in the East River near Roosevelt Island.

Vertical Axis – Vertical axis turbines have their blades oriented in line with the axis rather than perpendicular to it. An early example of this was the Darrieus turbine, which looks like an eggbeater. A more recent variation (about which we will hear more later in the Workshop) is the Gorlov helical turbine, although this device may in fact be deployed such that the axis is oriented either horizontally or vertically.

Other types of in stream devices have been proposed – for example, oscillatory devices and hydro venturi turbines; however, none of them are developed to the point of significantly affecting the emergence of this new technology.

EPRI Ocean Energy Feasibility Assessments

The presentation concluded with a brief overview of EPRI's Ocean Energy Program, the objectives of which include feasibility demonstrations and accelerated sustainable commercialization of technologies for:

- Offshore wave energy conversion (OWEC)
- Tidal in-stream energy conversion (TISEC)

- Hybrid offshore wind-wave energy conversion (HOW-WEC)

EPRI is carrying out this work in partnership among coastal state agencies, utilities, device developers, interested third parties, and the U.S. Department of Energy. Project reports are available at www.epri.com/oceanenergy. Monthly progress reports are available; to be added to the distribution list, request such of Roger Bedard at rbeda@epri.com. A more detailed presentation on this Program was made at the conclusion of this Workshop.

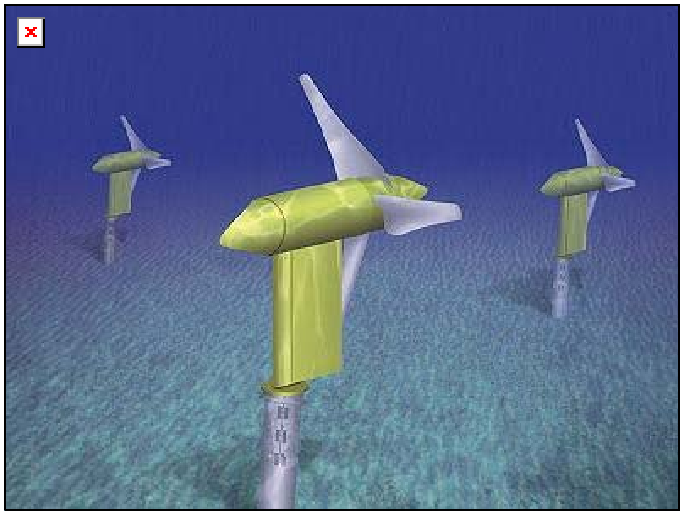
Axial Flow Machines

[2. T.Taylor Presentation_Day 1.pdf]

Trey Taylor, Verdant Power, LLC

Trey Taylor is President and Head of Market Development for Verdant Power, a "water-to-wire" systems integrator and site developer of "free-flow" or kinetic (dam-less) hydropower. In addition to studying a wide range of in-stream kinetic hydropower generation technologies, the company also performs resource assessments and has developed and tested three prototype turbines. Verdant is currently advancing one axial flow machine, the Kinetic Hydro Power System (KHPS) and its systems platform towards commercialization.

Verdant Power is a business with science, business and engineering expertise. Founded in 2000, the company has studied, and continues to study, more than 40 different kinetic hydropower concepts in the general category of "in-stream" or marine current energy generation technologies. Verdant has produced technology assessment reports on these concepts for EPRI's Technical Assessment Guide. We have performed assessments of in-stream hydrokinetic resources in the states of California and New York, for the Tennessee Valley Authority, and currently in Brazil's Amazon Basin. Verdant Power's studies have classified in-stream or marine current energy generation technologies into five primary families:



- Water wheels
- Lift or flutter vanes
- Hydraulic tapped ducted systems
- Cross-flow or cross-axis (sometimes referred to as "vertical axis") turbines; and

- Axial flow (sometimes referred to as “horizontal axis”) turbines.

The latter two, being most like wind turbines, are the closest to being commercially viable, with a potentially huge market. While Verdant is not wed to any one technology, the company has funded and tested the development of one cross-axis and two axial-flow prototype turbines. Verdant is now in the process of launching an operational test of its Kinetic Hydro Power System (KHPS), putting six 36-kW turbines into the east channel of the East River, just north of the Queensborough and Roosevelt Island bridges.

Description of the Technology Class

There are several examples of axial flow turbines (see slide presentation for photos and concept drawings) – in Norway (including a concept design and a project at Hammerfest Strom), in the U.K., and in the United States, including a project in Florida and Verdant Power’s project in the east channel of the East River at Roosevelt Island.

The axial flow design is simple and robust, more like a wind turbine than like conventional hydropower. The axis or drive shaft is oriented horizontally, parallel to the water bottom. The rotors can have from two to four or more blades. The sweep of the blade and the speed of the current determine how much energy can be produced. All of these systems are designed to work in natural streams or rivers, tidal straits and estuaries, in ocean currents, and in man-made channels such as canals, aqueducts, by-pass channels, discharge flumes, and head and tailwaters. The turbines can be unidirectional, in the case of a natural stream or man-made channel, or bi-directional in the case of a tidal application. Generators and gearing are inside, and the unit is completely submerged.

Assessing the resource potential involves doing acoustic (Doppler) profiling of the river, mapping the currents so we know how the technologies can be placed in the water, where the primary core currents are located.

Verdant Power conducted a Phase I test of the KHPS suspended from a barge in December 2002. The company now has a test permit to put six turbines in the water, just north of the Roosevelt Island Bridge, and monitor operations and impacts on fish. We have a customer ready to receive the power, and in April 2005, FERC put forth a declaratory order allowing us to generate and distribute power without a license during testing only. This allows us to conduct operational testing and fish monitoring studies over an 18-month period (expected to begin in December 2005) so that we can prepare to submit a license permit application for Phase III of the Roosevelt Island Tidal Energy (RITE) project.

What is the Market Potential of the Technology?

If Phase II of the RITE project is successful, Phase III would involve installing 494 36-kW turbines, taking up less than a third of the east channel of the East River, right up against Roosevelt Island. (All of the heavy, deep-draft vessels go in the west channel of the East River.) We have met with the United Nations, which is interested in putting a project in the river to generate power for the U.N. building. A third project is shaping up next to Governor’s Island. The City of Berlin produces 15 MW of renewable energy, putting it in the forefront of municipal renewable energy. When we finish just two of these projects (Roosevelt Island Tidal Energy

(RITE) and Governor's Island, for example), New York will become the world's leading renewable energy city.

Marine Current Turbines (another company) is focusing on using this axial flow technology for large-scale centralized generation, located further offshore. Verdant is focused more on distributed power applications. For example, we are conducting an assessment in the Amazon Basin of the potential for using this technology to replace diesel generators now being used to recharge batteries in small villages along the Amazon River and its tributaries.

Our costs right now are high compared with other energy technologies – about $4000 per kW for a 5 MW system – but we have a path to drive that cost down to about $2,500 per kW by 2010, through optimization of the technology and commercial economies of scale. The gross potential for Kinetic Hydro Power Systems is estimated at over 12,500 MW for the U.S., and over 50,000 MW for the developed nations (including the U.S.). However, where we see the biggest market for these technologies is in the developing countries: over 200,000 MW.

What are the Obstacles to Development?

To date, Verdant Power has proven and deployed a number of working prototypes. We have addressed over 87 issues that have been brought up from the environmental side. We have produced nearly 2000 pages of written reports. It is important to emphasize that the only way to really test this technology and learn about how the machines perform is in the water. There are no test flumes large enough to accommodate these machines. Natural streams are the best places to learn. Fortunately, because this is a modular type of technology that is easily deployed and removed from a given site, it is possible to respond quickly if monitoring shows evidence of unwanted impacts.

Unfamiliar technology, little interagency coordination. Unfortunately, because this is a new technology and the regulatory process only deals with existing technologies, it is very hard to get operational tests permitted. (To get an idea of the kind of issues facing new technologies trying to conduct operational tests, consider what the Wright Brothers would face in terms of environmental concerns and permit requirements if they tried to fly their plane at Kitty Hawk today.) Moreover, there is little interagency coordination when it comes to the regulatory process governing the deployment of pilot demonstrations in natural streams.

Lack of capital formation, R, D&D funding. There is a lack of capital formation and funding for R&D. We are a small start-up company, without the resources of a large utility company or oil company. Companies like Verdant need money to do the design, to do the tests – and right now we are spending more money for fish monitoring studies than we are on designing, building, and putting our turbines in the water. The only public entity that is helping us right now is the New York State Energy Research and Development Authority (NYSERDA), at about a third of the cost of the RITE project.

Overcoming these obstacles: FERC has helped us by giving us the declaratory order allowing us to test without a license. NHA is working with FERC about streamlining the licensing project. Agencies are starting to get direction from above that they need to work with us in a collaborative fashion so that we can find out about any environmental impacts associated with this technology, so that we can adjust our designs and mitigate any impacts.

However, we need to get more support for this research. The U.K. and the European Marine Energy Centre (EMEC) – more recently the Ocean Renewable Energy Group and the Natural Resources of Canada (St. Johns, Newfoundland), which is developing something similar – have the right idea for research, design and development. Part of the solution is to create waivers so that we can accelerate research, design and development, so that we can get these technologies right. This workshop is a good beginning.

Questions and Responses following the presentation

Q: How do these devices connect with shore?

A: For tests, there will be cables running along the bottom and up to shore. Eventually, those cables would be buried.

Q: How fast is the turbine going? What is the tip speed?

A: The rotor is moving at 32 RPM, tip speed = ? Percentage of strike area ≤ one percent. (See Glenn Cada's article for diagram: less than one half of one percent of the rotor swept area is strike zone.)

Q: You will leave a navigational channel open?

A: Yes. Phase III is still two years away. We will have to work with the Harbor operations, working with local communities, monitoring what happens with fish. Beauty of the system is that it is modular and easy to remove.

Q: Are you changing the hydraulics? How much energy can you remove before alter the current?

A: University of Edinborough says you can only remove 10% of the energy before you start altering the current. It may be as much as 20%. The East River is pretty wide, and we are talking about a very small percentage of the river. These units are designed to be installed 50 feet apart (side to side) and 100-120 ft fore and aft which allows room for fish to move, but also allows for energy to be regained as it moves through the field of turbines.

Q: Tides come in and out, peak velocity, velocities reversing – how many hours of the day are you above the effective velocity threshold to be producing power?

A: Not sure, but we are look at producing power about 10 hours of the day, or about a 27% capacity factor.

Open Center Turbine

[3. H.Williams Tech Presentation.pdf]

Herbert Williams, OpenHydro

Herbert Williams is a Florida-based marine contractor, boat-builder, and former commercial fisherman, and the inventor and founder of OpenHydro.

Description of the Technology Class

The Open Center Turbine is a propeller type technology, similar in some ways to the horizontal axis turbine described in the previous presentation, but designed for deployment in the open ocean and some tidal areas, as opposed to rivers and streams

The origins of the open center design began with conventional propellers and runners in high head applications. When working with ocean current applications, however, we found ourselves working with a lower energy content. We found that as propellers got big enough to be MW size, they got too big to be economically competitive. Cutting out the central portion of the propeller, i.e., the hub and the shaft, allows us to get energy at lower rpm, because the tip speed is faster than the shaft speed. The generator is a solid state permanent magnet generator encapsulated within the rim. As the water flows through, the housing remains stationary while the propeller/rotor turns. The electricity is formed in the interface, the small gap between the rotor and the stator (the housing).

We've actually worked at getting our tip speed down (to about 20 ft. per second). This makes the device more "fish friendly," as well as creating some production advantages. Because there is only one moving part, servicing requirements are minimal. (The machine only needs to be hauled out for servicing every four years.) There are no nacelles, gearboxes, seals, shafts, couplings, grease fittings, grease, oil, or braking devices, and no external generator. The machine is built of fiberglass, so there is no paint and no zinc anodes needed. There are basically six wires coming off the back. We are working on eliminating contact between the moving part (the open-center propeller) and the non-moving parts, which will eliminate problems with bearings.

OpenHydro has a Collaborative Research and Development Agreement (CRADA) with the U.S. Navy that gives the company access to the Navy's Carderock Division, a "center of excellence" for research and development of ships and submarines. Working with the Navy has brought credibility to the project, as well as giving us access to the Carderock Division's world-class laboratories and test facilities.

What is the Market Potential of the Technology?

We see our technology having high head applications, but today we'll just discuss open ocean aspects. We are now looking at the potential for deployment in the Gulf Stream to get gigawatt (GW)-class deployment fields. (The technology is scaleable, but generally speaking, it would require a deployment of three to four thousand of these turbines in the Gulf Stream to get 10 GW of power.)

Almost done with prototype testing, gearing up to build six 3-m diameter machines in 2006. The first couple of machines will go into tidal applications in Europe, but we are hoping to deploy at least one of the next four machines in the Gulf Stream. We see the challenge as being able to beat fossil fuels, and we think that we will be able to do that.

What are the Obstacles to Development?

To date, we have tested four prototypes, we have simplified the machine (fifth prototype) and the Navy has conducted tests. The Navy's involvement has brought some credibility to the project.

Ducted Turbine

[4. S.Meade Tech Presentation.pdf]

Simon Meade, Lunar Energy

Simon Meade is the Chief Executive Officer of Lunar Energy, founded in 2002 to develop the commercial potential of the Rotech Tidal Turbine (RTT), a ducted turbine technology to extract energy from ocean tidal streams for the production of electricity.

Description of the Technology Class

A *ducted turbine* is essentially a horizontal axis turbine enclosed within a duct. It may be either mono-directional, in which case a yawing mechanism is needed to direct it into the direction of the current; or bi-directional. It may be anchored to the bottom of the seabed using a gravity foundation or mounted on a monopole, or it may be tethered to the bottom.

There are two very different categories of ducted turbine:

1) *Duct used to maximize efficiency of power.* In any ducted turbine, the duct functions to accelerate the flow of fluid through the system by creating a pressure differential, forcing higher pressures as the fluid enters the duct at the front and then diffusing the fluid to create lower pressures at the back of the system. This is similar to the way an airplane engine is designed to work. However, designing a system to maximize the pressure differential so as to maximize the power that can be extracted from the fluid requires complex calculations to optimize the profile and fine-tune the blades; stators may be required as well. The ducted turbine in this case becomes very much like an airplane engine, hence very complicated and expensive to produce. It would be practical to produce only small units, and many such units would be required to generate large amounts of power such as would be sought from an offshore power generation application.

2) *Duct used to reduce cost and complexity.* A bi-directional duct may also function to reduce the cost of an ocean-current hydrokinetic system by removing the requirement for a yawing mechanism and separating the generation compartment from the turbine rotor to facilitate O&M. Such a system would benefit from some increase in pressure differential created by the duct, but would be engineered to maximize simplicity and robustness of the design.

Lunar Energy's Rotech Tidal Turbine (RTT) belongs to the second category. With any hydrokinetic system, if you want more power, you have to capture more fluid. When looking at offshore systems designed for centralized generation rather than distributed power, the units have to be big to be economically competitive.

What is the Market Potential of the Technology?

At this point there are a lot of conceptual designs, but not many applications have been tested:

- Clean Current (Canada) – This is a very complex bi-directional ducted design, with rotors spinning at high rpm and a "gridding" concept that has been proposed to mitigate fish impact. A 1-2 meter demonstration model, with an accelerator designed specifically for power augmentation, is expected to be ready in 2006.

- Underwater Electric Kite (USA) – This is another complex system with many blades spinning at high speed. The mono-directional ducted system is designed to be tethered to the seabed (hence the name). Like the Clean Current prototype, this has a duct designed specifically to maximize power generation.

- Lunar Energy Rotech Tidal Turbine (UK) – bi-directional, no gearbox, use of duct removes requirement of yawing mechanism. The blades rotate at 20 rpm. The device is deployed at 60-70 feet below the surface, allowing a clear draft of 30-60 ft. for surface traffic.

Bi-directional duct. The problem with single-direction ducts is that they have to be rotated whenever the tidal direction changes, requiring a yawing mechanism. A bi-directional duct is one way to solve the yawing problem. Note that tidal flows are predictable but do not always flow in exactly same direction. Indeed, a study of the 25 most energetic sites in the UK revealed that in almost 25% of the cases studied, after reversing direction, the new flow vector was not within 40 degrees of the reciprocal of the original. The effect of the duct is to change the direction of the flow of the fluid captured to ensure that it still meets the turbine at the optimum angle. Hence the RTT unit is not sensitive to off-turbine-axis flows and does not therefore require a yawing mechanism. When compared with an un-ducted turbine operating in the same conditions, a ducted unit will capture around 80% more energy with a flow 40 degrees off the turbine axis.

Simple, robust technology. The greatest practical obstacle to offshore energy generation is the cost of getting to it – for installation, for operations and maintenance (O&M). Lunar Energy's innovation has been to put the moving parts that need to be serviced in a smaller removable unit, or cassette, that sits on top of the duct. In addition to dispensing with the need for a yawing mechanism, the RTT uses fixed-pitch blades, has no gearbox, and can be quickly installed.

Environmental benefits. The RTT turns at relatively low rpm. There is no dynamic seal into the generation compartment, reducing the risk of leaks. Installation is relatively non-intrusive, with a small footprint, a gravity foundation requiring little or no seabed preparation, and zero visibility from the surface.

Apart from the blade profile, which is bespoke for this technology, most components and procedures have a proven commercial track record, mainly in the offshore oil & gas industry. A one-megawatt demonstration unit is scheduled to begin fabrication in Q4 2005, with a plan to put it in the water next summer at the European Marine Energy Centre (EMEC).

What are the Obstacles to Development?

Government support for new technology is essential. Lunar Energy has been funded by the UK government at £3 ¼ million to date, including two and-a-half years of theoretic work and one year of testing. EMEC plays a crucial role, allowing us to put several different types of turbine in the water together to do testing. This is a great program to have turbines of very different design in the water, testing, gathering data in one place.

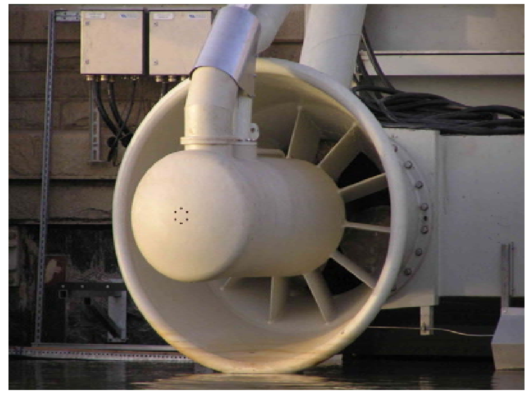
The government has to create a market for new technologies, to drive investment and facilitate demonstration of the environmental benefits and innovative technology.

Turbine Matrix / Hydromatrix®

[5. A.Bihlmayer Tech Pres-1.pdf]

Alex Bihlmayer, VA TECH HYDRO USA Corp.

Alex Bihlmayer is an engineer and project manager with VA TECH HYDRO, a major manufacturer of conventional turbines and hydroelectric equipment. Hydromatrix® is a niche product, "an innovative solution for low impact hydropower at existing engineered structures."



This presentation introduces an innovative approach to generating hydroelectric power using an array of small conventional-style hydro turbines.

Description of the Technology Class

This is a variation on the Axial Type Reaction Turbine. The basic principle is not a new one: water changes pressure as it flows through the turbine, giving up hydrostatic energy. An outlet draft tube helps decelerate the water and recover the kinetic energy. (See slide presentation for diagram.) What makes this different from a classic bulb-type turbine is that we have simplified the design, using stay vanes rather than wicket gates and a fixed-blade (propeller-shaped) runner.

The other major difference is size. The bulb turbine used in a conventional hydropower plant or run-of-river project has a runner diameter of 5-8 m. The Hydromatrix uses an array, or matrix, of many small turbines (runner diameter of about 50 inches) to capture energy from the same amount of water passage. This allows the technology to be deployed with greater flexibility, taking up less space and making use of existing structures. Unlike conventional hydropower turbines, the Hydromatrix turbines can be lifted out of the water easily. This technology provides a good solution for low-head and high flow structures.

The application range is similar to classic bulb turbines. The technology requires a certain minimum head created by a static upper and lower pool. As with conventional hydropower, the higher the head, the better; however, the technology can be economical with as little as 9-33 feet of head. A submergence of five feet is required for the turbines themselves. A flow of at least 3000 cubic feet per second (CFS) is ideal. Propeller speed varies from 250-360 RPM – fairly fast compared to large conventional hydropower turbines. Output varies from 200-700 kW per unit. Whereas a conventional hydropower turbine can be controlled to accommodate higher or lower flow, the matrix concept relies on being able to simply turn on or shut off individual units within the array as needed. (Turbines can be lifted out of the water during high flows or flooding.)

What is the Market Potential of the Technology?

Potential applications include irrigation and navigation dams, intake towers, and sluice gates in ship locks. The Hydromatrix concept was first patented by Henry Obermeyer in the US in the

1980s, with the first installation of this technology – a 3 MW plant in an intake tower in Hartford, Connecticut – becoming operational in 1988. VA TECH Hydro began seeking an international patent for a similar concept in 1990, and entered into a license agreement with Mr. Obermeyer to develop the business in the US. The first VA TECH HYDRO reference plant was built in the mid-1990s. An installation of 80 paired units installed in existing slots at an irrigation dam on the White Nile River in Sudan was completed this year. At 30.4 MW, the (Jebel Aulia) plant is the largest Hydromatrix installation currently in operation.

One interesting application is located in a side canal of the Danube River in central Vienna. Here because of the historic character of the location we were asked to create an "invisible power plant" – a matrix of 12 turbines completely submerged in a hollow body weir in the canal. Another planned application will use draft tubes embedded in a retaining wall in an abandoned auxiliary shiplock on the Mississippi River, at the Lower St. Anthony Falls in Minneapolis. This project will have two rows of eight vertically stacked turbines totaling 10 MW capacity. With a maximum of 24.9 feet of head, the average annual energy production is projected to be 62 GWh.

In assessing the market potential for the United States, we started with all existing dams without hydropower (about 900 sites) and filtered it down to 130 potential sites – mostly owned by the Army Corps of Engineers – where there has been recent FERC activity. Another example of the great market potential is to look at already existing hydropower plant licenses. Looking, for example, at licensed hydropower on the Ohio River, we see the potential for generating an average daily 4,372 MWh using the Hydromatrix technology at those sites. We think a good portion of these projects could be licensed with this technology, because the cost is low ($1,500-$3,000 per installed kW, less than 5 cents/kWh) compared to the installed cost of conventional hydropower at open waterways ($3,500-$5,000 per installed kW). As with all hydropower technology, it is only dispatchable with certain restrictions.

What are the Obstacles to Development?

The technology is proven; the key to successful project development is to find innovative ways to apply the technology that make the project economically viable. From the power industry's perspective, the simplicity, reliability and flexibility of the design mean lower maintenance costs. The use of existing engineered structures means that there is minimal civil construction cost (and shorter project schedules); no geological or civil contracting risk; and no additional land usage – hence minimal additional impact on the environment.

The main obstacle is the same set of issues Mr. Taylor of Verdant Power discussed: the licensing process is lengthy; agencies are not always communicating with each other. We see our role as being a partner, not only with our client but with the agencies and other stakeholders. We need to educate the agencies and other stakeholders and show them how we are addressing their concerns and requirements.

"Cross Flow" / (Helical) Turbine[4]

[6. A. Gorlov Presentation.pdf]

Alexander M. Gorlov, GCK Technology

Alexander Gorlov is Professor Emeritus in the Department of Mechanical Engineering at Northeastern University in Boston, where his research focuses mainly on the development of mechanical systems for harnessing hydropower from rivers, canals, tidal and open ocean streams. In 2001, Dr. Gorlov received the Thomas A. Edison Award from the American Society of Mechanical Engineers (ASME) for invention of the Helical Turbine.

Description of the Technology Class

In contrast to the propeller-type turbines (axial flow devices) we have heard about so far, a cross-flow machine's shaft is positioned perpendicular to the flow of the water (either horizontally or vertically, or any aspect in between). It always rotates in the same direction, independent of the water flow. Conventional propeller has no such ability in reversible tidal flow, for example.

The earliest type of cross-flow turbine developed was the *Darrieus turbine*, which looks like a big eggbeater and was developed in the mid-1920s specifically for wind applications. A modification of the Darrieus turbine using straight blades was developed for hydro applications. Dubbed an *orthogonal turbine*. (See slide presentation for pictures.) However, both the Darrieus and the orthogonal turbines have two disadvantages: they are not self-starting, and they pulsate as the angle of attack changes for blades with the rotation of the turbine. The helical arrangement of blades allows the *helical turbine*, developed about 15 years ago, to be self-starting and to rotate uniformly, which gives it an advantage over other cross flow turbines.

What is the Market Potential of the Technology?

The small 6-inch version of double helix turbine was initially developed for powering underwater equipment with slow currents. This turbine can provide up to 10 watts in 3 knots flow, and can start generating power in as low as 1.5-2 knots of flow. The power output increases in proportion of the cube of increasing in water velocity. The turbine is both easy to install and easy to remove, and can be used with a wide variety of hydrokinetic resources, from river streams to tidal and other ocean currents or waves.

A larger triple helix turbine has been designed for use in commercial applications. One meter in diameter and 2.5 meters

---

[4] It was noted by a some workshop participants that the conventional hydropower industry uses the term "cross-flow" to refer to a particular type of turbine (described as a cross-breed between a "Kaplan"-type runner and a fixed propeller) which is vertical in orientation but has a radial component as well. To avoid confusion, Dr. Gorlov's device will be referred to as a *helical* turbine, rather than as a cross-flow device.

long, it can be positioned either vertically or horizontally. In the horizontal position it has the capability of being deployed in shallow water – only about one meter of depth is required. Four different helical turbine models have been tested and demonstrated to work in the Cape Cod Canal during 1996 -1998. The technology also has been deployed in such varied sites as the Uldolmok Strait in Korea, Long Island region, in the estuary of the Merrimack River, Massachusetts, beneath the Tidewater Motel on Vinalhaven Island, Maine, and at a field study site near the mouth of the Amazon River. At the last research station, a six-blade helical turbine was positioned using jetties to force the flow of tidewater through a duct to attain higher efficiencies.

South Korea is very interested in this technology as a way of extracting thousands of megawatts from tidal resources. In the Uldolmok Strait, the reverse tidal current flow at a velocity more than 6 meters per second. We installed there a 1-m triple helix turbine, and are now installing a 2.2-m turbine. In 12 knots, a 2.2 meter turbine should be able to achieve about 210 kW power output.

Other possible applications of this technology include developing a Floating Ocean Power Farm to produce hydrogen fuel in-situ by electrolysis of sea water. It has also been shown that when partially-submerged, the helical turbine can be used as an efficient water aerator.

What are the Obstacles to Development?

The principal obstacle to further development and implementation of the helical turbine technology in this country is lack of resources for research and field testing.

Venturi Devices

John Hassard, HydroVenturi

This presenter was not able to participate in the workshop. More information about this type of device can be found at the HydroVenturi Ltd. company site: www.hydroventuri.com

Heave Wave Devices

Two presenters described their companies' heave wave devices.

Alla Weinstein of AquaEnergy Group described the development of a pilot offshore power plant at Makah Bay, Washington using AquaBuOY, a point absorber wave energy conversion device. The project is undergoing environmental permitting in support of FERC and NOAA licensing processes.

George Taylor of Ocean Power Technologies, Inc. (OPT), a publicly-held wave energy technology company, described the development and commercialization of OPT's patented PowerBuoy™ wave-power electricity generation systems.

Heave Wave Device (1)

[7. A.Weinstein Presentation.pdf]

Alla Weinstein, AquaEnergy Group

Description of the Technology

The AquaBuOY is a combination of predecessor devices, using Swedish hose pump technology. Where the Pelamis was described as an attenuator linking three point absorber devices, this is a single point absorber. The advantage of a single point absorber is that it is omnidirectional – it does not matter which direction the wave is coming from.

This is a two-body, or self-referencing device. The one body is the buoy at the water's surface; the second body is a piston that sits in the middle of an acceleration tube. The difference between the pressure from the water mass at the bottom and the pressure from the top is a damping force that acts on the hose pump. The hose pump is about 0.5 m in diameter, similar to hoses used in the offshore oil industry, but it has a ring, an armor around it. That armor is used to create a pressurized water flow, generating 50 pounds per square inch (psi) of pressure to turn a conventional turbine. Pressure travels from hose pumps to an accumulator to stabilize it, through a turbine and a generator, and via cable to shore (see slide presentation for diagram).

These hose pumps needed a lot of work. They were first tested in the 1970s. We started doing some further testing – to look at longevity, fatigue factors, and so on. The first testing was done on a fairly small chunk of hose pump, only six inches long but half a meter in diameter, with grants from the Danish energy agency. We are now ready to move from static testing to dynamic testing, with grants from the Carbon Trust in the UK. However, we cannot test a hose pump at full-scale (half a meter in diameter, ten meters length) on land, because there is nothing on land that will oscillate with the forces of the ocean. So we had to scale down the testing.

What is the Market Potential of the Technology?

In 2001, our investors told us that to go forward we needed to get permits and demonstrate a commercial-sized plant. The Northwest Energy Innovation Center (a collaborative effort of the Bonneville Power Administration, Washington State University, Energy Northwest and Battelle Lab) advised us that they could help us get a power purchase agreement from the utilities, and that with this we would be able to get a permit and go forward.

We were interested in locating such a plant in Washington State because it has vast wave energy resources. The periodicity of waves in the Pacific is in general much faster than in the Atlantic Ocean. At the location we selected, waves averaging 5 m in height arrive at 8-10 second intervals. We chose a specific location at Makah Bay, both for the wave resource, and because there were transmission lines already in place to receive the energy. Our plans for the Makah Bay demonstration plant call for four AquaBuOY devices in formation. Each has a rated nameplate capacity of 250 kW, with an expected capacity factor of 25%. Our annual energy production is projected at 2,200 MWh. (See slide presentation for diagrams of the Makah Bay project and plant characteristics.)

However, the location we chose also turns out to be part of a marine sanctuary. This means we had to seek licensing permits from both the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Fish and Wildlife Service (USFWS) as well as the Federal Energy Regulatory Commission (FERC). We had to make several changes to our design to comply with environmental permit requirements. For example, the buoys had to be capped to prevent sea birds from nesting, we needed filters to close the system. Because it was a marine sanctuary, there could be nothing sitting on or touching the ocean floor (e.g., mooring weights, cables). We dealt with all this (again with funding from the Danish Energy Agency as well as some from local utilities), and we expect to have our environmental assessment to be complete by the end of 2005.

What are the Obstacles to Development?

The main obstacle that we encountered was that none of the permitting agencies were familiar with our technology, so we had to create a permitting process as we went along. This was further complicated by the fact that there was no clear, consistent understanding of which was the applicable licensing agency for our technology.

FERC actually allowed us to go through an alternative licensing process, otherwise it would have taken much longer than three years. There are no exemptions for pilots or prototypes, yet we cannot reach the commercialization stage – or even answer all the questions that agencies have about environmental impact – without testing our machines in the ocean. Developers of new technologies have to spend as much or more money on enviromental impact studies (EIS) and on other aspects of the permitting process as they do on developing the technology. (See slide presentation for list of 13 permits required for the AquaBuoy demonstration plant at Makah Bay.

It took four years of effort (working with U.S. Senators in particular from Washington state), but now with the 2005 Energy Bill, the ocean is recognized as a renewable energy resource. However, we do not yet know what that will mean for the permitting process for our technologies.[5] Again, we are all in new territory, and we will have to figure it out as we go.

EPRI's resource assessments have been helpful, and we are hopeful that the Energy Bill will lead to funding for a Department of Energy program to do some of the research that will benefit all the small start-up companies.

Europe has gone some way towards commercializing wind, and is looking now to Ocean energy as the next emerging resource. The European Ocean Energy Association was formed to give input to the European Energy Commission. It would be great to have an EMEC (European Marine Energy Centre, which is funded in part by the UK Carbon Trust at a level of $12-15 million pounds) – with a permitted ocean testing facility. Developers can do environmental impact assessments (EIA), but we do not have the resources to do a full-scale environmental impact study (EIS). Having a test center is a good start, but there is still a cost to the developer for getting equipment tested at the test center. When it comes to bringing a new technology to commercialization, everything comes back to funding.

[5] U.S. DOE Wind and Hydropower Technology Program Director Peter Goldman notes that the Minerals Management Service will be considering all renewable energy technologies beyond three miles from shore as part of their responsibility.

Heave Wave Device (2)

[8. G.Taylor Presentation-revised.pdf]

George Taylor, Ocean Power Technologies

Description of the Technology

Ocean Power Technologies (OPT) began 11 years ago. We decided to use a well-proven piece of technology as the basis for our device, namely a buoy. It is a heave system, and we have developed two types of buoyed systems, a pressure-driven device that is fixed to the seabed, and a flotation-driven device that is moored but not rigidly anchored. (See slide presentation for diagrams.) Both are designed to be deployed in deep water (30-50 meter depths). The flotation-driven device is designed to accommodate tidal variation, which is important for most of Europe. As with some of other wave energy conversion models that have been presented, these PowerBuoys have a minimal visual profile and a high power density. We can get one megawatt from an area of 1.6 acres, given suitable wave conditions.

The pressure-driven buoy is sealed at the top and open to the water underneath. As the wave goes over the top, the change in pressure causes the cylinder to go up and down around a column that is anchored to the seabed.

Internally, the pressure-driven and the flotation systems are essentially the same. There is a power take-off control system and the generator. All fit inside the device and are sealed from the ocean. We have a PB-50 and a PB-250; eventually we will go up to half a megawatt. We have been ocean testing in both the Atlantic and Pacific since 1997, and have indeed, as other presenters have noted, found that ocean testing is a far cry from modeling or testing equipment in a wave tank.

What is the Market Potential of the Technology?

Worldwide, the market for primary utility-connected power is about $200 billion per year, but to compete in this market we would have to bring costs down to 3-4 cents/kWh. As with several of the other technologies we have seen, OPT's devices are designed for modular deployment. A 10 MW wave power station would consist of an array of 40 PB-250 units, with an ocean footprint of 16 acres at a depth of 30-50 meters (one to five miles off shore). The systems are easy to tow to (or from) the deployment site.

The market for remote (non-grid or small grid, such as Hawaii) power is much smaller – about $12 billion per year – but at this stage of development this technology is better able to compete in these remote markets where fuel costs are high (e.g., 7-10 cents/kWh). The military is interested in this technology; the U.S. Navy is sponsoring our 1 MW demonstration project in Hawaii. Other potential applications include desalination plants and ocean hydrogen production facilities.

Currently we are ocean-testing PowerBuoy 40 kW models off New Jersey and Hawaii. A 150 kW model design is underway; we are looking at demonstrating this model in several locations: Hawaii (1 MW - Navy); on the north coast of Spain (1.5 MW – Ibedrola S.A.); France (2-5 MW – Total S.A.); and New Jersey (1.5 MW – NJ Board of Public Utilities). OPT's cost models suggest that, at the 10 MW plant size using the PB-150 model, we can get our costs down to 7-10 cents/kWh, taking into account the capital costs of the power station in its entirety, financing, and O&M costs. Looking ahead, using the PB-500 kW for plants sized at 100 MW, we could expect to get our costs down to 3-4 cents/kWh.

What are the Obstacles to Development?

The two areas where OPT sees opportunities to improve the rate of commercialization of this technology are:

1) *financial incentives* – government -supported demonstration programs to bridge the gap from R&D to commercialization, energy price (per kWh) and capital cost (per kW) subsidies); and

2) *technical innovations* – efficiency improvements (increasing buoy diameter, advanced materials).

Ocean Power Technologies has successfully completed the permitting process for demonstration programs in Hawaii and Australia. In Hawaii, the environmental assessment (EA) had to meet 14 different legal requirements, including the National Environmental Policy Act (NEPA), the Coastal Zone Management Act, and laws protecting marine mammals, migratory birds, fish and wildlife, Native American graves, coral reefs and various other resources. The EA was conducted by the EA Division of the Office of Naval Research, which consulted with the National Marine Fisheries Service and the U.S. Fish and Wildlife Service and which, after a comprehensive investigation, issued a Finding of No Significant Impact (FONSI). (See slide presentation for details of the findings.)

Heave-Surge Wave Devices

[9. M.Carcas Tech Presentation.pdf]

Max Carcas, Ocean Power Delivery

Max Carcas is responsible for worldwide sales and commercial development of Ocean Power Delivery (OPD)'s Pelamis Wave Energy Converters. An offshore project using these devices is scheduled for installation next year off the coast of Portugal. Mr. Carcas and his team also have project agreements in place with ScottishPower and Amec in Scotland and Wind Prospect in England, and have worked with EPRI in California and BC Hydro in Canada to assess potential wave energy projects in North America.

Description of the Technology Class

The Pelamis Wave Energy Converter is a semi-submerged, articulated structure consisting of cylindrical steel sections linked by hinged joints. Moored at its nose, the Pelamis is a weighted buoyed system, free to swing about its mooring to point in the dominant wave direction. The device could be defined mechanically as an attenuator, or as a phased array of heave and surge point absorbers. Waves travel down the length of the machine, causing each section to articulate (both up and down and side to side) about the hinged joints.

Hydraulic rams located in the joints resist this movement, pumping high-pressure fluid via smoothing accumulators to hydraulic motors, which drive induction generators to produce electricity. Like the surface-swimming sea snake for which it is named, the Pelamis floats at the surface of the water, its underside submerged. This gives it a negligible visible profile. At full-scale, its movement is relatively slow.

Off-the-shelf components. The power conversion modules at the joints use off-the-shelf components that have been tried and tested by the oil and gas industries. The modules are linked together electrically. A transformer in the nose steps up the power to line voltage for transmission to shore. Power is fed down an umbilical cable to a junction on the seabed, connecting it and other machines via a common sub-sea cable to shore, using umbilicals similar to what the oil and gas industry use and conventional static cables.

Why a Heave-Surge Energy Converter? All wave energy converters have a natural frequency at which they absorb more energy. The energy we're accessing is the deep swell wave energy – wavelengths of about 100 m between wave crests, and time periods between those wave crests of around 8-15 seconds. As that varies, we can change the natural frequency of the machine to match it to the predominant wave conditions. When the waves are large, the machine moves principally up and down. In summer, when the waves are much smaller, we can restrain movement in the heave direction, allowing the machine to move principally in the sway direction, or side to side. The system's ability to adapt to wave frequency allows it to capture more energy (capacity factor between 25% and 40%, depending on the wave resource).

A typical Pelamis unit is 140 m long and 3.5 m in diameter. It consists of four sections, with three joints each containing a 250 kW rated power conversion module, for a total power rating of 750 kW. The system is optimized to maximize power capture per unit weight, and also to ensure survivability in the offshore environment. Its design allows it to be closely coupled to hydrostatic forces (regular wave patterns), but invisible to hydrodynamic forces (e.g., storm waves). When waves get above seven meters or so, the machine's physical properties actually limit its capacity to absorb the wave energy, causing it to go *through* the waves rather moving at their surface. This is somewhat akin to the way wind turbine blades can be feathered during high wind conditions. The machine has been independently verified up to a 28 m wave height – a so-called "100-year phenomenon" wave – this verification allows us to insure the equipment, which is critical to commercial development.

What is the Market Potential of the Technology?

This technology requires a minimum of half a wavelength depth (50-70 metres), as wave energy is reduced in shallower water. It is designed to be deployed (typically) 2-15 miles off the coast. A mooring system has to be constructed at the deployment site, but all other construction, maintenance, and repair work can done on-shore (off-site). The system can be rapidly attached and detached from its mooring and towed to shore for maintenance or repairs, minimizing the amount of downtime.

Although the wave energy resource is not as perfectly predictable as the tidal resource, you can forecast your output with a reasonable degree of accuracy.

OPD has successfully tested a full-scale prototype of the Pelamis at the European Marine Energy Test Centre in 2004. We successfully generated energy into the grid, recorded 1,000 hours of successful operation, and confirmed many of the operational aspects we wanted to test. Our first project is being built for Enersis, Portugal's largest developer of renewable energy projects, 5 km off coast of Portugal in 50 m depth of water. Phase I of this project consists of three Pelamis P1A 750 kW machines. This is not yet what we would consider to be a "commercial-scale" project, but from OPD's perspective it is commercial as opposed to a prototype or demonstration project. With Phase II we hope to expand the Enersis project to 24 MW, and Phase III would consist of multi-site deployment.

We are also working with Scottish Power and AMEC on a phased plan to develop a 22.5 MW wave farm off the coast of Scotland. In Cornwall we are part of a consortium planning to create a socket – offshore infrastructure that a number of different technologies can share the cost of installing – we see this site as a potential location for a 20-30 MW wave farm. In the United States, we are working with EPRI, five state governments, and the City of San Francisco, with installations targeted for 2007 (contingent on appropriations for programs approved in the 2005 Energy Bill).

What are the Obstacles to Development?

Because this is a modular technology, it is relatively simple to build incrementally. The important thing is to permit the site appropriately, and ensure that you have the grid infrastructure in place to receive the power. We think that we have a minimal environmental impact. Compared to wind energy, we have a much smaller footprint: a 30 MW project would occupy 1 square km, about 250 acres, four times less area than for an equivalently-rated wind farm. Nevertheless, clearly we need to go through the processes to verify our assumptions of minimal impact, which is why a forum like this one is so important.

One of the greatest challenges is competing in a commodity market against other well-established mature technologies at commercial scale. There has never been a new energy technology – be it gas turbines, nuclear or wind – that has been economic “out of the box.” Feeder markets are essential to bring costs rapidly down, as has happened in the case of the wind industry, where generating costs have fallen by 80% over the past 25 years. What gives us tremendous hope is that our opening costs are substantially lower than other generating technologies. The potential is for wave energy to become one of the least-cost energy options in the future – however, government’s role in enabling and accelerating commercial investment in project deployment is vital.

While the tariff provided in Portugal is relatively high (23.5 cents/kWh), its impact on the consumer is negligible because it is limited to the first 20MW of capacity – and it is helping to kick start an industry much as occurred with wind in California. Given that early small projects lack economies of scale, we think the Portuguese tariff is a reasonable starting point – in between the wind and solar energy tariffs – and can be set against the opportunity for a region to access a substantial energy resource that produces no emissions and will never run out.

Overtopping Wave Devices

[10. Erik F-M Tech Presentation.pdf]

Erik Friis-Madsen, WaveDragon

Erik Friis-Madsen is Managing Director of Wave Dragon ApS, the development company for the Wave Dragon, a slack-moored offshore wave energy converter of the overtopping type. Mr. Friis-Madsen has 30 years' experience as a consultant engineer and is a member of the Danish Association of Engineers and a member of the board of the Danish Society of Wave Energy.

To give an idea of the energy potential of the ocean waves, consider that in the western wind belt we have an annual average of 70 kW per meter from wave power. There are a wide variety of both fixed and floating wave energy conversion devices. This presentation focuses on a floating device of the overtopping type.

Description of the Technology Class

The basic design of an overtopping device is a floating reservoir with ramps. Two wave reflectors focus the waves towards a ramp, maximizing the energy content of the water that overtops the ramp and flows into the reservoir. Water then leaves the reservoir through variable-speed axial (Kaplan-type) turbines which utilize the head between the level of the reservoir and the level of the sea to generate power. The only moving parts in this design are the turbine rotors, whose rotation speed varies with the actual amount of pressure head in the reservoir.

The Wave Dragon is designed to be deployed at water depths greater than 20-30 meters to take advantage of high energy ocean waves. (See slide presentation for illustrations of wave dragon concept.) We use a Supervisory Control and Data Acquisition (SCADA) system accessible through the Internet, and we have three remotely controllable web-cams to help us when making manual overrides to the controls. Manual changes to the set points of the control system are necessary on a regular basis in order to test different regulation strategies in the actual sea state. In addition to being able to control the speed of the turbines and turn individual turbines on or off, we can adjust the floating level of the reservoir by letting air in and out of the chambers that keep it buoyant, somewhat like a hovercraft.

Other designs include a large coast-based design developed and built in Norway, and a newer design known as the Seawave Slot Cone Generator, which is also designed for a coastal application.

What is the Market Potential of the Technology?

In a test program at the University of Munich, our 340-mm runner turbine achieved efficiencies over 90%. We are able to achieve this level of efficiency by varying the turbine speeds. The Wave Dragon has been tested in sheltered waters in Nissum Bredning Denmark for about 18 months, and we are now moving to an area of higher wave intensity. (The tested prototype is 57 m wide and weighs 237 tons. This is about 1:4.5 scale for a commercial North Sea application.)

In the past 20 years, the estimated price per kWh for this overtopping wave energy conversion technology has come down considerably, making it nearly competitive with wind. Wave Dragon is designed to be deployed either as a single unit or in arrays of anywhere from 10 to 200 units. Our objective is to develop this technology to where it can be deployed on a scale comparable to a conventional fossil fuel-based power plant with units of 4-11 MW output each, with a production price of 0.04 € /kWh.

What are the Obstacles to Development?

Coast-based devices difficult to get approved. These types of devices have been tested all over the world, including a very large coastal installation at Tapchan, Norway. However, it can be difficult to get consent to construct a coast-based installation.

Biofouling. Biofouling not a problem on the wave run-up, because the action of the waves scours the surface. But it can be a problem for smaller wave energy devices which are dependent of wave induced movements of the structure, as we have seen heavy growth on the rest of the structure and mooring lines (10 cm of marine growth)[6]. We have painted three of the turbines with standard paint and three with a non-toxic antifouling paint that seems to work very well. (The paint has an effective lifetime of 20 + years, so this looks very promising.)

No difficulties siting test rig in North Sea. We had no difficulties getting permission for deploying our test rig in a bird protection area (Ramsar) in a Danish inlet adjacent to the North Sea. Even Greenpeace has been very supportive. They have not foreseen problems for the birds, but we have promised to keep a look-out for what kinds of birds we see there. We have observed a lot of wild life (birds, seals) around the structure. One seagull nested on top of the control room.

No visual impact, low noise. Visual impact is essentially nil when devices are deployed 7-8 km from shore. Because of the slow rotation (150-300 rpm) of the turbines, the noise level is low.

---

[6] This is not a problem for the Wave Dragon. The effect of the marine growth is to improve performance, because the weight and the added mass leads to a more level and steady reservoir which enhances the power production from the turbines. The same effect is seen when the size and/or the weight of the plant increases as will be the case when Wave dragon is dimensioned to more energetic wave climates.

Oscillating Water Column

[This presentation was made without slides.]

Cynthia Rudge, Energetech

Cynthia Rudge has provided services to early stage technology companies in a range of industries. Much of her commercialization efforts over the past five years have been directed at emerging energy technologies, and in particular at the marine renewables sector, principally with Energetech, an Australian company in the business of creating electricity from the energy in ocean waves.

Description of the Technology Class

An oscillating water column (OWC) is a device that converts the rise and fall of water (wave motion) in a cylindrical shaft to propel airflow to drive an air turbine. All the electrical and mechanical parts are contained within a single unit and do not pose a danger to the environment. The water in the column oscillates up and down in a cylinder with the normal motion of the waves.

The OWC is a versatile technology; it can be implemented at the shoreline (example given of a 500 kW sea cliff installation at Islay, Scotland). It is also suitable for near-shore applications, and can be deployed far off-shore as well. It can be made from a variety of materials, including concrete and steel. It may be fixed in place using a gravity foundation, but it can also be deployed as a floating installation or sitting on pads on the seabed and held in place with taut mooring (see slide presentation for examples).

What is the Market Potential of the Technology?

There have been over 30 years of academic study on this technology, and it has been demonstrated to work in a number of locations: a 150 kW plant off Trivandrum, India has been in operation since 1991; there also are plants in Scotland and Japan and off the Azores Islands. What no one has figured out is how to make the technology commercial. There are two companies that have been working on this over the past 6-7 years, Wavegen (UK) and Energetech (Australia).

Wavegen's approach was to come up with a turbine (the Wells turbine) designed to cope with bi-directional flows. Energetech created and patented a variable pitch turbine with 21 blades. The Japanese are studying an impulse turbine. WaveGen is looking at other approaches as well. Improvements in turbine efficiency in the next few years may be what brings the OWC to commercialOne key to commercializing the OWC technology is to capture more energy by directing the waves towards the device. Energetech's design accomplishes this by using a parabolic wall that focuses and amplifies incoming waves into the cylinder.

Energetech is in the process of testing a prototype 100 km south of Sydney. The machine was built in Indonesia, and towed into Port Kembla. The device was attached to its mooring, but was decoupled and taken back to shore to take care of some "teething" problems.

In the United States, Energetech has raised funding from green energy funds in Massachusetts, Rhode Island, and Connecticut to plan and design a 500 kW project off the coast of Rhode Island at Naragansett. The GreenWave project is expected to be commissioned in 2007, and is now undergoing a rigorous environmental permitting process (see Day 2 presentation for more on this), with environmental fieldwork now in progress.

What are the Obstacles to Development?

[This is addressed in a separate presentation given on Day 2 of the Workshop.]

Day One Wrap-up Discussion Summary

Following the technology presentations, the Facilitator observed that there was frustration on the part of developers at the "Catch-22" situation: not being able to give resource agencies the data they require to show that these technologies are environmentally benign without getting first demonstration projects into the water; yet not being able to site demonstration or pilot projects without first having to go through a permitting process designed for large scale installations of mature technologies. The following open discussion ensued.

Comment: Every new technology focuses on solving the engineering, and then comes to realize that there are all these other aspects (involved with siting a facility). Other technologies – gasification of coal, etc. – have been through this same process, which takes time and money; there's no quick fix. But other technologies have made it through it successfully.

Comment: Look at the availability of funding and time, though – how do these technologies compare with gasification of coal and the other fossil fuel technologies that have had to go through this process?

Response: In the US, there have been large government investments in the entire process for the fossil fuel technologies, whereas with the renewables there has been more of an expectation that the industry is going to take care of that on their own. So it may take longer for the renewables, though something like this forum may help speed things up.

Response: Yes, obviously the agencies have to look at all these aspects. There is a precautionary principle that says you have to really be sure about everything before you proceed. But at the same time, if the various stakeholders could agree to a practical principle that says we need these early installations to learn and improve, then we could go forward together with that.

In the UK, there are some 7,000 MW of offshore wind on the drawing boards, and each of these projects is quite large – 100 MW or more – and has gone through a siting process typically costing about a million pounds (about $2 million). The challenge we face is that the agencies then look at a very small wave energy project and say "we've got to have all the same things before we can approve siting – and in fact because this is a different technology we'd better have some more things as well." Part of it is because they don't know anything about the technologies, so perhaps a forum like this can be helpful.

Response: The National Resources Defense Council supports expedited procedures for cleaner, more efficient power technologies. But you do need to have a track record to claim that your technology deserves the speedier process. So forums like this are important, and it would be great to get the industry the money to get the demonstration work done, to find out what environmental impacts there are (or are not). But you can't put the cart before the horse – you have to do the groundwork. If it took AquaEnergy three years to get [the Makah Bay] project sited, that's not so bad. In New York State it can take three years to get a new fossil fuel plant sited. We're not even siting nuclear power plants in the US these days. (And, from NRDC's perspective, it would take a lot longer than three years to site a new nuclear power plant!)

Also, note that European countries have signed on to Kyoto and are internalizing the cost of carbon emissions (e.g., the UK Carbon Trust). We're not there yet, although we are seeing some of the Northeastern states developing cap and trade system for carbon – and that may be the turning point in getting the funding to deploy some of these technologies, to learn what the impacts are, so that project siting can be expedited if and where appropriate.

Response [John Griffiths, EMEC]: I'm in the position – with my EMEC hat on and because I work with the Marine Energy trade association – of saying to the government, we need to have a proportional response to the kind of deployment that is proposed. At the moment, in the UK, we're talking about very small deployments, which we need to do in order to find out what the impacts are. We also have to do studies to get the base data, and we might as well do those baseline studies publicly, because everyone needs the same data. And this message is beginning to get through, at least in the UK. We've tried to turn from a 'we-they' battle to a more constructive "how can we do this?" dialogue. New policy coming out from the UK Department of Trade and Industry hopefully early next month.

Comment: One of the frustrations that has come up is that it takes 3-5 years just to get a permit to put one or two units in the water to do studies, and then another three years of doing studies as part of a 4-5 year process to get a permit for the permanent installation, and near-shore technologies also need to go through the FERC process. So when you make the comparison to how long it takes to site a "permanent" power plant, we're really talking about an 8-10 year process altogether. Three or four years is the length of time just to put a few units in the water to do the studies.

Response: We can't be treated as a mature technology here, because we're not. We're a small part of the renewable field, and we're the survivors. When all said and done, somewhere in the system, we have to be accepted to at least let us build to the point where we have a viable commercial machine, and let that be low-cost.

Response: Consider this from the resource agency's perspective: To you it's a pilot project, but we're looking at areas where we have endangered species, where we don't have far to go before jeopardy, or maybe extinction. In that situation, we're going to take triple and maybe quadruple precautions – we're not going to go there unless we're sure about what is going to happen, and with a new technology we just don't know. I have lots of questions – especially in natural streams. You're asking us, is it o.k. to put your resource at risk for this test project?

Comment: I think everyone has sympathy with the situations faced by the agencies. I think the move in the recent Energy Bill is potentially very good, one of the issues that with lots of different agencies, it may potentially be very good to have one agency – in this case MMS – that will be taking responsibility for managing that process, at least with off-shore. In the UK, there is one agency that is responsible for managing the permitting process for off-shore oil and gas. Part of the difficulty is when you have to deal with multiple agencies.

Facilitator: I hear that the regulatory issues have to be addressed. But you've got people who want to put equipment up to test it tomorrow, and you've got people who are legally required to make sure that the resource they're responsible for is protected. So we need to come back to figure out what are the research questions that need to be addressed, and how do we raise the funds to address those questions, so that the agencies' questions can be answered and the technologies can go ahead with testing and commercial development.

Comment: I've heard numerous folks from industry say that there is no information, which is why you have a research facility (EMEC) to do these sorts of tests. The whole point of us being here at this workshop is to discuss what sorts of things to look for in these tests so that it doesn't take three years to get a pilot project up or 5-6 years as it would to get a hydropower project licensed. Let's try to figure out a way to take these pilot projects and turn them into something useful, a way to take all the resource issues that we agencies have and make it easier for us to get the information we need from industry.

Comment: One of the challenges with these technologies is that you're working in a physically and environmentally "hostile" setting. It's harder to put a project in the ocean or even a river or estuary and monitor it, than it is to work with something on land. We don't know as much about it, and harder to study. A lot of opportunities to learn from the consequences of new technologies that have come on line in the past – what are the kinds of problems that we only found out about after the fact; they want to find out before. That's where the resource agencies are coming from: they don't want to learn after the fact; they want to learn before.

Comment: Even once you have a process in place, you still have to go and acquire data. And even if you have a facility in place like EMEC, you still need to be able to get funding to make use of the facility to get data. NREL has such a mechanism in place for wind technology developers to make use of its wind energy test center, but we don't have anything like that in place for marine energy.

Facilitator: It sounds like we need to hear from DOE about what the funding might realistically be available for the Ocean Energy Program.

Response [*Peter Goldman*]: The 2005 Energy Bill authorized an Ocean Energy Program (OEP), but the Energy Bill does not itself provide for funding. President Bush's 2006 Budget Request did not include funding for ocean energy. We'll have to see whether there will be anything in 2007 budget. If someone wants this program to be funded, they have to go to Congress and convince them that this work is important and that money should be appropriated for it. Before, there was no place to put the money; now there is, but Congress needs to appropriate the money specifically for Ocean Energy Technologies. Right now we're spending some of our wind money because there's some synergy between wind technologies and ocean energy technologies, and we are also working with MMS to help them with both offshore wind and ocean energy technologies.

We did join the International Energy Agency's Ocean Energy Systems – DOE has a representative who attends meetings, but we're not in a position to provide any funds for collaborative ocean R&D efforts.

Question: Rumor that Dept. of Defense might have funding to support ocean energy technologies. Does DOE have some part in this? *Response*: Not familiar with this – check carefully the Energy Policy Act of 2005 language.

Comment: The National Hydropower Association worked very hard to get this language into the 2005 Energy Bill. I'm very glad to see all of us in the room together here today, because the only way we're going to get funding to continue this research is if we (environmental NGO community and industry members) can work together to lobby Congress for funding. It is hard to get money out of the Appropriations Committee. But we have to work together to explain why this is valuable, and that we have a plan for getting critical research questions answered.

Day Two

Facilitated Discussion with Technology Presenters

At the beginning of Day Two, an effort was made to summarize the classes of technology that were presented on Day One, and then the floor was opened to questions from participants about the technologies. Responses were given by one or more of the panelists who had presented on Day One, and in some cases other participants took part in the ensuing discussion.

Facilitator: Yesterday we heard about three classes of systems: rotating machines (axial flow, helical or cross-flow[7] turbine, and the "Hydromatrix" or turbine array[8] device); Point Absorber Systems (heave and heave-surge devices); Oscillating Water Column Systems.

<u>What is the distinction between the wave heave devices and the OWC? It seems like the principle is the same.</u>

Response: In an OWC, the up-and-down motion of the waves entering the column acts first on a column of air, whereas in a wave-heave device the medium acted upon by the motion of the waves is some kind of hydraulic fluid.

<u>Have there been any unexpected findings from being in the water with these machines in terms of environmental impacts?</u>

Response: Power Buoy consulted all interested parties (including environmental agencies) when obtaining permits in Hawaii and Australia. There have not been any surprises, except that we have found that fish accumulate around the buoys. Buoys actually are put in the water for this purpose; the fish see it as an artificial reef. In addition we have had interest from the Army Corps of Engineers about whether a field of buoys could be used to take energy out of waves to reduce erosion at shore.

<u>For the wave energy conversion devices, what distance from shore are we talking about? In some disciplines, "near-shore" refers to the breakwater. When you say a device is to be deployed "near shore," how is that distance defined?</u>

Response: I would refer to the breakwater as "shoreline," as opposed to "near-shore" or "offshore."

Response: Marine Energy Glossary defines "near-shore" as between shoreline and offshore. It's defined flexibly, because the precise requirements (having to do with depth, distance, and other parameters) vary from one marine energy technology to another.

---

[7] Dr. Gorlov's "helical" turbine was distinguished from the "cross flow" or "mixed flow" turbine used in conventional hydropower engineering. The conventional cross-flow or "mixed flow" turbine is vertically-oriented, but has a horizontal component as well. Dr. Gorlov's technology might be described as a cross-axis machine, or, to avoid confusion, might simply be referred to as a "helical" turbine, which is how it is referred to in its patent.

[8] It was suggested that because VA TECH has patented the Hydromatrix system, a more generic name for this type of device would be a small *turbine array*, which is more descriptive.

Response: What matters for most of these devices is depth, not distance. (Distance makes a difference in terms of the cost of cable.) If I were to generalize, I would define the terms as follows:

Shoreline = 0-10 m deep; Near-shore = 30-40 m depth; Offshore $\geq$ 50-60 m deep.

Comment: Given this definition, I would ask whether it even makes sense to have a "near-shore" term. Why not just say "shoreline" and "offshore," with offshore being 30 m. and deeper?

Facilitator: Let's wait until we've heard the presentations on the resource systems and see whether that makes sense for purposes of the discussion we want to have.

Response: Keep in mind that wave systems and tidal systems are different. Tidal turbines are scaleable, whereas wave systems are defined by the frequency of the waves and thus have to be a certain size and require certain depths.

<u>How are you defining power?</u>

Response: Marine Energy Glossary doesn't give a basic working definition of power. An engineer working in the conventional hydropower industry defines power as Q * Head, where Q (flow) is a function of velocity and area. In traditional power terms, the more head I have, the less flow I need to generate a given amount of power – but you need to have head or discharge to have power. How are you defining power?

Response: Power is defined as "rate of work discharged in unit time," work is defined in terms of foot-pounds. So, for example, one foot-pound per second is the amount of power it takes to lift one pound one foot in one second. Energy is the sum of power over time.

Response: There are many forms of "head." Static, kinetic, elevation, pressure. Head is equivalent to energy. In conventional hydropower systems, you are converting elevation head. In the case of in-stream tidal energy conversion systems, you are extracting kinetic energy from the flow of the medium.

<u>What are the speeds of the various systems that have been described to us when they are moving?</u>

Response: For the axial flow turbine (being tested in the East River), we need a water velocity of 2 m per second. The bigger the blade, the faster the current, the more energy.

Response: For any given in-stream energy conversion system – just as with wind turbines – energy increases exponentially with an increase in velocity. If you can take a 2 knot current and get x amount of energy, doubling the current velocity to 4 knots gets you x^3 energy. All of us using propeller-type devices are looking for faster currents, because of this exponential increase in energy.

Response: For something like Verdant Power's axial flow machine, we're talking about very fast currents as a rule. Knee-level water moving at 2 ft. per second is something you can stand in – faster than that and you're talking about a ripping current.

Response: Lunar Energy's fixed-pitch blade has a number of facets, because it's all about changing the load – it also depends on how much water there is above the blade. If you create too much water pressure on the blade, you get bubbles forming on back of blade. The design of Lunar Energy's ducted turbine is very, very site specific, with as little difference as between 7.3 knots and 7.5 knots velocity at the sea bed affecting the design of the turbine. The 1 MW turbine going in to the water for testing next year has a 15 m duct intake for a 10 m blade diameter. The turbine rotates at about 20 rpm, which is much slower than the rotation of a ship's propeller.

Response: The Hydromatrix turbines are relatively small. They turn at 250-360 rpm in water moving at 2.5-6 ft per second velocity through the turbine.

Response: A 1-m diameter helical turbine turns at up to 150 rpm in water moving at a velocity of 6 knots, or 3 m per second. At that velocity this turbine is generating 20-50 kW. (Power is measured in kW, energy in kWh.) The power is directly proportional to fluid velocity cubed. The helical turbine will start generating at 1 knot, but at this velocity it generates a very low level of power. From a commercial point of view, it is better to design system that starts at 2-3 knots.

Response: In the case of wave energy conversion devices, we don't rotate, we oscillate. Height and period of wave is what matters in our case. Our formula for defining energy is wave height squared times 0.56 times the wave period. How much useable energy you can produce depends on the physical limitations of device. The size of the device and the speed at which it oscillates depends on the periodicity of the waves at the site. For example, in the North Sea you might have a device 3 m in diameter, because the waves have a smaller period than Pacific Ocean waves. In the Pacific, you might need a device 5-6 m in diameter.

<u>When you design a project, you have to look at waves over whole year. What parameters do you choose?</u>

Response: We can download data for the last 20 years from NOAA. This gives us a matrix of the number of times a particular wave occurred in a particular spot. You design for 90% of that occurrence, and it comes down to an economic decision; you tune the device to some percentage of waves.

Response: For the Pelamis, we look at a range of periods from 6-18 seconds (0.7 m per second going up and down). To predict power for a site, we take an occurrence table wave height per period. EMEC is working on establishing standards to help work out power production estimates.

Response: All of our systems have a way to step up the frequency from the relatively slow frequency of wave periods to a frequency suitable for generating electricity.

<u>Do your operations and maintenance (O&M) costs include transmission and distribution (T&D) costs?</u> [*Participant clarified that the importance of understanding how developers are computing their costs is that, as costs go down, the potential to introduce these technologies into the market goes up. As market penetration increases, so does the potential for environmental impact.*]

Response: For the Power Buoy presentation, yes. The question of what energy ultimately costs has to include transmission and distribution costs.

Response: Most of us are pursuing these technologies because we feel there's an opportunity to have a very positive environmental impact as the cost of these technologies goes down.

Response: There is always going to be extra cost if the load you are serving is located far away from the generation site. But as long as we stick with the formula given on NREL's website, we will be talking in comparable terms.

Response: The existing grids were in most cases designed for centralized generation, and the transmission lines don't generally come to shoreline.

Response: However, in some remote locations there are coastal areas where there is a weak transmission infrastructure to the coast from the interior, but a growing need at for power at the shoreline. That's where the offshore systems have a real opportunity.

Response: There are always extra T&D costs for a new project, but those costs are recouped.

Response: In the UK, power cost includes any additional infrastructure costs, including T&D infrastructure improvements.

Response: It comes down to regulations – what piece of T&D costs you have to include in your costs.

Response: We build in not only our own manufacturing cost, but also the profit the utility will need to make on the power they sell to the distributor.

Response: Right. You have to think of yourself as an independent power producer, and calculate backwards from price you can sell the electricity you are generating to the T&D utility.

Response: In Florida, our capital costs are bundled to the point of interconnect. Our capital costs include whatever it takes to get power to the grid.

Response: Yes. For purposes of this discussion, in the US, costs include grid connection, period. When we talk about our costs in this workshop, we're not going to be taking into consideration the cost of upgrading transmission and distribution infrastructure.

Response: In strategic development terms, it's important to keep in mind that, in the short to medium term, this industry will not develop where there is the best resource, because the infrastructure isn't there.

Facilitator comment: There is a whole world of rules governing relationships between independent power producers, new technologies and the existing grid system. So as we are talking about costs, be clear about what's included.

<u>How are you taking into account licensing, construction, mitigation, financing costs. Do you roll</u>

all that into a loan, amortize those costs based on the principal and interest you have got to pay, and then factor that in to the per kWh cost? What kinds of loan periods and interest rates are you coming up with for these projects?

Response: Yes, all of the above. AIA defines cost in terms of two factors: "overnight" costs (all capital costs, including permitting, but no time-related costs) + "time" cost element (includes maintenance, loans, etc.). EPRI has a spreadsheet that we try to use for various assumptions so that we can compare our terms.

Response: EPRI does cost-of-electricity calculations for all types of energy generation. We have put out economic assessment methodology reports for ocean energy (both for waves and tidal energy conversion) for all the states we have worked with. These are quite detailed documents (about 40 pages long) that provide a standard guideline for estimating energy costs: what to include and how to include it as well as what financial assumptions (percent equity v. debt, financing interest rates, book life of plant, etc.) to use. These documents are publicly available on our website.

Where /how do these technologies fit into the electricity supply picture?

Response: To have a business, we have to take cost into account, but another element of the value of what we're producing is that the beauty of moving water as a resource is its reliability and predictability. Like wind power, these technologies provide intermittent capacity, but *unlike* wind, it is *very predictable* – power managers know when and how much power the unit will be generating.

Utilities like this form of renewable energy because the capacity value can be scheduled; it is closer to baseline power than the other renewables.

Clarification of terms:

Capacity factor is the actual amount of energy generated by a plant (over the course of a year) v. the ideal amount of energy that would be generated by that plant during the same period. For an oil or gas power plant this is on the order of 1 (minus the percentage of time the plant is offline for maintenance and repairs).

Firm capacity is power that utilities can count on 24 hours a day.

Intermittent capacity is power that is not being generated continuously (24 hours a day), but within this category there is a distinction between power supply that is predictable (e.g., hydrokinetic power) v. an intermittent supply that can be estimated over a period of time (such as a year) but cannot be scheduled hour by hour (e.g., wind power).

Comment: There is tremendous value in the predictability of wave and tidal power, but don't lets put something like wind and other forms of (intermittent) renewable energy resource in a negative light. Wind can be forecasted, and has a part to play in the overall supply picture.

Response: That's a good point. If you're pro-renewables, you can't say yes to this and no to that. It is important to produce a diverse mix of renewable energy technologies to increase the penetration of renewables in the overall energy market. (As well as to increase our energy security.)

Comment: Fossil fuel-generated energy costs do not typically take into account externalities – the environmental costs of extracting and burning those fuels. For renewables to compete with fossil fuels, these externalities have to be taken into account.

<u>How many of these projects are being directly marketed as Independent Power Production (IPP)?</u>

Response: Essentially all of them. Utilities don't want to own generation, they just want to buy power. Economics also dictate as well that these are not small facilities. When you add your cost of permitting and cable costs, those two huge costs mean you have to think in terms of 50 MW and up.

<u>Several other topics of interest were introduced during this Q&A session:</u>

1) <u>Biofouling</u>
2) <u>Debris strike</u>
3) <u>Fish being attracted to the structure (Power Buoy example) – has anyone added structure to their systems to attract fish?</u>
4) <u>Cabling impacts on the seabed;</u>
5) <u>Land fouling issues – when you go from open water to upland, crossing the traditional zones.</u>
6) <u>Boating safety (recreational and commercial)</u>

Facilitator: Is anyone going to speak to some of these issues in their presentations later on? [Some presenters indicated yes.] Let's wait to hear their presentations, and then you can raise these questions again if they haven't been answered by the presentations.

Resource Areas for Deployment of Hydrokinetic and Wave Energy and Associated Environmental Questions/Concerns

Facilitator: These kinds of conversations can be challenging because people are passionate – about getting the technologies into the water, other people passionate about the resources. We are going to have some differences today, but we are here to better understand each others' issues.

Resource Concerns Associated with Natural Streams

[1. Cada and Meyer - Natural Streams.pdf]

Glenn Cada, USDOE/ORNL (with Ed Meyer, NOAA Fisheries)

Glenn Cada and Ed Meyer have worked together since the early days of the DOE Advanced Hydropower Turbine Program, which began in early 1990s. They were part of a technical advisory committee, a combination of engineers and scientists who came from very different perspectives and accomplished a great deal by working together. Both presenters come from a background of dealing with the environmental impacts of conventional hydropower projects.

This presentation is structured in terms of the list of stream ecology concerns raised by conventional hydropower projects. Although many of these issues won't apply to technologies that don't obstruct an entire river channel, don't involve a reservoir, etc., its useful to work with a framework that considers the physical factors in the water column, physical factors in the substrate, chemical factors in the water column, and biological factors.

Physical Factors in the Water Column

- Flow varies quite a bit between drought and spate conditions, affecting not only power generation, but also physical, chemical, and biological processes that occur in the stream. Sometimes organisms are affected negatively by flow variability; sometimes they rely on it.

- Hydraulic factors like shear stress and turbulence also are highly variable.

- Width of the river even in large rivers is a fairly narrow range, so we need to think about the degree of obstruction resulting from an installation, and how they affect the effective width of the river.

- Depth of natural rivers fall within a fairly narrow range (especially when compared with ocean depths. Consequently, water pressures fall within a narrow range as well. With conventional hydropower, fish can get acclimated to high pressure levels in deep water reservoirs, and then suffer from the pressure change when they pass through the turbines. This may not be a problem for the kinds of technologies we're considering in this workshop.

Physical Factors in the Substrate

- Sediment size and composition are very important for the organisms that live there, as well as how uniform that sediment is. Some organisms need cobble and gravel to carry on their life cycle.

- "Extraction of kinetic energy" affects the ability of water body to transport sediment; so we need to look at the impact on transport and suspension of bed load.

- Debris transport is another issue – some of this debris forms fish habitat when it lodges downstream, so we have to look at how any change in transport function might affect habitat

- Aquatic vegetation – we would want to look at any impact on vegetation which provides food and habitat for fish and other organisms in the stream.

- Contaminants –any contaminants in the sediment that might be exposed by the action of the facility, need to be considered.

Chemical factors in the Water Column

- Temperature impacts – conventional hydropower projects can have a significant impact on temperature; this may not be as big an issue for hydrokinetic technologies.

- Dissolved oxygen, nitrogen supersaturation – again, conventional hydropower projects can have a significant impact on concentrations of dissolved gases; likewise, this may not be as big an issue for these kinetic technologies.

- Dissolved solids – does the technology cause these solids to change their chemical form?

- Extraction of energy may cause suspended solids to drop out, thereby changing turbidity

- Might the chemical form or distribution of dissolved contaminants be altered by the technology?

Biological Factors

- Natural streams provide habitat for resident fish, plants and other types of organisms. Some organisms require cobble stream beds to spawn, whereas silt is the preferred habitat for other species. So we have to think about how any change in the habitat affects the life cycle of the organisms that depend on that habitat.

- Rivers also serve as highways for upstream and downstream movements of organisms. This includes constant, passive drift of aquatic invertebrates (mayflies, stone flies, etc.) and seasonal drift of fish eggs and larvae – these passive drifters are weak swimmers, so they don't have much ability to avoid an obstruction. There are also organisms actively moving up and down – how do partial obstructions affect anadromous fish like salmon and shad, or catadromous fish like American eels? Resident (freshwater) fish may move great distances in a river. We know a lot about the challenges posed by dams to these species, but we have to consider what challenges a partial obstruction would constitute.

- Other organisms that may be affected by the presence of hydrokinetic turbines in the river include reptiles, diving birds, and mammals.

Competing uses of Natural Streams

Other uses of natural streams also need to be taken into account, some of which may be at cross purposes (e.g., the less visible a technology is, possibly the more hazardous from a navigation perspective).

- Recreational and commercial navigation
- Swimming and shoreline recreation
- Industrial discharges and withdrawals
- Aesthetics (visual and noise)
- Commercial fishing – e.g., gill-netting in rivers

<u>*Presentation on Natural Stream Resource was followed by a Q&A discussion*</u>*:*

Comment: Entrainment and impingement is another issue I would add to Glenn's list. We're putting rotating blades in the water, and what we're really worried about is collisions with organisms.

We say we don't know anything about the potential impacts, but in fact we have studied a lot of things that perhaps can be translated to these technologies. For example, in the case of entrainment and impingement, there have been a lot of studies done on power plant cooling systems (EPRI, Nuclear Regulatory Commission). With conventional hydropower technology, we've been studying the swimming behavior of fish, developing equations on their ability to navigate through and around turbines. We need to translate what we *do* know into this arena. <u>What do you think we already know the most about, and what can we say about how this might apply to these new technologies?</u>

Response [(G. Cada]: Yes. We have learned a lot about hydroelectric turbine effects on fish in the last ten years from the DOE's Advanced Hydropower Program and from Army Corps of Engineers studies, and a lot of that is applicable to what we are talking about here. In advanced turbine development, engineers needed to know what parameters were safe for fish – e.g., what pressure values do we need to stay within for pressurized turbines, what values of water velocity, shear, turbulence, and strike are acceptable? We did a lot of laboratory and other work to develop what are called "bio-criteria" – and yes, a lot of this is applicable. For example, you can quantify pressure changes with an unducted turbine (I would assume they are pretty minimal), and then take the literature from last ten years and apply that. For other parameters, such as strike zone, I'm not sure how well what we know about enclosed, pressurized passages relates to an unducted turbine in an open stream.

How would you determine what percentage of kinetic energy you can take away from a natural stream before you start having noticeable changes in ecology? What R&D program, what process or procedure would you use to determine an answer to that question?

Response [E. Meyer]: Any sort of extraction is going to have an effect somewhere. Some of the resource agencies have been discussing this. The problem is that, when you put in pilot studies, a small number of units in various places, it's very hard to extrapolate to the likely impacts of full-scale deployment. *For some systems, it may be possible to model physical impacts* (hydraulic models) – whether you're going to create or lessen erosion, sediment transport, turbulence etc.

Resource Concerns Associated with Estuaries

[2. T. Swanson - Estuaries.pdf]

Estuaries: Christina Swanson, Bay Institute of San Francisco

Tina Swanson is a research scientist with the University of California, Davis, and Senior Scientist for the Bay Institute, a non-profit environmental research, education and advocacy group based in San Francisco.

This presentation focuses on the key characteristics of estuaries relevant to exploring the possibility of installing hydrokinetic technologies in these settings, and what sorts of things you would need to consider if you do so.

Essentially, an estuary is the place where a river meets the ocean. By definition, at least a portion of an estuary is surrounded by land, but by their nature, estuaries are very complex and very diverse, each one unique. The U.S. has over 100 estuaries, many of which are designated as being of "national importance," or as National Estuarine Research Reserves, which will have implications for permitting.

Estuaries can be large or small, shallow or deep. Some are formed by the creation of barrier islands offshore, while others (such as San Francisco) are predominantly inland estuaries.

San Francisco is a good example of how complex estuaries can be. They are dynamic in terms of the amount of freshwater inflow, which can be fairly steady or extremely variable – both seasonally and from year to year. As a consequence, measures of environmental conditions within an estuary are extremely variable. In a coastal plain estuary like San Francisco, a lot of the physical processes – which in turn drive the biological processes – are more driven by tides and ocean conditions than by fresh water flow.

This is a highly studied estuary, US Geological Survey has stations all over the bay, and have determined that flow conditions in this estuary are unbelievably complex. They change with the tides, the river flows, with where you are in the estuary, with depth, and with water quality (salinity level), with the complex underwater topography. So this sort of system is much harder to predict than the flow of a river or a tidal current offshore. There also is an imbalance in tidal excursion in the rivers, and as a consequence of artificial connections between some of these rivers, you get rivers flowing backwards in one place and forwards in another.

Debris is an issue within the San Francisco Bay estuary, especially upstream. This includes a lot of anthropogenic debris – like cars – as well as pervasive, invasive exotic weeds, mitten crabs. This is not unusual; estuaries tend to be highly invaded environments, so you have to look both at the natural (indigenous) system and at how the system is changing.

Depending on the flow coming into the estuary, and whether any of that upstream flow has been diverted or otherwise altered, an estuary may be either depositional or erosional. Hurricane Katrina's impact on New Orleans is an example of what can happen when you reduce sediment deposition in an estuary. San Francisco is considered to be a sediment-starved estuary as well.

Estuaries are tremendously rich and for the most part productive ecosystems. They have a wide variety of habitats, with the shallower areas providing the more ecologically important habitat. (At the same time, it is important to recognize that a lot of organisms move around within an estuary, and that, like rivers, estuaries are important migration corridors. So while you may site your machine in a deep-water area, that may represent a passage or corridor between one critically important habitat and another.

Estuaries not only produce a lot of biological material, they also import energy from the ocean, so you have to be careful about interrupting that.

The biological diversity of estuaries encompasses plants, invertebrates (including some too small to see), fish, birds, and mammals. Thus you have to consider how the various organisms use these ecosystems for their various life cycle needs. Estuaries are known to be important spawning and nursery habitat for many fish and invertebrate as well as bird species, including many commercial species. Thus it is a commercial as well as recreational resource.

Resident species of estuaries include many small and delicate species – most of which were not included in the bio-criteria development work (on swimming/navigation performance, ability to withstand pressure, etc.) that was conducted for the Advanced Hydropower Turbine Technology program. So there tends to be less background information about the species that you are going to encounter in estuaries, compared to the natural stream resource.

Because estuaries tend to be subject to a high degree of anthropogenic alteration, any proposed impact has to be considered in the context of modifications that have already been made. This includes dams and flood control; water diversion (for drinking water and for agriculture); habitat conversion, pollution, dredging, urbanization. Estuaries tend to be already ecologically stressed, and the cumulative impact of all these stresses has to be considered when you're considering a site and trying to evaluate the impact of a proposed project.

Finally, people tend to congregate around estuaries: they are population centers, they are ports, with activities including shipping, fishing, recreation, and education.

Presentation on Estuaries was followed by a Q&A discussion:

EPRI is looking at a 500 kW pilot plant between Lands End and the Golden Gate on a shelf just south of the navigation lane. Would you consider that part of the estuary, and what environmental considerations do we need to be thinking about at that location?

Response: Golden Gate area is part of the San Francisco Bay estuary. Three considerations that come right to my mind are:

1) Golden Gate is a huge migration corridor. There is a very large, very healthy salmon population. Have to consider *where* are the fish when they're migrating through the Golden Gate – are they hugging the shore, are they going out into deeper water as they come up from the south?

2) Physical effects: how much energy are you extracting? (With such a small project most likely not much energy is being extracted relative to the amount of energy in the flow – *response*: less than one percent.) Even if it isn't a big issue, you do need to look at what the impacts are on erosion, sediment deposition.

3) Finally, there is some recreation in the area that you would want to take into account.

What about cultural resource?

Response: I don't think that this is an issue so much in San Francisco Bay, but generally do need to consider. It is a public trust resource, so you need to consider from that perspective.

Response [A. Weinstein]: In Washington State, our interaction with the Makah Indians has been positive. We talked first to fishermen, and they were positive. It is a marine sanctuary, but there is a provision that as long as the project is providing economic benefit to the Indian Nation, and they were o.k. with it, then that is not an obstacle. Fishermen were receptive because the buoys serve as navigational markers, and also because they attract fish. (Could be a problem if fishermen try to moor their boats to the buoys, but apart from that, it is not a problem.)

Ports have a lot of traffic, which may mean that noise is already an issue in a lot of estuaries. The most acoustic-sensitive category of aquatic animals is anadromous fish, and American shad are a particularly sensitive species. So developers have to consider the impacts of their projects adding noise during installation, operations, and maintenance. (This has been a real issue for offshore wind.)

Response: True – noise is an issue in San Francisco Bay. Pile-driving can kill endangered species – has been issue for CalTrans as they're doing earthquake reconstruction.

Comment: In some cases the noise from pile-driving has been shown to kill endangered species, so yes, it is an issue that you cannot avoid. You may be able to dispense with it quickly, but you really cannot avoid it.

Comment: There have been before and after studies of noise impacts conducted for construction of offshore wind in Europe. The impacts do appear to be temporary – during the ramming of the poles. The Danes have tried some mitigation measures to drive fish away during construction. These kinds of questions (biological impacts) can take a long time to understand. How do we research this, how do we achieve "clean green" label?

Response: You can model and monitor, and you can try to learn from what has already been done. There have been studies of fish swimming behavior done in connection with hydropower turbines, but there also have been ecological studies in systems like estuaries that tell you where the fish are and what they're doing at various times of the year. There has also been a lot of physical studies and hydrodynamic modeling that can guide you.

But – and this is a critically important question – you can monitor and model, and it doesn't necessarily tell you what the overall long-term effects of a system or systems will be. If you are sincere about wanting to develop a "green" technology – and I think you are – then you need to take the long-term view. This means that you have to plan for a phased and monitored introduction of technology, with the clear understanding that you may have to go back. Sometimes we try to go too fast. Given the life-span of some species, the consequences of our actions can take ten years to learn, or even longer. Probably not all of these technologies are equally environmentally benign; some may be o.k. in one habitat but not in another.

Comment: When you talk about phased introduction of technology with monitoring, keep in mind that some impacts can take many human generations to find out about and longer to correct. If you think salmon have a long life-span (3 years), consider that rockfish off the coast of San Francisco, for example, live for 140 years – and 10 years ago we didn't know this; we thought they had a life-span of only 10 years.

Comment: Keep in mind also that existing generation has impacts as well – conventional hydropower systems, of course, but also fossil fuel impacts such as pollution and global warming, for example. When we look at potential impact of these technologies, can we factor in the impacts of the alternatives (that is, the default energy technologies)?

Response [E. Meyer, NOAA]: We don't weigh conventional hydropower v. renewable or other energy resources when considering the impact on our resource. Nobody comes to us and says, we want to put in this hydrokinetic technology and take out a conventional hydropower plant. From our perspective, our resource is always taking a hit. A conventional hydropower plant is a point-source impact (although, granted, impacts do propagate up and down) – but if we're talking about modular and distributed systems which may be spread out along the course of a stream, the question is, how do we think about the impacts?

Response [T. Swanson]: One of the things we need to do is start planning for the management and installation of these technologies in the future. In the San Francisco Bay Area – the estuary and its watershed – agencies are planning for the next 30 to 40 years based on 50-year old data, but with the understanding that the watershed is changing dramatically as we speak. This is a real problem.

Response [L. Church-Ciocci, NHA]: There are places where dam removal in one place is being traded off against installation of facility in another part of the natural system, but that is the result of very creative thinking.

Comment: American Society for Testing of Materials (ASTM) is doing life-cycle costing of various electric generation technologies from fuel extraction to end-of-plant, and they are putting together a methodology to do that. This is not a standard, and it is not being used by any regulatory agencies, but it could be a useful tool.

Resource Concerns Associated with Near-Shore Environments

[3. J.Gibson - Near Shore.pdf]

Near-Shore: Jim Gibson, Devine Tarbell & Associates

Jim Gibson is a Senior Scientist and Regulatory Specialist and the manager of Devine Tarbell & Associates' Syracuse, New York office. In addition to assisting multiple clients with obtaining FERC licenses and applicable permits for hydroelectric projects, Jim has been working with Verdant Power, LLC, to conduct environmental studies and obtain permits for both their Roosevelt Island Tidal Energy Project and their Merrimack River (Massachusetts) Project. In addition to working with Verdant, Jim has been providing technical support to the AquaEnergy Group's Makah Bay Project and Phase I of EPRI's Tidal Energy Project.

There is no official definition of the term "near shore." Clearly it cannot be distance-based, as we heard earlier. From the perspective of a technology developer, the characteristics and requirements of the technology may dictate whether a device is deployed "near-shore" or "off-shore." But if that developer wants to get a device permitted, it makes more sense to think about this question from the resource agencies' perspective. From this perspective, I would say that "near-shore" includes estuaries, or at least overlaps that resource category – and as with estuaries, the near-shore resource is a transitional zone, a combination of the riparian, the beach and the tidal zones. Similarly, it is a very complex and productive environment.

I would say that the near-shore environment is best defined as a vegetative zone. When I try to distinguish between near-shore and off-shore, I look at three things: substrate, the primary producers, and the converters.

Distinguishing Near Shore from Off Shore

	Near Shore	Off Shore
Substrate:	Vegetation, mineral nutrients, gravel, sand, silt, mud, rock, water	Sand, mud, detritus, water
Producers:	Wetland flora, algae, phytoplankton	Phytoplankton
Converters:	Aquatic invertebrates, fish, birds, marine mammals, lowland wildlife, bacteria	Aquatic invertebrates, fish, birds, marine mammals

Once you are in the photic zone, the area where the influence of the sunlight resulting in vegetation, I would say that you are in the near-shore zone.

Functions of the near-shore are similar to what we heard about with estuaries. As a regulator or resource agency person, I want to make sure that the technology is not going to interfere with the food web: primary production, nutrient processing, food for birds, substrate for secondary production. In addition to providing critical habitat, other functions of the near-shore include: wave and current buffering, protecting water quality, floodwater attenuation, ecological buffer zone. From the permitting perspective, another distinction between near-shore and off-shore is that recreation and aesthetic considerations are going to play a more significant role in the near-shore environment. This is likewise the case for navigation and transportation.

The following is a check-list of potential concerns that project developers should be prepared to address when looking to site a technology in the near-shore environment:

- Food web impacts
- Phytoplankton and zooplankton
- Forage fish – smaller fish that feed on invertebrates and plankton, and that in turn become food for larger fish
- Vegetation impacts – have to think about wetland impacts, particularly as you bring that power up to shore (lay-down impacts from cables, for example).
- Essential fish habitat – those habitats that are critical during specific stages in the life-cycle for designated fish species
- Threatened and endangered species – if you have an option, try to avoid any area that provides habitat or migratory corridor for threatened or endangered species. In the Northeast, the American eel is one such species.
- As with estuaries, a lot of these areas are sensitive to increased turbidity and scour impacts
- Increased predation – if your technology attracts fish, that may not be a good thing, because you are increasing the opportunities for predators
- Migration routes and patterns

- Visual impacts
- Cultural and historical impacts
- Recreational resources
- Erosion and sedimentation
- Sediment contamination
- Hydraulic alteration
- Noise and temperature pollution
- Diving birds and mammals
- Creating or altering habitats
- Invasive species

Resource Concerns Associated with the Off-shore Environment

[4. J.Ogden - Offshore (Bigford).pdf]

John Ogden, Florida Institute of Oceanography
Presented by Tom Bigford, NOAA/NMFS

Tom Bigford presented material put together for this Workshop by John Ogden of the Florida Institute of Oceanography. (Mr. Ogden was prevented from attending the Workshop because hurricane damage to the Institute required his presence in Florida.)

The continental shelves of the United States (to 200 m. depth) cover a total area of approximately 2.3×10^6 km^2 – less than 25% of the area of the Exclusive Economic Zone (EEZ), which extends from the shoreline to 200 nautical miles. Over 60% of this shelf area is in Alaska, with other key regions being the Atlantic Coast, the Gulf of Mexico, and the West Coast. The shelves and slopes are a critical national resource, important for fishing and extractable resources, recreation, and commerce. They also provide ecosystem services including diluting, dispersing, and metabolizing the effluents and pollutants of growing coastal human populations.

Although the oceans are huge, only a small fraction of this shelf area is environmentally and economically feasible for the deployment of such innovative technologies as hydrokinetic and wave power generation and aquaculture. Thus there is great potential for conflict and environmental damage. The areas people are considering for these projects are relatively close to coastlines. Although not necessarily within sight of the land, this “photic zone” (or “inner shelf”) is the area of greatest diversity, density, where most of the resource agencies have most of their interest, the primary carbon (and biological) productivity areas.

In most regions of the world, the transition from shallow near-shore waters to the deeper waters of the continental shelf and slope involves a shift from benthic (or bottom-based) to water column productivity. Where the water becomes very deep, oceanic food chains are supported by the phytoplankton, and here the bottom is less important.

Putting structures out in deeper water provides a hard substrate for attachment of organisms that do not normally occur there, and these, in turn, are attractive to ocean predatory fishes. It is an open question whether such structures add substantial new productivity and therefore increase the populations of marine organisms. Certainly, they attract and concentrate naturally occurring populations – potentially (depending on the size of the structure) from a wide area. They can also attract exotic and invasive species, and act as stepping stones, assisting their dispersal to new areas (for example, enabling inner shelf organisms to "leapfrog" out to deeper ocean).

Other potential environmental problems include: disturbances to marine mammals and larger organisms during facility construction and operation; toxic waste and spills including anti-fouling coatings; destruction and damage by hurricanes or ocean storms, and disposal of obsolete or damaged structures.

The United States is thinking now about a 200-mile zone of ocean around all the islands and atolls (from NOAAs perspective). Offshore hydrokinetic power generation technologies are among a large number of recent proposals by industry for offshore development in response to energy crisis, over-exploitation of resources, and the increasing scarcity and cost of coastal lands. The Commission on Ocean Policy, reporting to the President in December 2004, anticipated this and emphasized the need for Ecosystem-Based Management (EBM) of coastal waters to the extent of the EEZ and any extended continental shelf.

The rush to develop "the Motion of the Ocean" is analogous to a land rush. There are many different activities already going on out in the ocean, including aquaculture, offshore wind, gas and oil platforms.[9] (In the Gulf of Mexico, for example, there are over 4,000 oil industry structures, over 800 of which are staffed.) The need for comprehensive planning is urgent. It is critical that we consider the *cumulative* impacts of all the activities using the resource. We have to consider what is already out there affecting the environment, and that how these activities shift the baselines. A lot of species and habitats are already imperiled – no one wants hydrokinetic and wave energy conversion technologies to be the straw that breaks the camel's back.

There are three developments currently advancing US ocean policy:

- The Pew Oceans Commission issued its report in April 2003
- The President's Commission on Ocean Policy (COP) issued its report in December 2004
- U.S. Ocean Action Plan, the President's response to the COP, also was issued in December 2004

---

[9] See slide presentation for list of 18 different activities currently taking place in the offshore environment.

As a nation, we must use ocean resources – but we cannot afford to use them up. Industries with an interest in offshore development must work in cooperation with other interested parties towards a U.S. Ocean Use Plan, a first step towards sustainable use of our marine resources.

Presentation on Offshore Resource was followed by a Q&A discussion:

What are major differences/similarities between near-shore and deep water in terms of deploying technology? For example, you are probably less worried about noise above water in deep water, whereas nearer shore you worry about above as well below-surface noise.

Response: Deeper offshore, you would probably be less worried about migratory corridors, as migrating species probably have more options. In general, as you get into deeper water, both human and non-human uses are sparser.

Response: It is not that there are no offshore issues, but rather that these issues escalate as you come in closer to land.

Comment: For any area where you might consider deploying a technology, it is important to do some habitat use characterization – what's there using the habitat for what purpose. Try to do this for more than one year to account for variability in getting your baseline data. In terrestrial development, if we don't characterize well in advance what's there, it becomes very hard to assess impact. It is very difficult to characterize what's happening in an estuary or a river because of the complexity of these systems, but it's also hard to characterize what is happening offshore because it's a remote and hostile environment. Many marine mammals are extremely acoustically sensitive. There is sometimes so much anthropogenic noise that these animals can't communicate with each other.

What impacts do you see from these environments on the technologies?

Response: Debris transport could damage machinery. Boat traffic, flooding may also pose problems.

Response: Sediment deposition downstream could have a rebound effect, causing erosion somewhere else – which may in turn begin to effect river currents. Actions a developer takes to divert debris could also have an impact.

Response: Som of the stuff that grows in or on these systems may be invasive species, such as the zebra mussel. Storms can also have an impact on the technology by changing the course of a river. It's important to keep in mind that these systems do change, and that there's a limit to how much we can (or should) prevent them from changing.

It seems to me that there is some question about the way we are separating different zones in the environment. These processes are interconnected. What happens to the near-shore environment when you start taking energy out of the waves offshore (especially when you start doing this on a large scale)? What is the impact on the wave system when you start farming this ocean wave energy on a large scale?

Canals and Other Engineered Waterways

[No slide presentation]

Charles Bagwell, Zerwell Energy, Inc.

Charles Bagwell, President, Zerwell Energy, Inc. Erie, MI – spoke briefly about a project he has been working on over the last 15 years trying to get water turbine/generators into the condenser cooling water discharge pipes at one of Detroit Edison's steam-powered electric generating power plants, Monroe Power Plant, in Monroe, Michigan.

Steam turbines in existing power plants use flowing water to cool the steam after it leaves the turbines. The head of cooling water is discharged after it has served to cool the steam, and no one taps it. Using low-head technology to tap the kinetic energy of this cooling-water flow through the discharge pipes of existing steam-powered plants could supply a lot of megawatts.

At the Monroe Power Plant, for example, four 800-MW coal-fired units use water from the Raisin River to cool the steam after it leaves the steam turbines. The cooled water is then discharged into Lake Erie. River water flows through each of two pipes in the steam condensers at a rate of 318 cubic feet per second (CFS) at 26 ft. head, giving each pipe a potential 500-700 kW. There are eight pipes at Monroe, for a total potential capacity of 4-5 MW. An additional 1 MW potential exists in the water discharge canal (3,120 CFS at 3 ft. head), that could be tapped with ultra-low head technology, such as a "tidal curtain."

Known and Potential Environmental Questions/Concerns Raised in Connection with Hydrokinetic Technologies

For each of the basic types of hydrokinetic/wave energy conversion technology, presenters were asked to: 1) briefly state what is already known about the actual or potential environmental questions or concerns raised by the technology in the environmental resource area for which it was designed; 2) describe the state of knowledge about these questions, either from experience or extrapolation; and, 3) indicate whether there is planned or ongoing research into the questions.

I. Rotating Machines

Resource Questions Associated with Axial-Flow Turbine Arrays in Existing Structures

[1. A. Bihlmayer Hydromatrix Envr Info.pdf]

Alex Bihlmayer, VA TECH HYDRO USA Corp.

In our experience with licensing low impact hydropower technology at existing structures in the US and overseas, the issues we have been asked to address fall within five topics:

- Natural habitats impacts
- Water quality (dissolved oxygen)
- Potential for oil spillage
- Hazards for navigation, including recreational vehicles
- Cultural impacts

Natural habitat

Because this technology is designed for deployment in an existing structure, habitat has already been disturbed. In most cases, the additional disturbance is relatively minor, but this has to be determined on a site-specific basis.

Fish mortality and migration. The degree to which this becomes an issue is site-specific, depending on existing fishery resources. A lot of the research (e.g., fish entrainment and mortality studies) and mitigation strategies that have been done for conventional hydropower turbines can be applied to our technology. Risk mitigation strategies include: small trash rack spacing (turbines shrouded to prevent entrainment of fish); set turbines as deep into the water, as close to the river sill as possible; use of spillway and/or fishways to attract downstream fish mitigation; installment of ultrasonic (behavioral) deterrence and guidance systems.

Disturbance of vegetation and sediments. Erosion and disturbance of sediments and vegetation is an issue wherever significant changes in river flows are being proposed. In the case of this technology, there is no major disturbance beyond what has already been disturbed by the existing structure. There may be limited disturbance of the riverbed and shoreline during construction, but there is no major excavation required, so these impacts are not likely to be significant.

Endangered species. This is a site-specific issue that we have not encountered at any of our job sites to date. The presence of endangered species is something that needs to be considered on a project-specific basis as part of the siting process. Again, it is less likely to be an issue for this technology because we are siting projects at existing structures.

Zebra mussels. This also is a site specific phenomenon. We did work at one site where zebra mussels were a concern; we used non-metallic trash racks as a mitigation measure, and close monitoring to ensure that zebra mussels do not infest the site. It helps with monitoring that our turbines can be lifted out of the water for maintenance and during flooding.

Water Quality

The problem of low concentrations of dissolved oxygen is a seasonal phenomenon, usually occurring during the summer months during periods of lower flow. Mitigation strategies include use of spillways and air injection, but there is a tradeoff with loss of power generation.

Potential for Oil Spillage

The main potential sources of oil spillage are from bearing lubrication, hydraulic fluid, and transformers. Mitigation strategies include: oil containment in well-defined chambers, use of biodegradable oils (actually esters) but they have application limits, especially in terms of low-temperature use; oil-less designs (greaseless bearings) for wicket gates, which is becoming an industry standard.

Hazards for Navigation and Recreational Vehicles

The main issue for applying HYDROMATRIX in existing structures is the possible effect on the existing flow distribution at the intake and outlet of the powerplant and the consequences on barge traffic and recreational vessels. Further, temporary flow increases during load rejection also have to be taken into consideration.

Flow distribution must be investigated on a site-specific basis using either numerical or physical modeling. Physical modeling of river flow conditions is very costly, but still the commonly used way to assess flow conditions. Mitigation strategies include: evening the flow distribution; locating devices away from locks, designing facilities to allow quick shut-down during load rejection to minimize flow changes, and use of security barriers.

Cultural Aspects

This topic is always site-specific. We have two urban projects – in Vienna and in Minneapolis – where we have to deal with cultural commissions. Potential issues include visual impact in historic areas, and the disturbance of archaeological resources (which has not been a concern at the mentioned locations). Strategies are to minimize the number and size of above-ground structures (or use low-profile structures), and to use a visually non-disruptive design.

Resource Questions Associated with Free-flow Axial Turbines

[2. J.Gibson - Free Flow Axial Turbines Envr Info.pdf]

Jim Gibson, Devine Tarbell & Associates

For this presentation, I will use Verdant Power's Roosevelt Island Tidal Energy (RITE) project as a case study, with an emphasis on the permitting process Verdant had to go through to get this temporary pilot project[10] to where it is now, at Stage II in the FERC licensing process.

- New York State Section 401 / Excavation and Fill
- Department of State Coastal Consistency Review
- New York SEQR and Federal NEPA reviews
- Army Corps of Engineers Section 404 and Section 10 permits

The pilot project installation permitting process has required four public notices, and numerous agency and stakeholder meetings. Verdant Power was asked to respond to comments received from the public and from numerous public agencies (see slide presentation for list of agencies that commented on the study design for the pilot). The focus of these comments, and Verdant's response to them, is summarized below.

Rare, threatened and endangered species. Verdant did research to find a stretch of the East River where NOAA's Marine Fisheries Service (NMFS), Fish and Wildlife Service (US FWS) and New York State Department of Environmental Conservation (DEC) agreed that rare, threatened, or endangered species would not be an issue.

Water quality. We dropped one unit into the river and did sonar imaging of the riverbed, and reached the conclusion (with concurrence of Army Corps of Engineers and New York State) that there was no sediment within the footprint, and that turbidity and disturbance of potential toxins was not going to be a problem.

---

[10] The pilot project consists of 6 16-ft. diameter turbines, rotating at 32 rpm, to be installed on a temporary basis in minimum 32 feet depth of water (5 ft. clearance above and below rotor-swept area) in the East Channel of the East River at Roosevelt Island.

Recreational users and commercial fishermen. This is not a recreational area; the water is moving too swiftly. We did talk with some commercial fishermen, and they agreed that they can live with avoiding the 0.8 acre pilot project area for the duration of the pilot.

Navigation and Security. There are many parties interested in this topic. We have put together a task force (study group?) to study potential impacts during the pilot phase, and to look together at the implications for build out in later phases of deployment.

Temperature changes, leaking oils and fluids, toxicity of anti-fouling measures. We've been able to demonstrate that these do not present problems with this technology.

Demobilization plan. The New York State DEC has written a permit stating that the units will be taken out of the water if certain environmental thresholds are exceeded. The fact that units can be demobilized within 24-48 hours if necessary has helped convince agencies that it's o.k. to go ahead with the pilot project.

Aquatic birds. We have logged hundreds of hours of observation.

Hydrodynamic and hydraulic impacts. We are doing studies to measure water velocity in the channel both before and after installation of the pilot units. This information matters as much to Verdant Power as to anyone; it is in our interest to get good information on how much energy is being taken out of the flow.

Wetland, aesthetic and historical impacts. These issues are grouped together in this list because none pose major concerns for this site.

Bottom scour. We will be looking at this using hydroacoustics.

Construction impacts. This applies to anyone installing any kind of device; we have had to provide a plan showing how the equipment will go into the water.

Fishery impacts. Several concerns have been raised about the potential impact of the technology on fisheries. Specific issues (and Verdant Power's responses) are outlined below.

- Strike probability – This is the biggest issue for a free-standing axial flow machine. We have done a great deal of desktop and probability analysis; based on this, the probability of strike for this installation at this location appears to be less than one percent. However, this is something that we will monitor as we implement the pilot study.

- Sheer stress and behind-the-unit turbulence

- Predation – We don't want to see increased predation as a result of attracting foraging fish

- Impingement, entrainment and cavitation are not a problem.

- Cavitation and pressure changes

We have done four hydroacoustic monitoring studies to establish the pre-development baseline. The plan is to install two of the six units and conduct hydroacoustic monitoring (like "a fish finder on steroids") 24-hours per day for two months, followed by netting. DEC will look at this data, and (provided there is no problem) we will go ahead and deploy the other four units. This kind of continuous monitoring (100% of water column, 24-hours a day continuously over entire 18-month pilot period) is very expensive. We would appreciate input from this group as to how we could get adequate results using sub-sampling.

Resource Questions Associated with Cross-Axis (Helical) Devices

[*See earlier slides:* 6. A. Gorlov Presentation.pdf]

Alexander Gorlov, GCK Technology

People have asked me, does the helical turbine make sushi in the water? And I would have to say no. First of all, because it extracts energy from very large masses of water, it rotates slowly. Second, when the turbine rotates, it develops resistance to water flow because of energy extraction. Fish approaching the turbine avoid it. In the unusual case where a fish does swim through blades, if a blade were to strike a fish, the impact is very low. Salmon swimming up a waterfall survive ten times the pressure. Moreover, on the helical turbine the leading edge of the blades is rounded, not sharp. There are no sharp components that could injure fish.

No one has reported any evidence of fish getting chopped up by any of the turbines where they have been installed and operated (Korea, Long Island, the Amazon, etc.).

The accumulation of seaweed and debris more likely to pose a problem for turbine operation than turbine operation is likely to pose for the environment. When Koreans installed helical turbines, they put mesh screens in front of turbines, then wanted to know why the turbines didn't operate(!)

The question has been posed, what about the extraction of energy? Note that there are many applications for this type of turbine might where there are no fish at all – e.g., discharge tubes. (Charles Bagwell spoke of these in his presentation.) Also in deep waters. Another potential application where there is little likelihood of negative environmental impacts would be for pumping irrigation water. It can be efficient on a small scale, for example, to charge batteries on sailboats.

II. Wave Energy Devices

Resource Questions Associated with a Heave-Surge Device

[3. M.Carcas - Pelamis Envr Concerns.pdf]

Max Carcas, Ocean Power Delivery

This presentation covers the environmental and permitting aspects of siting the Pelamis device.

As a company, Ocean Power Delivery's expertise is in developing, manufacturing and operating wave energy generators rather than project site development or owning power projects; at the same time, we are an environmentally-aware business, and we want to work closely with partners who are good at these other aspects to ensure that we are developing and marketing an environmentally sound technology. We have produced a generic scoping document reviewing environmental impacts and what we are doing to study and mitigate them. (See website: www.oceanpd.com)

Environmental Impact Considerations

Installation. At the European Marine Energy Centre (EMEC), the substation is built right on the coastline at Orkney, but at a larger installation, the substation might be located further inland. There is disruption during cable installation, but (see slide presentation for photos) EMEC has done a good job of restoring the site afterward. The cable is buried along shoreline, then runs along the seabed out (under water) to the mooring site. There are different options for mooring system deployment. All work is done from the back of a boat, using clump weights rather than driven piles to anchor the device.

Acoustic impact. Within the power conversion modules in the joints of the Pelamis machine, there is equipment rotating at 1500 rpm, but within close proximity to the device, wave noise swamps any noise that might be audible from this not particularly loud machinery. We do have to be aware of low frequency vibrations.

Visual impact. The low-profile of the device in the water means that, even though these are quite large pieces of equipment, they are not particularly visible from shore. The other side of this is that we have to take into careful consideration navigation, shipping and spatial requirements – being careful about site selection, ensuring that our locations are well-marked on charts and with navigational markers, etc.

Wave energy abstraction. Looking at the overall footprint of a large ocean energy farm, it might appear to be comparable to a small island. However, it is more like a transparent screen rather than a solid block, because the machines are designed to allow a lot of the wave energy to pass through – particularly during storm conditions. Nevertheless, we feel that it is important to engage with the surfing community, not because we foresee a problem, but to make sure that people are informed and don't get concerned.

Pollution risk. The big sectional tubes don't have any fluids. The hydraulics are located in the power conversion modules at the joints, where we use containment and double and triple sealing to prevent leaks. In the unlikely event of a leak, we use environmentally-benign fluids that are non-toxic to marine organisms and rapidly biodegradable. The entire machine is designed to be seaworthy – this is a requirement we must meet in order to get insurance – the tube sections can still float even if pierced.

Commercial fishing resource. This is something that has to be taken into consideration in site selection. Nevertheless, the sea space required is quite small – about 4-5 times less area than that required for a wind farm of the same electrical output.

Biofouling. Because these devices are designed to move *with* the water rather than *through* the water, the way a ship does, bio-fouling is not a particularly important issue for this type of technology. The mooring yoke may need some anti-fouling measures, however.

Positive Benefits

While we feel it is absolutely critical to get the environmental impact considerations right, it is also important to keep in mind the bigger picture: how wave energy conversion devices compare to the alternatives. Compared with a conventional fossil-fueled generating plant, this technology has the potential to displace 2,000 tons of CO_2 per year per machine (e.g., 80,000 tons/year for a commercial-scale wave farm consisting of 40 machines), in addition to providing other socio-economic and energy supply security benefits.

Resource Questions Associated with Heave (Point-Absorber) Devices

George Taylor, Ocean Power Technologies

[4. G.Taylor - OPT Envr Concerns.pdf]

As I noted in my earlier presentation, Ocean Power Technologies has successfully permitted installations in Hawaii and Australia, both very tourist-conscious and wildlife-rich areas.

Our Hawaiian site is at the Marine Corps Base at Kanehoe Bay, where the Environmental Assessment (EA) Office of Naval Research (ONR) consulted with National Marine Fisheries and USFWS and eventually issued a Finding of No Significant Impact (FONSI). We had to meet with a wide variety of interested parties and meet quite a number of legal requirements for the Hawaii study. (See slide presentation for list.) The FONSI took into account the following:

- No oceanographic condition impact; no affect on wave scattering and energy absorption
- No entanglement issues (once cable is rock-bolted to the sea floor) and minimal entrapment risk
- Unlikely to have adverse impact on marine biological resources: site selected to avoid areas of rich biological diversity and high percentage of coral coverage; unlikely to affect any threatened, endangered, or otherwise protected species; possible beneficial impact on growth of benthic organisms (such as corals) on the subsea cables and anchor
- Minimal impact to shoreline conditions, no alteration to currents or wave directions; no adverse impacts on shoreline erosion or change in sand deposition patterns
- Minor and temporary impact from EMR
- Mild discomfort to marine organisms and divers in unlikely event that damage to cable causes electrical fault
- Noise localized and of short duration during installation; similar acoustic output to that of ship traffic during operation; no adverse acoustic affects likely on humpback whales, dolphins, green sea turtles
- No incompatabilities with land or Marine use.
- No affect on historic or cultural properties (a blessing was done by Native Hawaiians on nearby land-based burial site)
- No impacts on public safety within 500-yd buffer zone; potential impacts to public safety outside the buffer zone – mitigation measures to include appropriate buoy markings; communication measures

We have been able to get commercial insurance for both loss and liability at a reasonable cost. Insurers look at this technology as being similar to a buoy used for navigation purposes.

Alla Weinstein, Aqua Energy

[Weinstein-051027_DOE_HW_workshop_ea.pdf]

In permitting a pilot installation of the AquaBuOY at Makah Bay, we had the benefit of data from predecessor technologies, combined with environmental studies already done at Makah Bay.

Bio-fouling and debris. In six months' testing we have found that bio-fouling is not a big problem for the buoy, but more of an issue for the hose pump. However, what matters is not the outside of the tubing, but the hose pipe inside. There is an inlet valve – US FWS told us we have to control the velocity of water coming in to oscillating device. We use mesh to prevent plankton from being sucked up.

For us there is also the issue of floating logs, of which there are many in the Pacific Northwest. There is not much you can do about that other than to prepare for the possibility of finding and recovering buoys in the event of a catastrophic failure.

Siting. We cannot disturb the beach. In running cable out from the shore, we use a horizontal boring technique. We want to pass the kelp beds and other plant life in the near-shore zone. Sedimentation movement was an issue for us. We lost three buoys within 75 feet of shore because they got buried in sediment. Sediment sampling is necessary for plotting the cable route. Our approach is to bury the cable until we are out past the low tide-line. This also means going further out (beyond where there is a lot of sediment) to moor, but on the positive side, there is less marine life to worry about out there.

Acoustics. In the Pacific Northwest, gray whales and other migratory sea mammal impacts had to be considered. Noise and acoustic impacts are an issue for these species, but our device is not above the ambient ocean noise, so that was not a problem.

Licensing process. We started by going to the Washington State Permit Assistance Center, then we went to file a declaration with FERC, which led to a public comment period. FERC granted us the opportunity to go through an alternative licensing process. This means that the developer becomes responsible for the process. If the developer can get all the resource agencies together and get consensus from them, the developer can get a licensing permit from FERC 12 months after completion of the environmental assessment.

We had two public hearings, one in Makah Bay and the other was in Port Angeles, a larger population center. The main source of comments was from the surf-rider association; once they learned more about the project, they agreed that it was a good one. Overall, people did not object to the test project itself, but expressed concerned about what happens when you put 70 or 80 buoys there. Obviously, we have to do an environmental impact statement before we can go to a 15 MW project, but we won't be able to do an EIS until we gather the data from the test project.

In the State of Washington there is something called the Joint Aquatic Resource Permit Application (JARPA). This comprises the Section 404/Section 10 Permit (US Army Corps of

Engineers); a Hydraulic Project Approval from the Washington State Department of Fish and Wildlife; and, an Aquatic Lands Use Authorization from the Washington Department of Natural Resources. Because we are working on Indian land, we don't really have to get state permits, only tribal permits and federal permits: Olympic Coast National Marine Sanctuary Permit; US FWS review; an archaeological evaluation (Makah Tribal Council); and an Aid to Navigation Permit from the US Coast Guard.

III. Oscillating Water Column Devices

Resource Questions Associated with an Oscillating Water Column

[No slides with this presentation]

Cynthia Rudge, Energetech

Energetech's experience with the permitting process was fairly straightforward in Australia, where the device was issued the equivalent of a FONSI by the Department of Land and Water Conservation. For the Greenwave project in Rhode Island, we began by studying the Coastal Resource Management Commission (CRMC)'s requirements. After consulting with them, we developed four areas of study[11]:

1. *Bathymetric and benthic characterizations.* CRMC agreed that our environmental consultants (who are based in Naragansett, Rhode Island, working with the University of Rhode Island) would look at the geology of the seabed and water quality issues. Permitting requires a water quality certificate, which entails consideration of water transport, sediment, and turbidity, as well as the structure of the currents and nutrient concentrations. We will be looking at the abundance of lobsters and crabs.
2. *Fish & wildlife characterizations.* We consulted with US FWS regarding vegetation, species of birds, fish, and pellagic species; at the moment we don't believe there are any threatened or endangered species in this site.
3. *Human use* and
4. *Navigation and safety issues.* Energetech has hired a "conflict of use" consultant to investigate human use issues.

We also had to consider issues associated with the cable landfall and on-land infrastructure. So far we have received every indication from regulators that we are looking at the right things, doing appropriate characterizations and getting the necessary baseline information, so that we will be able to understand what effects the pilot may have on the environment once it is installed.

[11] Our environmental study is scheduled to be completed by the end of 2005.

Discussion Summaries

Two general themes emerged from the discussions that took place on Days 2 and 3, following presentations on the environmental questions and concerns raised by the deployment of hydrokinetic and wave technologies in the various water resource areas. The first theme reflected on the environmental questions that need to be addressed – particularly as development moves towards full-scale build-out – and on the kinds of research needed to estimate impacts and develop mitigation strategies. The second theme focused more on strategic questions – i.e., how should such research be organized, funded, and integrated into the licensing/permitting process. Discussion pertaining to the first theme is summarized here, followed by a summary list of research topics and questions proposed by workshop participants. Discussion pertaining to the second theme (*Strategic Questions about How to Address Environmental Research Needs*) concludes this section, leading into the final section, which summarizes presentations about *Research Approaches and Models for Collaboration*.

First Discussion Theme:

Preliminary Thoughts on Environmental Questions Posed by Development of Hydrokinetic and Wave Technologies

Significance of the difference between pilot-scale and full-scale build-out

- There is a major difference between small demo project and a full-scale build-out, as far as environmental impacts are concerned. We need to be very clear which mode we are talking about, because impact information needed for a demo or pilot project may not translate into the information needed for the full-scale build-out.
- [*Facilitator*]: As someone remarked, these hydrokinetic and wave devices are "where wind was ten years ago." People wouldn't be here if they didn't envision an eventual full-scale build-out. Given that we need to do demo or small installations first, how can we look at the micro impact, then try to figure out from that what might be the impacts of macro-scale build out?
- A demonstration project is used to test the technology, how it works in the field. But environmental impacts from a small-scale demo are necessarily different from the impacts of a full-scale project, and not necessarily extrapolatable.
- [*Facilitator*]: In this case "pilot" or "demonstration" projects are being used to test both the technology and the impacts. But you are saying that small-scale project impacts are different from those of a full-scale project, much less multiple large-scale projects.
- At the European Marine Energy Centre (EMEC), we're testing a number of different technologies in the same area, so in addition to monitoring the environmental impacts of these individual devices, we have a chance to do common monitoring, to look at issues and impacts as we build up a number of devices in one ecological area (Orkney). This gives us an opportunity to see how the impacts scale up as multiple projects are deployed. Note that we're just focusing on tidal stream and wave energy conversion devices deployed in an open ocean environment. (We don't distinguish near- and off-shore.)

- Modeling is critical. Even if you have a device in the water and don't see any interaction when you monitor it, have to use modeling to think about implications of larger scale.

Adaptive Management Concept

- Because there aren't baseline data available, there has to be site-specific testing of prototypes. There has to be a conversation among developers and agencies about how to test the feasibility of a project, including the environmental consequences. There are ways to adapt projects to mitigate effects. So the first question is dealing with prototypes. Then you can take the next step of talking about how you go to the next level using an adaptive management approach, including more on-the-ground testing as you scale up (as Tina Swanson described [during the Q&A session following her presentation on estuaries]).
- From the resource agencies' perspective, the key to getting approval for trial and testing in the field is knowing that there is a disassembly plan in the event that a project crosses certain thresholds (of environmental or other impact) as you build out. Willingness on the part of developers to adopt a phased approach is very important.
- That is the approach that Verdant Power has taken with its Roosevelt Island Tidal Energy (RITE) project in the East River. Verdant sat down with NY DEC, and worked out an agreement. Part of the settlement was to come up with an adaptive management strategy, with incremental build-up. It is very encouraging to hear both FWS and FERC say that they are o.k. with this approach.
- In the UK, projects go through the permitting process as either "commercial" or "pre-commercial," with "pre-commercial" projects being given different sort of permitting considerations, in conjunction with a closely defined monitoring program.
- The end-game is that we do full-size projects. Getting baseline data, testing prototypes – these steps are all part of the normal development process. We need to approach this from the perspective of "What do we need to achieve ultimate goal of full-size projects?" It's inherent that there will need to be adjustments along the way. Some questions can be answered on a generic basis, others will need to be site-specific.
- The baseline data needed to get to a prototype stage may be different than what's needed to go to the full-scale installation.
- [*Facilitator*]: The question is, are there generic research tasks that can be done that can help facilitate the site-specific testing? What kind of baseline data are needed to ultimately conduct full-scale projects? You start with testing prototypes, some or all of which may go on to scale up. Is all the research site-specific, or is there any generic information that could be useful?
- We need to know about how the technologies operate in the environment to be able to make more definitive permitting decisions, focus the regulatory process. There are major general (not just site-specific) gaps that need to be filled.

What are the key strategic resource questions?

- Developers are clear about site-specific issues, but the resource managers are not going to relinquish their responsibility for those site-specific issues. I see two different “platforms”: developers need to know how they can take the risk out of their investment, but resource managers need to reduce risk for the resource. What can DOE do for us?
- Tell us (DOE) what we can do for you. What are the resource / development questions we can help developers as a group help answer. Help us define a research plan. DOE wants a clear sign: here are the ten top questions that a DOE research program could answer.
- Look at Aqua Energy’s and Verdant’s environmental assessments (EAs). We probably have answers to 90% of the questions the resource agencies wanted to know, and a lot of that came from existing studies. The DOE labs should identify the gaps in the individual EAs and look to answer those questions, to fill in those gaps on the generic level. The top two questions that Marine and Fisheries and other agencies asked concerned:
  - Impact on the ocean floor
  - Biofouling
- When looking at issues at a specific site, it is important to then make those data public. This can help jump-start other projects at other sites.
- When DOE first sat down to plan this meeting, we were hoping product of this workshop would be a research plan. If we have $X million, what research do we want to do, what’s going to give us the biggest bang for whatever bucks we can get?
- If you have $X million, focus on the “strategic” research questions – the larger issues that effect the entire industry:), not just one technology or site or another. For example:
  - How much energy can we extract from wave and tidal systems before you make a radical change? (This is an issue UK government is putting research funding into.)
  - What are the impacts of laying cables, and of deploying mooring structures on the seabed?
- What kinds of characteristics and variables do we need to look at to assess cumulative and population impacts?
- We do have to look at cumulative impacts. We also need to define the boundaries for the zone of impact. How far from a project footprint do you have to look when you’re looking for impacts?
- Yes. When monitoring for fish strike, for example, the “footprint” for monitoring around the “strike zone” in an ocean is very big.
- Add to those questions: What length of monitoring is appropriate? What would be reasonable amount of time to do a study (for a given issue)?
- It would also be helpful to develop species sensitivity indices: which species are (for whatever characteristics – status, habitat needs, vulnerability to certain types of technologies) more sensitive to impacts.

- There is tremendous diversity among the devices, but there are two broad categories: surface (buoy) and in-stream turbines. These are the kinds of things that lend themselves to generic study. So, for example, surface-based technologies in the ocean suggest one set of questions: e.g., issues with surface-migrating mammals. With axial or helical turbines (including the Open Hydro propeller), fish strike is an obvious example.
- Consider experimental options when looking at ways to answer the big-picture/generic questions. With respect to impacts on habitat, consider modeling techniques.
- No matter how much generic information you come up with, there still will be site-specific studies that need to be done, and this is going to be costly. Need to look not just at a "strike zone," but more broadly at where fish are moving with respect to a particular project.
- Yes, we need to look at fish migration, pattern changes, up as well as downstream. I like the idea of field-testing – setting up experiments to find out what we might expect to find with a deployment. What happens in a penned area when you scare fish using a startle response – how do they move with respect to the device? Do they go around? Are there strikes? If we can set up some controlled experiments, that would be useful.
- From the perspective as a global developer of sustainable energy, about 60% of our costs are deployment and retrieval – how can we test the impact of various new deployment and retrieval techniques quickly, given the environmental issues that have been raised?

How to synthesize what is already known? Suggestion made to develop a generic table of potential impacts from various technologies in various resource settings.

- What does this list of generic research issues get you? How much of a resource is this to developers when they go to try to permit a site-specific project?
- No matter what happens with regard to project, when you have to go through a NEPA process, have to go through a lot of this research (sensitive species, cumulative impacts, etc) on a site-specific basis.
- We have no baseline with a new technology. Extrapolating from one site to another is always an issue, but knowing that this set of technologies have (or don't have) a certain set of expected/not expected effects. I'd like to see a table that gives some idea of that for these technologies – from pilot to build-out, construction and operation.
- [*Facilitator*]: One of the things we developed (credit to Doug Hall) in preparation for this workshop was to try to create such a table. It may be that filling out such a table is a research project of itself.
- Ocean Power Delivery (OPD) did a generic environmental scoping document in conjunction with an environmental consulting agency: we created a table of issues, how you mitigate them, etc. But it has to be done independently to have credibility. www.oceanpol.com
- Yes. Rather than start from scratch, it would be useful to start by looking at what has been done. WaveDragon has an interesting chart on their website [www.wavedragon.com], for example. Other sites include [OPD's] piece [www.oceanpol.com], EPRI's website [www.epri.com/oceanenergy/]

- EMEC's spent time thinking about environmental impact guidance for developers. We have a document that goes through all the issues associated with the various technologies. [See Appendix D: PO4-037-022 Final EMEC EIA Procedure.pdf.]
- Part of the challenge is knowing what environmental impact information is needed.
- We think of ourselves as a global developer of sustainable energy. We look first for viable technologies, then work closely with regulators and NGOs to expedite our site analyses. We look to you to tell us "where the dragons are."

How to apply what is already known to what we want to find out (e.g., fish strike)?

- A lot of this discussion assumes that we don't know anything. But no, there is a lot that is known about all of these things. The information exists within the DOE Hydropower Program, hydropower re-licensing, thermal power plant re-licensing, nuclear power plant re-licensing. For example, fish strike, DOE has made tremendous advances in understanding fish strike.
- Sure. The tools and the whole approach we developed for advanced hydropower program with fish strike are applicable here, including experimental design to identify thresholds of no effect – of, say, shear, pressure, all the physical stresses associated with the technology. It involved computational modeling of the field of effect, also field studies – all this is very applicable to in-stream turbines.
- [*Facilitator*]: So, we would have to figure out whether it is directly applicable or, if not, what would be the next step.
- Open Hydro uses a propeller technology, so fish strike is the obvious question. We have stacks and stacks of literature from DOE, but the DOE info was about high head dams where fish have no choice, when we started dealing with FERC, they accepted the limitations of the existing information; they told us to go ahead and put one machine in the ocean and monitor it. (Open Hydro was able to arrange with the Discovery Channel to video monitor the device, and with the Navy to do sonar studies.) And then we'll see what we need to do.
- [*Facilitator*]: One task is to take what we know and figure out what applies, and then figure out what next.
- What if we were to take a "representative" project at a "representative" site? We could research the impacts, monitor. We've studied fish strike at advanced hydropower. We could study something like that: fish strike (for example) at a hydrokinetic installation.

Mapping domains appropriate for development

- It is extremely costly for developers to have to assess both the wave and tidal energy resource and the marine/river habitat sensitivity. One area where a government or joint research would be helpful is in determining:
  - Where are the protected areas?
  - Where are the areas of the ocean that, because of their energy resource and environment characteristics are most appropriate for development for a given technology?

- Yes – nothing helps policymakers more than a pretty graphic. EPRI has done some mapping of wave energy resource. It would be helpful to identify sensitive habitat areas to avoid.
- [*Facilitator*]: Is this kind of mapping happening?
  - MMS and NOAA are going to do [this kind of mapping].
  - A lot of this has been done in places. Oregon has a lot of this – designation of sensitive zones, lists of species of concern, etc. Anyone looking to do this kind of mapping should look at what information has already been developed.
- This conversation is very familiar from siting power plants in the 1980s. State and federal agencies went through and identified places in each state that were o.k. and not o.k. to develop terrestrial power plants. Included all the resources, including where were loads, what T&D, as well as environmental characteristics. Deregulation and restructuring may have eliminated this process, but we could look at how this was approached on land and use the same approach to identifying hydrokinetic technology development areas. Start with the end in mind: we want to end up with a set of domains where these technologies should be developed; work back from there to what you need.
- [*Facilitator*]: We did try to get some state regulators here, but were not successful. Should this question be addressed on a state-specific basis?
  - The State of Texas has asserted a role. Other coastal states. Point is there are documented methodologies for making these decisions.
  - Bob Thresher (NREL) and EPRI have been working with state agencies for two years to identify good wave energy sites for several states – we have received funding from state energy agencies (AL, CA, HI, OR, WA, MA, and ME etc.) EPRI's website has site survey and wave characterization reports for each of those sites [www.epri.com/oceanenergy/]. The Wave Feasibility Project looked at a dozen or more different attributes of sites (at 60-m depth), including wave energy, geophysical properties of subsite, T&D, etc. We looked at general environmental issues.
  - Were these reports coordinated with coastal zone management? You could "narrow the box" (or domain) by adding the coastal zone management layer on.
  - No. EPRI was only doing Phase I definition studies. If there's interest in a next phase, that would be permitting, then phase III would get into design and construction issues.
- DOE has done a resource potential assessment for rivers[12] – do we need to do it for ocean energy as well? The states have some of this, EPRI has some of that information.

Where should resource agencies focus their own limited resources?

- Does this argue for a sort of programmatic EIS? When I want to figure out where to invest my energy, I try to focus on areas where the resource is greatest and risks appear to be lowest, so that site-specific analysis doesn't have to go as deep.

---

[12] http://hydro2.inel.gov/resourceassessment/pdfs/03-11111.pdf

- My hypothesis is we're going to see lower impacts from wave generators than from near-shore and in-stream generators. From a resource standpoint, I would think you'd want to focus on the technologies with the smallest impacts within any given environment. I would like to know more about that – for example, does the helical turbine have lower impact than axial turbines?
- [*Facilitator*]: Jan has just articulated a policy-level question – these kinds of questions are useful for us all to hear at this point.
- It seems pretty clear that upstream venues are not going to see large-scale deployment of most of these technologies. Even [Verdant's axial turbine project in the East River] is a downstream/ tidal project.
- From an agency perspective, I need to know how big an issue is in the scheme of things before I can budget my resources.
- One role that agencies can play to move things in a positive direction: DOE and MMS are going to have to deal with a variety of marine resource development questions (LNG, hydrokinetic and wave technologies, aquaculture, etc.). Many of the questions will be the same: the agencies can start taking a look ahead of time at what resources are there and where they may be sensitive. What animals are there, what vegetation, what's in the benthos. Put this information together. Putting this picture together will be of value to more than just hydrokinetic energy industry.

What existing information needs to be synthesized?

- AquaEnergy took EPRI's report and followed-up, filling in additional details needed for the site-specific Environmental Assessment. We went back to the state agencies to make sure we were covering the information that they needed.
- It is well worth looking at the EPRI website. It gives us something to build upon.
- Along the lines of making use of information that has been produced by others – there is an environmental assessment that was done by Wales – provides a really good matrix of impacts of wave, tide and wind projects.[13]

---

[13] http://www.ccw.gov.uk/reports/index.cfm?Action=ViewRecent&lang=en

Summary List of Research Topics for Hydrokinetic and Wave Technologies

At the beginning of Day 3, the Facilitator distributed a list of issues and research questions compiled from notes made by participants during Days 1 and 2. Workshop participants did not attempt to reach consensus about which items should be included in the list, nor on their priority. A summary of the research topics suggested by participants is presented here; the complete list, organized by topic after the workshop was adjourned, is included as Appendix A.

Research and development is needed to evaluate:

- **The environmental impacts of various technology-resource site combinations using a standardized set of measures including:**
  - Cumulative and synergistic effects of multiple installations
  - Effects on all resources that might be impacted (including aesthetics and recreation)
  - Effects on/of future freshwater flow/sea level conditions
  - Consequences of accidents and equipment failures
  - Possible mitigation strategies
  - Appropriate monitoring

- **Water energy resources including:**
  - Locations of applicable resources and estimation of their gross power potential
  - Evaluation of applicable resources regarding the feasibility of their development and estimation of their true power potential

- **The long term reliability and susceptibility to damage of the various technologies within various resource settings**

- **The effect of power generating equipment and their mooring systems on stream bed or sea floor, and shoreline including effects on:**
  - Sediment and contaminant transport, deposition and re-suspension
  - Long-term scour from slack lines
  - Alteration of shoreline and shallow water processes
  - Alteration of benthic habitats and the consequent effects on bottom-dwelling animals

- **The effects of technologies (individual units and mass deployment) on resource hydraulics and the resulting impacts to open water habitats including:**
  - Local small-scale effects
  - Alteration of current patterns
  - Alteration of other large-scale effects including hydrological regimes
  - Effect on sediment dynamics

- Turbidity
- Effect on habitats for aquatic organisms

- **The electromagnetic fields produced by these new technologies as well as the impacts to migratory and resident aquatic organisms**

- **The toxicity of paints, hydraulic fluids, and chemicals used to control biofouling**

- **The risk and consequences of strike by moving structures and impingement on screens for aquatic organisms and diving birds and mammals**

- **The noise impacts of technologies including:**
  - Source characteristics (generating hardware and operations, frequencies, sound levels, and audible range)
  - Effects on biota

- **Impacts on drifting and actively migrating fish, benthic fish and invertebrates, aquatic mammals and turtles, diving birds, shore birds, and aquatic vegetation resulting from:**
  - Creation of damaging pressures and shear
  - Creation of physical barriers to movement/migration
  - Attraction to structures
  - Degradation of pelagic and benthic habitats
  - Entanglement in cables

Second Discussion Theme:

Strategies for Addressing Environmental Research Needs

Need for leadership

- What's missing is some sort of leadership role. As a developer, we're always reporting to this agency, then being told that someone else is taking the lead; first we're dealing with FERC, now we're going to be working with MMS – who do we go to? What hoops do we have to jump through? Who is going to be the umbrella/lead agency.
- There is no one agency that's taking the lead; we have no national policy. Jurisdictional issues, zoning problems – if you're close to shore, have to deal with the states. It's hard to say what the R&D priorities are is when we have no national policy.
- [*Facilitator*]: There really are two questions you are raising here: 1) How does this group want to organize itself to move forward? 2) What is the regulatory structure that we have to deal with?
- There are places to deal with all the environmental issues – NMS, NOAA. What we came here for is to somehow simplify this process, the structure, what role people will play.
- MMS does not intend to entertain any applications for stuff on ocean bottom until they complete their rulemaking process (beginning December 2005?)
  - So what happens to applications that are in progress with FERC? Do they stay with FERC or move over to MMS?

- We [Open Hydro] were told that we would probably stay with FERC for projects already in progress, but that new projects will go thru MMS.

  - MMS isn't even going to entertain putting up met towers until rulemaking is done.

- Does our national government want this kind of technology to move forward? Historically, that's how energy technologies have moved forward. We have to ask the government to make an investment for an expected return. In the early days of hydropower – or any other technology – there were policies put in place. (And yes, the funding has to include a budget that enables the resource agencies to participate.)
- The resource agencies are underfunded, understaffed, with an important job to do.

Need for a common language: how to synthesize the information we have (or will be collecting)?

- The EIA guidance document from EMEC is helpful for synthesizing the questions raised here.
- [*Facilitator*]: Question for resource agency representatives - Are the questions posed in EMEC's EIA Guidance key issues section the ones that you would ask, and if not, what would you include? In the UK, they've worked out a way to test projects and get some of the

environmental questions answered so that projects can go forward. Does something similar make sense in the US? Getting back to the compilation of questions/topics workshop participants submitted – are these the issues, or are there others?

- Given the diversity of technologies out there, it's important not just to identify generic questions we want to ask, but also to make sure that when we ask questions about specific technologies, we ask them in common terms. That way, as we gather data, we can build a base of knowledge – and we can begin to identify which among these technologies has the least environmental impacts (as well as the greatest efficiency of energy extraction, etc.).
- Communication and collaboration are important for the industry as a whole, but specifically for regulators and resource agencies. The more we understand each others' language, the more we can learn what we need to know together – not have different agencies asking the same questions in different terms and making companies jump through so many hoops.

Importance of collaborating to identify research priorities and lobby for funding

- Regulatory agencies just oversee getting answers to questions that the environmental community wants to know…
- If this is going to go forward, we have to recognize that DOE isn't going to have capacity to do any R&D in the short term – but bringing people together here is the first step in forming coalitions that can get funding for R&D in the future.
- The best licensing in traditional hydro comes out of collaborative efforts to educate people about the impacts of these technologies, to determine what research needs to be done.
- At least there is more awareness now. [This type of workshop] is not going to help us developers to move things forward as quickly as we would like to. The reality is that it is going to be 3-5 years. But collaborative efforts to educate each other and determine what research needs doing is a step in the right direction.
- The wider question for DOE is the strategic one: what's the size of the energy resource we're talking about, and what kind of investment and technical R&D are called for?
- The money for research comes from states, non-profits, etc. To get the money to do the research, we need to come up with a concrete list of things we want to see done.
- Rather than funding the national labs to do research, why not have a mechanism to channel money to the people who want to test devices. There are models for doing this, involving resource agencies and NGOs in research plans.
- There are two different ways to approach this. Individual developers and some others are suggesting a bottom-up approach of funding individual projects and trying to extrapolate the information. I'd suggest the opposite, a coalition to address the big-picture questions, such as:
  - What is the resource and its potential? (This may be key to getting public funds.)
  - In an underwater axial turbine, what is the zone of influence?

- How do you scale that up, get the big questions answered broadly, and then apply those answers broadly.

- [*Facilitator*]: I'm not sure you're going to get the macro-level funding for what you're talking about. But it may not be a case of either-or. May need to do some of both: fund and gather information on individual demonstration projects, but then try to develop support for synthesizing what you learn from those projects, pulling the information together to see what larger questions you can answer, what other work you need to do to fill in the gaps.
- Just having all these people in one place, meeting each other face to face, is a good thing.

How do we organize to move forward?

- I don't sense that people here want to get together the way I've seen happen in some other sectors. Consider liquid natural gas (LNG) There are now 48 LNG facilities in operation. In the LNG arena we didn't have a list of questions as good as what John [Griffiths, EMEC] has shown us. Yet we see Shell doing work to test, adapt, and monitor one LNG facility that will yield information that will apply to a lot of other companies. Adaptive Management has to be part of the mantra.
  - Verdant is doing something involving an adaptive management approach.
  - But without a budget like Shell has!
  - Yes, but wind isn't Shell either. So how are you financing it?
  - Mostly from our own personal pockets. The investment community is interested, but they want to see things in the water. Seven million dollars have come from NYSERDA. The DOE labs have helped a great deal with R&D, gathering information that we can all use.
- Hydrokinetic technologies are in a very similar situation to where wind was 10-15 years ago: small, under-capitalized. Collaboration and having a national program was important for wind energy. Maybe this industry should consider working with other industries that are working in the same environment, dealing with similar problems. Consider the aquaculture matrix at NOAA – likewise a new industry, with three demo projects.
- Knowledge is power. One thing to walk away from this meeting with is how do we continue to foster international collaboration?

Research Approaches and Models for Collaboration

Four presentations were made addressing the question of how research necessary to address the environmental questions raised by these hydrokinetic and wave technologies is being or might be carried out. On Day 2, John Griffiths presented the European Marine Energy Centre (EMEC). On Day 3, Roger Bedard presented Electric Power Research Institute (EPRI)'s Ocean Energy Program. (Note that the presentations are summarized here in agenda order, so that Griffiths' presentation follows Bedard's rather than preceding it.) Ken Rhinefrank of Oregon State University's School of Electrical Engineering and Computer Science presented a proposal for a US Marine Energy Center, and Kit Kennedy of the National Resources Defense Council (NRDC) presented an NGO perspective on renewable energy development. This session was followed by a discussion of Next Steps.

Electric Power Research Institute (EPRI)'s Ocean Energy Research Program

[1. R.Bedard EPRI Future.pdf]

Roger Bedard, EPRI

The diversity of energy sources is the foundation of a reliable electrical system. North America has significant wave and tidal in-stream energy resources, and the technologies to harness those resources are becoming available. According to EPRI's calculations, the annual average incident wave energy (not tidal, not in-stream, just wave energy) at the US coastline at a 60 m depth is equal to 2,100 Terawatt hours per year. More than half of that is located off the coast of Alaska. Harnessing just 20% of that total at 50% capacity would be comparable to all of our conventional hydropower, currently 7% of total US electricity consumption.

A resource comparison of solar concentrating power v. wind v. wave v. tidal current resources tells us that the power or energy density of wave and tidal is significantly more than it is for solar or wind. This means that the devices can be smaller, and therefore lighter weight and (assuming it is built of similar materials) less expensive to build. From a predictability standpoint, this makes it easier to integrate into the grid and provides additional capacity value (not capacity *factor*, but capacity *value*).

We think it's important to put things in the water and test them, not only from the technological and investor/insurer perspectives, but also from an environmental perspective.

Our approach is to be inclusive as possible, to facilitate a public-private collaborative partnership among coastal states, involving state agencies, utilities, technology developers, research institutions and other interested third parties, and the US DOE. We recognized that US DOE was not going to be able to fund this, so we sought other funding, mostly from nine state and (and city) agencies, and in-kind resources from (currently 30) wave and tidal development companies, DOE, and utilities, which are working with us primarily on grid interconnection.

EPRI began in 2003 by getting commitments from ocean states and from DOE (NREL) to do a techno-economic feasibility study. Beginning in 2004 with the Offshore Wave Energy Conversion (OWEC) project, EPRI has launched a series of strategic projects to evaluate the current state and future prospects of ocean energy technologies, with the aim of identifying where commercial wave energy installations may be cost-competitive with current land-based wind capacity once the technology reaches a cumulative production volume of 10-20,000 MW. In 2005, we launched the Tidal In-Stream Energy Conversion (TISEC) project, and in 2006 we will launch a third project to evaluate Hybrid Offshore Wind-Wave Energy Conversion (HOW-WEC). To date we have 17 feasibility reports on our website: www.epri.com/oceanenergy/.

Our objective is to demonstrate the feasibility of wave power to provide efficient, reliable, environmentally friendly and cost-effective electrical energy. Both OWEC and TISEC have completed Phase 1, project definition and pre-implementation planning: this includes both technology assessment and site assessment, and the selection of site and technology combinations. We design a pilot plant, looking for ways to make that plant as inexpensive as possible to build, and then we design a commercial-scale plant, estimating yearly performance, levelized cost, and cost-of-electricity for a utility generator and internal rate of return for a non-utility generator, and compare the economics with energy alternatives. One of the sites we have identified as part of the Phase I project definition for a pilot and commercial wave power plant is in an exclusionary zone from the National Marine Sanctuary in San Francisco Bay. Because of its exclusionary status, we expect it to be easier to permit, and the project will benefit from the existence of ongoing environmental monitoring, and from existing infrastructure at the Hunter's Point Naval Shipyard. (See slide presentation for maps and diagrams.)

We are now ready to hand off the OWEC effort to our partners for Phase 2: design, permitting and financing. (Phase 3 will be building a demonstration project, and Phase 4 is testing.) For Phase 2, we are looking at five wave energy projects for the US. a pilot project in the marine sanctuary (exclusionary zone) in San Francisco Bay. The City of SF has been doing environmental monitoring for many years already.

OWEC Phase 1 – Conclusions and Recommendations

In 2004, our accomplishments included: developing standardized methodologies for estimating power production and performing economic assessments; surveying and characterizing potential North American wave farm sites; establishing five conceptual designs for pilot and commercial-sized wave energy plants; and performing an independent cost and economic assessment for the commercial-scale plants. We found good to excellent wave energy climates in all of the coastal states we looked at except Maine. Our studies made a compelling case for investing in RD&D to answer a host of application questions, as outlined in EPRI Report 009-WP-US Mar 2005. (See slide presentation for detailed list of application questions.)

EPRI made eight recommendations for the Federal government to support RD&D:

- Leadership for a national ocean energy program
- Operating a national offshore ocean energy test facility
- Development of standards

– Joining the IEA Ocean Energy Program (US DOE is now a paying participant in the IEA)
– Leadership in the streamlining of permitting processes, particularly for small, short-term feasibility demonstrations
– Studying provisions for incentives and subsidies
– Ensuring that the public receives a fair return from the use of the ocean energy resource
– Ensuring that development rights are allocated through a fair and transparent process taking into account state, local and public concerns.

The last two points pertain to MMS' role in ensuring fair public return and fair, transparent public processes.

There are five wave energy projects on the drawing boards, including the Ocean Power Tech (Power Buoy) project at Kanehoe in Hawaii, the AquaEnergy (Aqua BuOY) project at Makah Bay in Washington State, the Energetech oscillating water column project at Point Judith in Rhode Island, San Francisco PUC (quote requested from Ocean Power Delivery for a Pelamis unit); and Oregon State University (see summary of Ken Rhinefrank's presentation, below).

Tidal energy sites that have joined the EPRI Collaborative include Nova Scotia, New Brunswick, Maine (Eastport Western Passage), Massachusetts (Cape Cod Canal), Delaware (Indian River inlet), San Francisco Bay (Golden Gate entrance, just west of the bridge and south of the navigation lane), Washington (Tacoma Narrows in Puget Sound), and Alaska (Cook Inlet). Vancouver, BC has its own program (Clean Currents).

All EPRI Ocean Energy Program technical work is transparent and available to the public. Project reports are available at www.epri.com/oceanenergy/. To receive monthly progress reports, contact Roger Bedard: rbedard@epri.com.

European Marine Energy Centre (EMEC)

[2. J.Griffiths EMEC Overview.pdf], [PO4-037-002 Final EMEC EIA procedure.pdf]

John Griffiths, EMEC

John Griffiths is the Technical Director of EMEC Ltd., the European Marine Energy Centre, located at Orkney in the North Sea. He described the EMEC facility and its role in building a new industry.

EMEC is an independent test center for marine energy technologies. Why test independently? We are trying to build a new industry. Even if there was no global warming, global dimming, or ocean acidification, we would still want to pursue marine energy renewables. What do we need? We need technology that works; we need investors and insurers to pay for these technologies. We need credibility. To get these things, we need independent test results.

EMEC is independent, not allied with any developer. We are accredited by the UK Accreditation Service (ISO 17025). EMEC was set up as a "Centre of Excellence" (a facility to build skills and know-how, set governance standards) to stimulate the industry, encourage standards and recommended practices, foster and initiate R&D projects. We are funded entirely by public bodies.

The Test-Site Facility

We are located at Billia Croo Bay in Orkney, at the northernmost point of Great Britain. The site has four berths connected to shore by four cables (about 2 km long). The ends of the cables are separated by about half a kilometer; the idea being that a device in one berth operates as if there were no other devices operating in the vicinity.

We monitor the sea state with wave-rider buoys, providing continuous wave statistics via VHS radio. These give us all the statistics for the wave scatter diagram, and for calculating wave energy. The large, double-armed cables are capable of handling 2.3 MW capacity at 11 kV. There are optical fibers in them for video communication. At the substation on-shore, we communicate back to data center in Strom Ness nearby. We have a capacity there for a total of 7 MW.

In addition to the wave site there is also a tidal site on Island of Eday. The Fall of Warness has an 8-knot current. Capital cost for construction of both the wave and tidal sites was in the range of ₤12-13 million, for a total generation capability up to 11 MW. Operating costs are about 8% of capital costs.

A number of factors have had to be taken into account in constructing these facilities. The beach is of special interest, so we had to do restoration after laying the onshore cable. The sandstone is of great geological interest, so when we drilled into the cliff to hide the cable, we had to have a geologist on site. There are also many archaeological remains on Orkney (5,000 year-old remains), so we had to have archaeologists standing by as well. Construction has to be tough – we used pre-stressed concrete – as there are boulders flung in by the sea during winter.

Surveys and studies were completed for the site in October 2001. The main design-build contract was let in May 2002, and we were ready to accept our first wave device in October of 2003. The tidal site got the go-ahead in May 2005, and we expect it will be ready to accept its first device in April 2006.

We've been doing six months of environmental monitoring for marine mammals: harbor seal, grey seal, harbor porpoise, Minke whale, white-beaked dolphin, and other (unknown) seal species. Sightings are done in three-hour stints, twice a day, on designated days. The observer notes the species and marks its location on a grid.

Organization chart – our board has grown, because of the importance of showing good governance; we have a new Board Chair. Our staff has just doubled. A number of services, including HV electrical, QA management and others are contracted out. We use a SCADA system to alert on-duty staff if there are any operational problems.

Funding comes from: Highlands and Islands Enterprises, Scottish Executive, DTI, Scottish Enterprise, the European Union, the Orkney Islands Council, and the Carbon Trust.

Getting Devices Commercial

The first step for any new or unproven technology is qualification. With a new piece of technology such as AquaBuOY's Hose-Pump, there is no established standard to describe how it should be built, so they have to go through independent testing to qualify that piece of the device. Verification is the development of the qualification process to verify the key parameters of a specific device. Once the design, manufacture, testing and final product evaluation is recognized to accepted industry standards, then a device can be certified. EMEC plays a role in verifying performance, and in certification. Standards provide a framework for development of industry requirements, which in turn will allow global opening of the market.

Open Sea Wave Test Standard. We have written a draft, which allows people to go through a process for testing site/facility including key performance parameters, how and what to measure, how to test and report findings, including any deviation from the recommended standard. The standard also lists the uncertainties involved in calculating performance. Eventually, we hope to be able to help developers certify their devices for environmental standards as well as for performance standards.

<u>*Question and Answer, Observations Following EMEC Presentation*</u>

Comment: I would like to hear more about whether there's a possibility of the US government developing or supporting development of an EMEC-type facility? That would be ideal for everyone. Developers could get their demo projects out in the water at a site that has been identified, and the developer could focus on answering site-specific questions without having to get all the demonstration permits.[14]

Comment: It is important to be clear about what EMEC does and what it doesn't do. It cost $26 million just to build the facility. It costs the developer ₤1 million just to put a device into the water at EMEC to do testing. Then we need to test the device at the site selected for development, because our devices have to be designed for a specific site. We need assistance to support device testing – developers can't absorb all those costs.

Response: You would have to spend far more to do on your own what you can do at EMEC, where you have the infrastructure, you have the background information that we have developed for the site. It's cost-effective for government to give developers money to do testing. It took four years, but UK now includes testing costs as part of government R&D grants.

Facilitator: This presentation raises two sets of questions. First, Does it make sense for US to replicate what EMEC is doing? And if so, what can be done for small developers who can't afford to pay operating costs to test their equipment, even if someone else has built the infrastructure for conducting the tests?

Second, if it were economical for a given developer to get their equipment tested at such a facility, what sorts of information would regulators and resource agencies look for from the testing center as part of an environmental certification for a given technology?

Comment: Verdant Power is looking to get over to EMEC. We will be going into the East River with six units, but we want to bring back additional information from EMEC on new designs for deployment installations. So to us, the test center is valuable.

Facilitator: What information would you [regulators, environmentalists] be looking for?

Response: With wind energy, for example, I can look at what monitoring and modeling has been done in Denmark and use it to gauge what I need to look for here. I would be looking for impacts on common species, noise monitoring, etc. Agencies can use information from prototype testing to decide what degree of concern we should have about a given characteristic. If I have no information, I am going to err on the side of caution.

Response: Speaking as an environmental scientist, rather than as a regulator, one of the things that would be helpful for evaluating environmental impacts of these technologies would be identifying and quantifying relevant characteristics of a machine – e.g., how big is the footprint, how much noise and at what frequencies, zone of influence for flow velocity, whether or not flow passes through the device, what pressure differentials are created. If we could come up with key characteristics that could be developed for all these different types of technologies, different

[14] See also Ken Rhinefrank's unscheduled presentation about Oregon State University's proposal for a U.S. Marine Energy Center.

machines, then regulators would have some common terms to use in comparing technologies, and also to consider with respect to deploying a device at a particular site.

Question: What other environmental parameters is EMEC measuring besides marine mammal impacts? Is there any monitoring of fish movement relative to the technologies? That's what FWS would like to see.

Response: We've got aspiration to do that, but we've got to develop a wish-list of common denominator information that we take back to government funders and say, everyone would benefit from knowing more about this.

Comment: Because there are so many unknowns, there is great value in 4-5 developers pooling baseline data at a common testing site.

Comment: You can't extrapolate to a production field of 250-3,500 units from 6-unit demo project. From a wave standpoint, the diagram showing how that energy extraction permeates down wave, disappearing eventually does go a long way toward alleviating some of the concerns about these types of devices. But on the other hand – if it's located in a migration corridor, or juveniles have to come past a device – these kinds of biological impacts are harder to get at. The physical characteristics of the technologies are relatively easy to get at, but that doesn't tell us what will happen [on a large scale] in a biological setting.

Response: One use of facilities like EMEC is not just to test individual machines, but to validate models that can be used to extrapolate.

Comment: The best way to meet these needs is for government, industry, and environmental groups to do it together. I've seen it work for other technologies: aquaculture, LNG facilities. Working together on pilot or larger studies, or on monitoring plans, goes a long way toward agreeing on what the findings mean.

Response: EMEC developed an environmental impact assessment (EIA) guidance document for developers [PO4-037-002 Final EMEC EIA procedure.pdf] Tables 2.1 and 2.2 outline project decription details and key impact issues, along with economic and social impact issues, providing a good framework for thinking about how to outline the issues that need to be addressed.

Question: How much info do people have to provide before people use EMEC?

Response: We had to do a full set of surveys before we developed our site, but also when a device applies to use our site, they have to do an EIS pertinent to the device being tested at EMEC. Our list is derived from UK's regulatory requirements. Nothing terribly complicated about it, but it is a good synthesis of what is required. Only way to progress is to show that we are working together, that we are serious about what we are doing. Developers don't necessarily have answers to all these questions. If we are going to share this information, it has to come out of the public purse, not out of individual developers.

Comment: Does it make sense to build an EMEC in the US? I don't see US as an ISO country. But it does seem like DOE in particular could have a facility where you could take your device for six months to answer agencies' preliminary questions. This would make it easier to answer investors' questions while on a parallel path you could be working out site-specific questions.

Comment: Canada's Ocean Renewable Energy Institute has tanks that recreate frazzle ice, have a flume with currents up to 2 meters per second.

Proposal for a US Marine Energy Center

[3. K.Rhinefrank - Oregon St Activities.pdf]

Ken Rhinefrank, Oregon State University

Ken Rhinefrank is a Research Assistant at Oregon State University's School of Electrical Engineering and Computer Science. Although not originally scheduled to present at this workshop, he was asked to talk about OSU's Strategic Facilities to Advance Wave Energy.

Oregon State University is a key location for ocean wave energy research, with both a Motor System Resource Facility (MSRF) and the O.H. Hinsdale Wave Research Lab (HWRL). With a 750 kVA adjustable power supply, the MSRF is the highest power university lab in the US, enabling multi-scale energy research. The facility includes a four-quadrant dynamometer, a bidirectional grid interface, a flexible, 300 hp motor/generator test-bed, and a 120 kVA programmable source. HWRL has a 342-ft. long, 12-ft. wide, 15 ft. deep test flume that can be used for conducting wave energy research. It can generate wave periods ranging from 0.5 to 10 seconds, with a maximum wave of 1.6 m (5.2 ft) at 3.5 second intervals.

We envision establishing a US Ocean Wave Energy Research, Development and Demonstration Center with R&D headquarters at OSU. In addition to utilizing the MSRF and HWRL facilities, our goal is to develop a Wave Park for research, demonstration and power generation off the coast at Reedsport, Oregon. The idea of the Wave Park is similar to what EMEC is doing at Orkney: to have a pre-permitted site for companies to come in and test their devices in the water. The project would facilitate streamlined research to pursue optimum topologies, aid industry and government in comparing competing technologies, and accelerate scaling devices to larger and smaller applications.

There is a pipe already in place to lay cables underground at the Reedsport site. The substation would handle up to 50 MW capacity. We are working with Oregon Sea Grant and the Port Liaison Project (PLP) to identify optimum wave park sites and provide technical expertise on buoy tethers, bottom anchors, mooring and maintenance of equipment. We are working with fishermen as well to take their interests into account.

The National Science Foundation has been funding a lot of research on the wave energy devices since 2003. We had our first Stakeholder Collaboration meeting in February 2005 to develop a work plan and roadmap for implementation of responsible wave energy extraction. In addition to OSU, stakeholders include several Oregon state agencies, including the Departments of Energy, of Land Conservation and Development (including marine affairs), of State Lands, and Oregon Economic and Community Development. Federal agencies include: the DOE's National Renewable Energy Lab (NREL), US Army Corps of Engineers (including environmental protection), and the US Department of Fish and Wildlife. Public power authorities and both municipal and investor-owned utilities are also represented: EPRI, Bonneville Power Authority (BPA), Central Lincoln Public Utility Department, PG&E, Pacific Power (PacifiCorp). Energy Trust, Energy NW, and the Hatfield Marine Science Center also are involved.

Public response to this proposal has been very positive, and we are pursuing a wide range of funding opportunities.

Addendum:

Since the October 2005 Hydrokinetics workshop, the opportunity that OSU and Oregon DOE have been promoting for the nation's first commercial wave park has been attracting developers. OSU, Oregon DOE, and Central Lincoln Public Utility district are currently working with these potential developers on plans for commercial wave parks off the Oregon Coast, as well as the proposed U.S. Wave Energy Center.

Possible Models for Collaboration

[Presentation made without slides]

Katherine Kennedy, Natural Resources Defense Council

Kit Kennedy is a senior attorney with the Natural Resources Defense Council (NRDC), a national environmental advocacy organization. NRDC has participated in many collaborative efforts, and this presentation describes some possible models for working collaboratively with the environmental community to support research and development of hydrokinetic resources.

The Natural Resources Defense Council (NRDC) was founded just as the modern environmental movement was getting started, and during the first half of our history, our efforts went mainly into fighting projects (dams, power plants, etc.). We also helped to write many of the federal environmental statutes. We have since developed a more affirmative vision of what we'd like to see – more renewable energy generation, cleaner power plants, sustainable growth – and we've shifted into taking a more positive role, trying to make things happen Currently, most of these issues are being tackled at the state level.

On the energy front, we are working with renewable energy developers. It's a complicated dance; because the NRDC is somewhat of a microcosm of the environmental community. We have to find ways to work with developers that respects all the different interests within the NRDC. It is important to understand that all forms of energy generation have environmental impacts – no one gets a "free pass" – there needs to be a form of review to determine whether those impacts are benign or within an acceptable range.

Because NRDC has a climate center, an energy center, and an ocean center, we are in a good position to bring together environmentalists who care about clean energy, to create a united front that can help to support good projects. For example, in the case of the Cape Wind project, we hired experts to look at the EIS and make recommendations for what more had to be done. It was a case of ocean and energy folks coming together. NRDC is also part of the Pew Ocean Commission, an organization established to assess the condition of America's oceans and living marine resources, and set national priorities to restore and protect them for future generations.

We support the development of renewable energy resources through policies like Renewables Portfolio Standards (RPS). In New York State, for example, we brought together all the environmental groups that cared about renewable energy, and the renewable energy industry members, and worked together to get consensus and present a united front when lobbying for the RPS program. We are now working on turning that coalition into a non-governmental organization that can be an ongoing, independent voice for renewable energy in New York State. In California, we are working with the Center for Energy Efficiency and Renewable Technologies to create state policies that promote environmentally-benign technologies.

Suggestions for Hydrokinetic and Wave Energy Developers

To get wave/tidal energy through the research and development stage to commercialization, there's no one-stop shopping. You have to brainstorm to come up with multiple funding sources, patch the resources together. It is hard to get money, but if you can get a half a dozen senators interested in what you're doing, you could make something happen for DOE, or from the Navy. Don't give up, keep building support.

Public benefits funds. The states have been doing a lot of work on clean energy. Sixteen states now have public benefits funds, created in the wake of deregulation to support energy efficiency and renewables. In New York State, most of the $150 million fund goes mostly to energy efficiency, but $16 million has gone to renewables. That's not huge, but it's a good program. California also has a robust renewables program, as does New Jersey. Collectively, this amounts to a lot of funding. If you could get $1 million from each state, you would have a big enough pot to support the environmental research piece. These public benefits funds are not permanent, so it is important to be on top of that and to be prepared to weigh in on the policy decisions as they develop. Again, it is essential to present a united front – not only amongst yourselves, but with other renewable sectors.

Renewables portfolio standards. Twenty states (and the District of Columbia) have RPS programs. While it may be too early in this industry's development to get RPS funding, it is important to be aware of it. You want to make sure that your technology is included as one of the renewables eligible for these programs.

Public power authorities. Another resource to think about are the public power authorities, such as the Long Island Power Authority (LIPA), the Bonneville Power Authority (BPA), and, in California, the Sacramento Municipal Utility District (SMUD). Over the years, these authorities have invested a fair amount in renewable energy projects. LIPA's renewables portfolio is twice as large as New York State's overall.

Investor-owned utilities. EPRI has funding from the investor-owned utilities, of course. In some areas of the US, there is growing interest in utilities are getting back into long-term planning for resource procurement, including renewables. That's something to be watching, as it could mean more in the way of RPS funds.

Academic institutions. Academia doesn't have a lot of money, but there is a great deal of interest and expertise. Think about pooling resources from several institutions, e.g., Stanford, MIT, Woods Hole Oceanographic Institute, State University of New York (SUNY) Stonybrook, Oregon State University, etc.

Other renewable energy partners. Finally, think about what you have in common with other renewable energy developers, e.g., offshore wind. What mutual information needs can you work together to address? Impact of deployment on the ocean bed, for example. The Ocean Renewable Energy Coalition should reach out to the offshore wind industry.

This research piece is so important. It isn't just that you need the information to get your permits; you also need the public and the broader environmental interest community to understand and support what you're doing. Invite this community to learn about what you're doing. Don't give the appearance of resisting the review process. Don't set yourself up for the kind of bad PR that Altamont Pass has created for the wind industry. Get it right early on if possible, and get that public support – even if it slows you down a bit at the beginning, it can become a big positive for you in the long run.

Questions, Observations, and Discussion following Presentation

Comment/Question: Regarding the potential for getting support. A "push" is needed, but the market "pull" from RPS programs also is important. What about "Green E" programs, funding from trusts like the Massachusetts Technology Collaborative? Is NRDC willing to work with the Ocean Renewable Energy Coalition?

Response: Green marketing has been slow to take off in the United States. The hope was that deregulation of the electric utility industry would lead to real residential customer choice. But it hasn't happened so much. Cost is still an issue.

Foundations are another source of support (e.g., in the case of Verdant Power's RITE project, the Hudson River Foundation may be helpful). Foundations typically only fund 501-c3s, which could be OREC. These are likely to be small grants, but they might be helpful with a particular aspect of a particular project. I'm happy to continue to talk with industry. You should look as well at other renewable-energy/environmental organization coalitions, such the Northwest Energy Alliance. Join us. If you can make the case that the environmental impacts are benign, you will get a lot of interest and support.

Concluding Thoughts and Observations

The Workshop concluded with an open floor, facilitated discussion among all participants.

Facilitator: Based on what we discussed over past two days, what are the next steps? How do we proceed with demonstrations of technology while gathering environmental impact information and developing possible mitigation responses? How do we find and obtain funding for future activities? Who will do what by when to carry out next steps? [Note that the list of ideas and research questions – included in these Proceedings as Appendix A – is *not* a consensus list.]

- Be very specific and discrete in making requests when looking for federal government funding. Don't think feasibility, think need. Think potential line items.
- As you're thinking about environmental community, remember that we are not one entity. Some are focused on clean energy, some are focused on habitat and animal welfare. Don't think that because you have one group represented that you have all environmentalists there. Important to include some of those organizations which might be perceived as "naysayers" at the table early on so that we don't find ourselves in a confrontational situation down the road.
- *Facilitator*: You want to get some of the leadership and cutting edge folks from both renewable energy and environmental communities.
- Please contact [Roger Bedard] if you want to be part of EPRI's research effort.
- Just because environmentalists are concerned with the potential impacts of these renewable energy technologies doesn't mean that we don't recognize the potential benefits – we don't want to ignore the impacts of fossil fuel use.
- Bear in mind that resource agencies are trying to figure out alternative approaches – that government includes information brokers, not just regulators.
- This is new information for a lot of us in this room. To avoid an Altamont Pass with this technology is very important. You don't want to stunt your growth as that did with wind.
- When comparing different technologies it's important to do so from a life-cycle perspective.
- The Hydropower Reform Coalition has a lot of expertise on impacts in rivers, but I'm not sure how our expertise could apply to oceans. Keep in mind that there is a lot of expertise out there in the environmental community, but you won't find everything in the same place.
- "Clean technologies" is a buzzword in the investment community.
- We should not be looking exclusively to DOE for funding the needed research. MMS may also have a role to play in funding some of the needed research.

Facilitator: I think we accomplished what the Planning Committee hoped for. I encourage you to stay in touch with each other.

Appendix A:
Grouping of Workshop Participants' Research Questions/Concerns

[*This listing is a compilation of questions and issues submitted by workshop participants. It has been organized by topic, but it has not been prioritized, nor does it reflect a consensus.*]

Policy / Procedural / Philosophical Research Issues

- Long-term research is essential.
- Assumption that we keep piling on without reducing or replacing other stressors should not be the basis for planning.
- Need federal policy to support investment in exploration of wave/tidal technologies.
- Develop a design for collaborating on research.
  - Labs and states collaborate with resource agencies.
- What alternative permitting or licensing process could be applied to each or all technologies? What best management practices could help to add predictability and efficiency? Can that burden be shared with agencies and others? Consortia to fund research, establish BMPs, etc?
- Essential for public confidence that research be guided, conducted and synthesized by public agencies and resulting policy be openly debated. This does not preclude incorporation of vetted, privately funded research/monitoring. States, NGOs and universities should be players in a coordinated effort.
- Need for an EMEC-like facility in U.S. instead of the "shotgun" approach to pilot projects that is happening now.
  - These projects and impacts would be confined to one site where we would have a common environmental baseline for monitoring.
  - Focus should be on proof of concepts/prototypes and establishing "specifications" for how the device affects basic ecological functions/processes.
  - For instance, every device could be tested for impacts on the seabed. Same for hydrodynamic effects. This would help resource managers make informed decisions about what device is most appropriate for given ecosystem.
  - Another goal could be to develop standard protocols and techniques for monitoring. If we are going to transfer information from one site to another, we need data collected to comparable standards.
  - With the above type of information at hand, developers would only have to focus on a few site-specific studies rather than the usual full array of study requests.
- Minerals Management Service and FERC will be addressing siting facilities in marine environments.
  - All projects will have to address issues related to resources, benthos etc.
  - Need a collection of maps and other data.

   - Need MMS and FERC to collaborate with NOAA and other resource agencies to compile data in one place for developers and the public to access and use.

Summary: There should be Federal support for technology development, long-term research on environmental effects and mitigation measures, and well-designed operational monitoring. Coordination/collaboration is the key to getting beyond the present "shotgun" approach to examining environmental issues. Research would be better accepted if done by independent organizations or consortia (not developers). An EMEC-like facility that uses standardized approaches in a common testing environment would be valuable.

Environmental Assessment Needs (General)

- Answer environmental impact questions on a generic level, using similar metrics so as to compare sites and technologies.
- Develop and verify models for extrapolating impacts/effects from pilot projects to full scale projects.
- Use existing pilot projects as case studies.
- Site-specific and generic must address:
   - Cumulative and synergistic effects
   - Carrying capacity
   - Avoiding myopic "tyranny of small decisions"
- Major concern with removing or creating imbalances in energy of any dynamic ecosystem (Sorcerer's Apprentice?).
- Compare environmental impacts across a variety of energy resources.
- Assess impacts under current/future sea level conditions
- What are the critical environmental issues associated with extracting this energy from the ecosystem, and based on where we are on the economic feasibility curve, how soon do we have to address these issues? (i.e., as the cost of electricity goes up, and cost of producing these technologies goes down, the tendency to land rush goes up)
- What are the key technology characteristics that might cause impacts?
- Where are the protected areas, species sensitive areas, vulnerabilities, habitat needs?
- What are various deployment and retrieval technologies?
- What is the zone of impact, how far outside of specific development?
- Are there mitigation strategies found to be effective?
- What is a reasonable amount of time to conduct a study – dependent on issues/what studying?

- Is it possible to conduct a programmatic EIS?
- Need to develop standard study methodologies:
  - Transparent, independent studies; peer review;
  - Independent certification of performance.
- It is a necessity to include biological and physical/geological assessments in site assessments prior to construction.
- Monitoring must be well-designed and defined. Monitoring the wrong things generates useless data, but provides a "no-effect" result.
- Identify what was learned from conventional hydropower program and what is applicable to new technologies.
- What visualization techniques exist in the U.S. for monitoring of fish?
- Are there competing uses of an area (not just commercial fishermen using the site)?
- Consider aesthetic, cultural, and recreational impacts.

Summary: Environmental assessments (e.g., Programmatic EISs) should be used to identify gaps in our understanding of environmental effects. A high-level, programmatic EIS could compare impacts of different sites and technologies using similar metrics. These assessments should evaluate cumulative and synergistic effects of multiple installations, employ models to extrapolate effects from pilot projects to full scale projects, consider all possible resources that might be impacted (including aesthetics and recreation), consider future freshwater flow/sea level conditions, and suggest appropriate mitigation and monitoring. In addition to routine installation and operation, the consequences of accidents and equipment failure should be assessed. Information from previous work on conventional hydropower projects should be applied to new technologies where possible.

Resource Assessment Needs

- Conduct a resource assessment of tidal areas and waves/oceans.
  - Collaborate with coastal states.
- Where are particular technologies likely to be useful?
- What is the amount of energy that could be extracted from wave/tidal resources in the US?
- Based on what is learned, can we adapt projects to minimize impacts, maximize energy output?

Summary: Resource assessments are needed to develop estimates of the amount of energy that can be extracted, especially from marine and estuarine systems. These would include (1) ascertaining locations of applicable resources and estimation of their gross power potential, and (2) evaluating the feasibility of development and estimation of their true power potential.

Engineering Performance Studies

- What are the transmission constraints?
- How robust are these systems? Will they survive debris contact (i.e. weeds, wood debris, flood conditions, etc)?
- If there are other ships/vessels in the area, is there potential for collisions between structures and ships?
- Risk of accidents/failure.
- Is there any work done on acoustic data transmission in high energy tidal streams?

Summary: More work needs to be done on the long term reliability of these technologies and their susceptibility to accidents/damage within various resource settings.

Sediment / Bottom Habitats Studies

- Do these technologies result in:
    - Benthic habitat conversion? Habitat exclusion?
    - Changes in sedimentation and turbidity?
    - Resuspension of contaminants?
    - Alteration of benthic/pelagic community structure?
    - Erosion/scour around anchors, cables and other structures?
- What are the effects on erosion/sediment transport due to energy extraction?
- Effects on geomorphology of streams?
- If deployed in several hundred units, do these systems exacerbate erosion or do they act as a breakwater and decrease erosion?

***Summary*:** Cables, mooring structures, and the motions of hydrokinetic machines in shallow water could alter sediments. Research is needed to address possible effects including resuspension of sediments and contaminants and resettlement elsewhere, increased turbidity, long-term scour from slack lines, alteration of shoreline and shallow water processes, and alteration of benthic habitats and the consequent effects on bottom-dwelling animals.

Water Column Habitat Studies

- Do these technologies result in:
    - Alternation of hydrological regimes?
    - Altered current patterns?
    - Alteration of benthic/pelagic community structure as a result of these structures?
    - Thermal impacts (i.e. heating and cooling of water around structures?
    - Water withdrawals?
- Displacement and/or exclusion from habitat and possible degradation of habitat.
- What are the near field hydraulics like around these structures and what are their effects on the field (i.e. velocities, flow fields, head change, etc.)?
- What are the hydraulic effects for a large number/production facility of these structures in a waterway?
- What is the impact of sediment strike due to vortex shedding?
- If you remove energy from the deep portion of an estuary, what is the impact on the shallow parts?
- What are the effects on sediment and debris transport?
- Effects on shoreline processes.

Summary: Research is needed on the impacts these technologies would have on local hydraulics (small-scale effects) and current patterns and other hydrological regimes (large-scale effects). Hydraulic impacts could alter sediment dynamics and degrade habitats for aquatic organisms. Modeling may help extrapolate effects from a few units to a large energy production facility.

Electromagnetic Effects on Biota

- Do these technologies create electromagnetic fields? If so, what are the impacts on marine organisms?
- Electromagnetic force can be a critical issue with a number of migratory vertebrate and invertebrate species. How will these forces add to known magnetic concentrations on the earth's surface?

Summary: Research is needed to quantify the electromagnetic fields produced by these new technologies as well as the impacts to migratory and resident aquatic organisms.

Chemical Contamination Issues

- What are the plans to control biofouling organisms?
- Are the paints and cleaning chemicals used on the structure non-toxic?

Summary: Information should be developed on the toxicity of paints, hydraulic fluids, and chemicals that will be used to control biofouling.

Strike

- Fish strike
  - Identify what was learned from conventional hydropower program and what is applicable to new technologies.
  - Conduct pilot tests and develop methods for monitoring.
- Biological entrainment and impingement in systems.
- Strike and pressure damage to finfish, shellfish, turtles, diving birds and mammals
- What protection is provided for fish flowing downstream?

Summary: Research is needed to determine the risk and consequences of aquatic organisms and birds striking moving structures associated with these technologies. If screens are employed to protect aquatic biota, there may be a risk of impingement injury and mortality. Information developed from conventional hydropower plants may be useful for making initial predictions of impacts and for guiding future research.

Noise Studies

- Do these technologies result in:
  - Noise impacts – short intermittent blasts or long, sustained noise/vibrations?
  - Acoustic signal of technology and effects on resident and migratory species?
  - Signal clearing installation, when operating and during maintenance?
- Noise impacts during construction
- How will fish and marine mammals behave? What are the fish movement patterns? At what heights from seafloor or where in the water column is there potential impacts?
    - Quantify noise, frequency, zone influence for all machines –
    - Can analysis be provided in similar units/features.?
- Is there a difference between the technologies in level of noise, vibrations?

Summary: Research is needed on both the noise made by these new technologies (frequencies, sound levels, and areal extent) and the effects of noise on aquatic organisms (damaging or attractive).

Other Effects on Biota

- Do these technologies result in whale/turtle entanglement in cables?
- Does this technology attract fish? If so, is there a greater likelihood of fish mortality or turtle/marine mammal "takes"?
- Effects on fish migration – routes, patterns, knowledge of migratory routes, delay, injury, predation (i.e. height in water column, proximity to shoreline?)
- What is effect of avian use of structure? (positive/negative)
- What are effects on swimming performance and locomotion of aquatic systems?
- What are the fish behavioral responses to single, multiple, or complexes/full-field arrays of these devices. Same for migratory birds and mammals.
- Effects on near shore marine life – so these devices become "attractive nuisances" that place resources at risk that could otherwise be avoided?

- What is the impact of blocking sunlight in the near shore on the food web?
- Do we know enough about the American eel?
- Disturbance to shorebird feeding and nesting?
- A park with multiple installations (as Emersis in Portugal) would appear to present migratory challenges to surface species like whales migrating.
- Can these be designed so they are placed parallel to shore (so whales can migrate past structures?

Summary: Research is needed on the impacts of construction and operation of these technologies to aquatic organisms. Potential impacts to aquatic organisms include strike by moving structures, impingement on screens used to protect organisms or structures, creation of damaging pressures and shear, creation of physical barriers to movement/migration, attraction to structures, degradation of open water and benthic habitats, entanglement in cables, electromagnetic fields, and chemical toxicity. Potentially affected organisms include drifting and actively migrating fish, benthic fish and invertebrates, aquatic mammals and turtles, diving birds, shore birds, and aquatic vegetation.

Questions/Concerns Regarding Specific Technologies

OpenHydro, Open-Center Turbine

- o Does the OpenHydro system create strong electromagnetic fields? If so, are there impacts on fish migration?
- o These structures can be placed in the Gulf Stream – are they an impediment to the migration of turtles, whales, and/or fish?

AquaEnergy, IPS Buoy

- o If deployed in several hundred units, do these systems exacerbate erosion or do they act as a breakwater and decrease erosion?

Ocean Power Technologies

- o Can these be designed so they are placed parallel to shore (so whales can migrate past structures?

Wave Dragon

- o How can the design screen out marine life so they are not forced into the reservoir and affected by the pistons or trapped against the intake?

Pelamis

- Does this system use less water than other systems? Does this translate to less impingement, entrainment, and screening?
- A park with multiple installations (as Emersis in Portugal) would appear to present migratory challenges to surface species like whales migrating.

Axial Flow Turbine

- What is the level of fish mortality, what data is available on this question?
- Do fish get caught in the blades?
- Are there changes in water flow?
- Is there pelagic habitat conversion?
- Is navigation affected if structure deployed in shallow water?
- What is the impact of sediment strike due to vortex shedding?
- What protection is provided for fish flowing downstream?
- Are there competing uses of an area (not just commercial fishermen using the site)?
- If there are other ships/vessels in the area, is there potential for collisions between structures and ships?
- What is the potential to change the hydraulics of the river?
- Does this technology attract fish? If so, is there a greater likelihood of fish mortality or turtle/marine mammal "takes"?

Technologies in Water Column

- While fish strikes are the most obvious, the larger question is what type of habitat alteration may occur due to energy extraction.
- Electromagnetic force can be a critical issue with a number of migratory vertebrate and invertebrate species. How will these forces add to known magnetic concentrations on the earth's surface?
- How can we assess the cumulative effects of a technology implemented at a commercial level? How can we determine carrying capacity?
- Direct impacts on fish are not the only concern. Impacts on invertebrates and/or plankton impacts are equally or more critical.

- For items that spin in the water, what are the rotational speeds (i.e. rpm and tip speed)?
- How robust are these systems? Will they survive debris contact (i.e. weeds, wood debris, flood conditions, etc)?

Technologies on Water Surface

- How can impacts on migratory species be mitigated?
- Impact on sea bottom.
- Displacement and/or exclusion from habitat and possible degradation of habitat.
- Entrainment/injury.

Appendix B:
Alphabetical Listing of Planning Committee Members, Presenters, and Workshop Participants with Contact Information

Planning Committee Members

Edward Abrams
Federal Energy Regulatory Commission
888 First Street, NE
Washington, DC 20426
Ph: 202-502-8773
edward.abrams@ferdc.gov
[NOTE: Did not attend.]

James Ahlgrimm
U.S. Department of Energy
Wind and Hydropower Technologies
EE-2B FORS
Washington, DC 20585
Ph: 202-586-9806
jim.ahlgrimm@ee.doe.gov

Fred Ayer
Low Impact Hydropower Institute
34 Providence Street
Portland, ME 04103
Ph: 207-773-8190
info@lowimpacthydro.org
[NOTE: Did not attend.]

Michael Bahleda
Bahleda Management and Consulting, LLC
515 Colecroft Court
Alexandria, VA 22314
Ph: 703-863-0409
mbahleda@bahleda.com

Tom Bigford
National Oceanic & Atmospheric Administration, National Marine Fisheries Service Headquarters
1315 East West Highway, Suite 14828
Silver Spring, MD 20910
Ph: 301-713-4300 x131
thomas.bigford@noaa.gov

Glenn Cada
Oak Ridge National Laboratory
P.O.Box 2008
Oak Ridge, TN 37831-6306
Ph: 865-574-7320
cadagf@ornl.gov
[NOTE: Also a Workshop Presenter]

Linda Church Ciocci
National Hydropower Association
1 Massachusetts Avenue NW, Suite 850
Washington, DC 20001
Ph: 202-682-1700 x22
Linda@hydro.org

Stefanie Damiani Stavrakas
U.S. Fish and Wildlife Service,
Division of Habitat and Resource Conservation
Arlington Square Building
4401 North Fairfax Drive, Room 820
Arlington, VA 22203
Ph: 703-358-1755
stefanie_damiani@fws.gov

Jim Gibson
Devine Tarbell & Associates, Inc.
290 Elwood Davis Road, Suite 290
Liverpool, NY 13088
Ph: 315-641-1624
james.gibson@devinetarbell.com

Douglas Hall
Idaho National Laboratory
2525 North Fremont Avenue
Mail Stop 3830
Idaho Falls, ID 83415-3830
Ph: 208-526-9525
douglas.hall@inl.gov

Russell Moursund
Pacific NW National Laboratory
PO Box 999
Richland, WA 99352
Ph: 509-376-3251
russell.moursund@pnl.gov

Richard Roos-Collins
Natural Heritage Institute
100 Pine Street, Suite 1550
San Francisco, CA 94111
Ph: 415-693-3000 x103
rrcollins@n-h-i.org
[NOTE: Did not attend.]

PRESENTERS/PANELISTS

Roger Bedard
Ocean Energy Leader
EPRI
3412 Hillview Ave.
Palo Alto, CA 94304
Ph: 650-855-2131
rbedard@epri.com

Alex Bihlmayer
VA Tech Hydro USA Corp
University Research Park,
Five Resource Square
10715 David Taylor Dr., Suite 250
Charlotte, NC 28262
Ph: 704-943-4343
abihlmayer@vatechhydro.com

Max Carcas
Ocean Power Delivery
104 Commercial St.
Edinburgh, UK EH6 6NF
Ph: +44 (0) 131 554 8444
max@oceanpd.com

Erik Friis-Madsen
Consulting Engineer, Inventor
Wave Dragon
Blegdamsvej 4, 1st Floor, DK-2200
Copenhagen N, Denmark
Ph: +45 3536 0219
Loewenmark@city.dk
info@wavedragon.net

Alexander Gorlov
Professor Emeritus and Director of Hydro-Pneumatic Power Laboratory
Northeastern University
MIE Dept., 334 Snell Engineering Center
Boston, MA 02115
Ph: (617) 373-3825
amgorlov@coe.neu.edu

John Griffiths
EMEC Ltd.
23 Dancer Rd. Fulham
London, UK SW6 4DU
Ph: +44 20 7736 6201
jwg@jwgconsulting.com

Kit Kennedy
Senior Attorney
Natural Resources Defense Council
40 W. 20th St.
New York, NY 10011
Ph: 212-727-4463
kkennedy@nrdc.org

Simon Meade
CEO
Lunar Energy Limited
The Walled Garden, Caythorpe Hall
Church Lane
Caythorpe
Lincolnshire, UK NG32 3EL
Ph: +44 (0) 140 027 5023
simon.meade@lunarenergy.co.uk
simonmeade@btinternet.com

Ed Meyer
Hydraulic Engineer
Northwest Region, Hydropower Division
NOAA Fisheries
1201 NE Lloyd Boulevard, Suite 1100
Portland, OR 97232
Ph: 503-230-5411
ed.meyer@noaa.gov

Cynthia Rudge
Director, Global Business Development
Energetech
44 Jackes Ave., Suite 1205
Toronto, Canada M4T 1E 5
Ph: 416-410-2900
cyn@133king.com

Tina Swanson
Senior Scientist
The Bay Institute of San Francisco
500 Palm Drive, Suite 200
Novato, CA 94949
Ph: 415-506-0150 (Main)
Fax: 415-506-0155
swanson@bay.org

George Taylor
CEO
Ocean Power Technologies, Inc.
1590 Reed Rd.
Pennington, NJ 08534
Ph: 609-730-0400 x.218
gtaylor@oceanpowertech.com

Trey Taylor
President & Head of Market Development
Verdant Power
4640 13th St, North
Arlington, VA 22207
Ph: 703-528-6445
ttaylor@verdantpower.com

Alla Weinstein
President & CEO
Aqua Energy Group, Ltd.
P.O. Box 1276
Mercer Island, WA 98040
Ph: 425-430-7924
allaw@aeg-ltd.com

Herbert Williams
President
Openhydro
171 Comfort Rd.
Palatka, FL 32177
Ph: 386-328-2470
herbert.williams@openhyro.com

WORKSHOP PARTICIPANTS

Charles Bagwell
President
Zerwell Energy Inc.
11367 Strasburg Rd.
Erie, MI 48133
mrcdb@charter.net

Philip Beauchamp
Manager, Device Synthesis Lab
GE Global Research
1 Research Circle K1-3A36
Niskayuna, NY 12309
Ph: 518-387-4140
Fax: 518-387-5459
beaucham@crd.ge.com

H. Suzanne Bolton
National Marine Fisheries Service, Office of Science and Technology
1315 East-West Highway
Silver Spring, MD 02910
Ph: 301-713-2363 x.122
Suzanne.bolton@noaa.gov

David Bryson
Biologist
U.S. Fish and Wildlife Service

Stan Calvert
Cheif Engineer
U.S. Department of Energy,
Wind and Hydro Program
Room 5H-072
1000 Independence Ave, SW
Washington, DC 20585
Ph: 202-586-8021
Stan.calvert@ee.doe.gov

Scott Carlon
National Marine Fisheries Service,
Northwest Region
1201 NE Lloyd Blvd., Suite 1100
Portland, OR 97232
Ph: 503-231-2379
Scott.carlon@noaa.gov

John Cooper
Principal and CFO
Ocean Renewable Power Company, LLC
2430 NE 199 St.
N. Miami Beach, FL 33180
Ph. 703-734-0844
jcooper@oceanrenewablepower.com

Doug Dixon
Program Manager
EPRI
7905 Berkeley Dr.
Gloucester Point, VA 23062
Ph: 804-642-1025
ddixon@epri.com

Joan Harn
Rivers and Hydro Lead
National Park Service
1849 C. St., NW (org. code 2220)
Washington, DC 20240
Ph: 202-354-6929
Joan_harn@nps.gov

James Ives
Chief Executive
OpenHydro Group Ltd.
66 Fitzwilliam Square
Dublin, Ireland
Ph: +353 (0) 1 703 7300
james.ives@openhydro.com

Jeffrey Leahey
Manager of Regulatory Affairs Ass.
National Hydropower Association
One Massachusetts Avenue, NW Suite 850
Washington, DC 20001
Ph: 202.682.1700 x.15
jeff@hydro.org

Kimberly Lellis
Marine Habitat Resource Specialist
National Marine Fisheries Service,
Office of Habitat Conservation
1315 East West Highway (F/HC2)
Silver Spring, MD 20910
Ph: 301-713-4300 x156
Kimberly.Lellis@noaa.gov

Steve Lindenberg
Team Leader
U.S. Department of Energy
1000 Independence Ave. SE
Washington, DC 20585
Steve.Lindenberg@ee.doe.gov

Robbin Marks
Director, Hydro Reform Campaign
American Rivers
1025 Vermont Ave. NW
Suite 720
Washington, DC 20005
Ph: 202-347-7550 x3051
rmarks@americanrivers.org

George Martin
President
National Hydropower Association
241 Ralph McGill Blvd. NE BIN 10221
Atlanta, GA 30308
Ph: 404-506-1357
gamartin@southernco.com

Steve McAllister
Kearns & West
1255 K St., NW Suite 410
Washington, DC 20005
Ph: 202-535-7800
smcallister@kearnswest.com

Mary McCann
Senior Aquatic Scientist
Devine Tarbell & Associates
970 Baxter Blvd.
Portland, ME 04103
Ph: 207-775-4495
Mary.mccann@devinetarbell.com

David McCarron
Project Manager
MTC
75 North Dr.
Westborough, MA 01581
mccarron@masstech.org

Patrick McGinnis
Project Manager
U.S. Navy
5001 South Broad
Street Code 985
Philadelphia, PA 19112
Patrick.mcginnis@navy.mil

Estyn Mead
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
911 NE 11th Ave.
Portland, OR 97232
Ph: 503-231-2012
Estyn_mead@fws.gov

Ann Miles
Director, Division of Hydropower Licensing
FERC
888 First Street NE
Washington, DC 20426
Ann.miles@ferc.gov

Michael Murphy
Devine Tarbell & Associates
970 Baxter Blvd.
Portland, ME 04103
Ph: 207-775-4495
Michael.murphy@devinetarbell.com

Vivian Newman
Vice-Chair, National Marine Committee
Sierra Club
19 Coves End, POB 388
Thomaston, ME 04858
Ph: 207-594-7534
newviv@adelphia.net

Robert Nicholson
President
Sea Solar Power, International
111 S. Calvert St. Suite 2300
Baltimore, MD 21202
Ph: 410-547-1300
Fax: 717-854-4498
Nich2088@aol.com

Sean O'Neill
President
Ocean Renewable Energy Coallition
P.O. Box 61584
Potomac, MD 20859
Ph: 301-869-3790
soneill@symmetrix.biz

Bonnie Ram
Energetics
901 D St. SW, Suite 100
Washington, DC 20024
Ph: 202-406-4112
bram@energetics.com

Tim Redding
Minerals Management Service, National Offshore Office
381 Elden Street
Herndon, VA 21070
Ph: 703-787-1215
Timothy.redding@mms.gov

Ken Rhinefrank
Research Assistant
Oregon State University, School of EECE
Owen Hall 220
Corvallis, OR 97331
Ph: 541-760-1833
rhinefke@engr.orst.edu

Mike Robinson
Deputy Director
NREL/NWTC
1617 Cole Blvd.
Golden, CO 08401-3393
Ph: 303-384-6947
Mike_robinson@nrel.gov

Michael Sale
ORNL
P.O. Box 2008, MS-6036
Oak Ridge, TN 37831
Ph: 865-574-7305
salemj@ornl.gov

Chris Sauer
Ocean Renewable Power Company, LLC
2430 NE 199 St.
N. Miami Beach, FL 33180
Ph: 813-417-6660
CSauer@OceanRenewablePower.com

Anne Secord
Branch Chief
U.S. Fish and Wildlife Service
NY Field Office
3817 Luker Rd.
Cortland, NY 13045
Ph: 607-753-9334
Anne_Secord@fws.gov

Charles Smith
Minerals Management Service, National Offshore Office
381 Elden Street MS 4022
Herndon, VA 21070
Ph: 703-787-1561
Fax: 703-787-1544
smithc@mms.gov

Carl Vansant
Editor-in-Chief
HCI Publications
410 Archibald St.
Kansas City, MO 64111
Ph: 816-931-1311 x 115
cvansant@hcipub.com

Sharon Young
Marine Issues Field Director
The Humane Society of the U.S.
22 Washburn St.
Sagmore Beach, MA 02562
Ph: 508-833-0181
syoung@hsus.org

RESOLVE STAFF

Abby Arnold
Senior Mediator
RESOLVE, Inc.
1255 23rd St. NW, Suite 275
Washington, DC 20037
Ph: 202-965-6211
aarnold@resolv.org

Jenifer Peyser
Post Graduate Fellow
RESOLVE, Inc.
1255 23rd St. NW, Suite 275
Washington, DC 20037
Ph: 202-965-6215
jpeyser@resolv.org

Bradford Spangler
Associate
RESOLVE, Inc.
1255 23rd St. NW, Suite 275
Washington, DC 20037
Ph: 202-965-6214
bspangler@resolv.org

TECHNICAL EDITOR

Susan Savitt Schwartz
Consultant
Writing and Editing Services
3257 N. Mount Curve
Altadena, CA 91001
Ph: (626) 345-0307
ssavitts@pacbell.net

Appendix C: Workshop Agenda

Purpose:

To provide a forum for experts in hydrokinetic and wave technologies, marine and riverine habitat and ecology to describe and discuss available hydrokinetic energy and wave technologies, the appropriate water resources for deployment, environmental concerns associated with deployment using those resources, and possible mitigation measures.

Objectives:

- Identify the varieties of hydrokinetic energy and wave technology devices, their stage of development, and the projected cost to bring each to market;
- Identify where these technologies can best operate (i.e. natural streams, tidal areas, ocean currents, waves, canals and other engineered facilities);
- Identify the potential environmental issues associated with these technologies, attempted or conceptual mitigation measures, and the effectiveness of those measures where implemented;
- Develop a list of research needs and/or practical solutions to address unresolved environmental issues.

Workshop Product:

- A technical proceedings of the workshop that will include:
    - A list of research needs that must be addressed for environmentally sound development of hydrokinetic and wave energy technologies; and
    - Proposals for what is needed to answer these questions while proceeding with the development of the technology.

DAY 1 – Wednesday, October 26

1:00-1:30 pm **Workshop Registration**

1:30-2:15 **I. <u>Welcome and Introductions</u>**

1:30-2:00 Welcome from Planning Committee Representatives

- *Jim Ahlgrimm (USDOE)*
- *Linda Church Ciocci (National Hydropower Association)*
- *Robbin Marks (American Rivers)*
- *Tom Bigford (NOAA/NMFS)*
    - Why are we here?
    - What questions do we want addressed during the workshop?
    - What products would we like to see come out of the workshop?

2:00-2:15 Introductions

- Review of workshop agenda – purpose, products and ground rules.
- Hand out and explain purpose of workshop participant worksheets.

Abby Arnold, Facilitator

2:15 –3:15 **II. <u>Presentations of Hydrokinetic and Wave Energy Technologies: What are the Classes of Technologies?</u>**

Presenters will briefly cover questions II.A – II.C in the workshop discussion questions [10 minutes each]. Questions from the floor will be taken as time permits.

2:15-2:25	**Overview: Technology Classes and Key Terminology**	*Roger Bedard, EPRI*
	Rotating Machines	
	Axial Flow Machines	
2:25-2:35	**Watermills**	*Trey Taylor, Verdant Power (tidal areas)*
2:35-2:45		*Herbert Williams, OpenHydro (open ocean)*
2:45-2:55	**Ducted Turbine**	*Simon Meade, Lunar Energy*
2:55-3:05	**Turbine Matrix / Hydromatrix**	*Alex Bihlmayer, VA TECH HYDRO*
3:05-3:15	**Cross-Flow Machines (Darrieus, Helical Turbines)**	*Alexander Gorlov, GCK Technology*

3:15-3:40 **Break**

3:40-4:30 **II. Overview Presentations of Hydrokinetic and Wave Energy Technologies (Continued)**

Presenters will briefly cover questions II.A – II.C in the workshop discussion questions [10 minutes each]. Questions will be taken from the floor as time permits.

	Wave Energy Devices	
3:40-3:50	**Heave Wave Devices**	*Alla Weinstein, AquaEnergy Group*
3:50-4:00		*George Taylor, Ocean Power Technologies*
4:00-4:10	**Heave-Surge Wave Devices**	*Max Carcas, Ocean Power Delivery*
4:10-4:20	**Overtopping Wave Devices**	*Erik Friis-Madsen, Wave Dragon*
4:20-4:30	**Oscillating Water Column Devices**	*Cynthia Rudge, Energetech*

4:30-5:45 **III. Questions and Answers with Technology Presenters**

Open Floor, Facilitated Discussion w/Panel and Participants

5:45 **Adjourn to light reception (@ RESOLVE)**

DAY 2 – Thursday, October 27

8:30-8:45 **IV. Opening Session**

Reflections on Day 1 and review of Day 2 agenda.

- Address questions or concerns from participants.

Abby Arnold, Facilitator

8:45-10:00 **V. Questions and Answers with Technology Presenters (Continued)**

Open Floor, Facilitated Discussion w/Panel and Participants

10:00-10:15 **Break**

10:15-12:30 **VI. Resource Areas for Deployment of Hydrokinetic and Wave Energy Technologies and Associated Environmental Questions/Concerns**

Environmental experts will cover VI.A in the workshop discussion questions for natural streams, near-shore and offshore marine resources. Canals and other engineered waterways will be covered in an open discussion [10 minutes each].

10:15-10:25	**Natural Streams**	*Glenn Cada, USDOE/ORNL*

		Ed Meyer, NOAA Fisheries [Panelist Only]
	Near-Shore & Offshore Marine Resources	
10:25-10:35	Estuaries	*Christina Swanson, Bay Institute of San Francisco*
10:35-10:45	Near Shore	*Jim Gibson, Devine Tarbell & Associates*
10:45-10:55	Offshore	*Tom Bigford, NOAA/NMFS*
10:55-11:05	**Canals & Other Engineered Waterways**	*Open Discussion*

11:05-12:30 **VI.B. Known and Potential Environmental Questions/Concerns**

Technology experts will cover VI.B. in the workshop discussion questions, with a panelist summarizing the known and potential environmental questions/concerns and mitigation strategies for each technology class.

Rotating Machines	
Axial-Flow (Existing Structures)	*Alex Bihlmayer, VA TECH HYDRO*
Axial-Flow (Free Flow)	*Jim Gibson, Devine Tarbell & Associates*
Cross-Flow Devices	*Alexander Gorlov, GCK Technology*
Wave Energy Devices	*Max Carcas, Ocean Power Delivery* *George Taylor, Ocean Power Technologies* *Alla Weinstein, Aqua Energy*
Oscillating Water Column Devices	*Cynthia Rudge, Energetech*

12:30-1:30 **Lunch (Food served on site)**

NOTE: A few short demonstration videos will be screened in the conference room during lunch for those who are interested.

1:30-3:30 **VI. Resource Areas for Deployment of Hydrokinetic and Wave Energy Technologies and Associated Environmental Questions/Concerns (Continued)**

VI.C. Reflection on Environmental Questions and Discussion of Mitigation Strategies

For each resource area, panelists and participants will discuss questions outlined under VI.C. on the attached document. [120 minutes].

Open Floor, Facilitated Discussion w/Panel and Participants

3:30-3:45 **Break**

3:45-5:30 **VII. What Studies/Research Is Needed To Assess Known and/or Potential Environmental Questions/Concerns and Mitigation Strategies?**

Identify research that could address questions about environmental questions/concerns and mitigation strategies in the resource areas under consideration for deployment of hydrokinetic and wave energy technologies. Panelists will provide initial thoughts on research needed for natural streams, marine resources and canals/engineered waterways and then the floor will be opened to all participants [105 minutes].

Open Floor, Facilitated Discussion w/Panel and Participants

5:30 **Adjourn for evening**

NOTE: Overnight, participants are asked to consider what was discussed on Day 2 and identify additional research needs they would like to propose to the group on Day 3.

DAY 3 – Friday, October 28

8:30-10:00 **VIII. <u>Review and Add to Research Needed</u>**

Review the research needs identified on Day 2 and field additional thoughts and suggestions from workshop participants [90 minutes].

- Summary of outstanding questions/research needs mentioned so far.
- Additions to list of research needs.
- What are the top research priorities?

Open Floor, Facilitated Discussion among All Participants

10:00-10:30 **Break**

10:30-12:00 **IX. <u>Discussion of Next Steps</u>**

Three primer presentations on lessons learned from the development of other, more mature renewable energy technologies. What institutions, collaborations or other endeavors have been undertaken to support research on emerging renewable energy technologies [10 minutes each].

10:30-10:40 *Kit Kennedy, Natural Resources Defense Council*

10:40-10:50 *Roger Bedard, EPRI*

10:50-11:00 *John Griffiths, European Marine Energy Centre*

11:00-12:00 Discussion of next steps [60 minutes].

- Based on what we discussed over past two days, what are the next steps?
- How do we proceed with demonstrations of technology while gathering environmental impact information and developing possible mitigation responses?
- How do we find and obtain funding for future activities?
- Who will do what by when to carry out next steps?

Open Floor, Facilitated Discussion among All Participants

12:00 **Adjourn**

Appendix D: List of Slide Presentations

Day 1 – Technology Presentations

Overview of Technology Classes and Key Terminology – Roger Bedard, EPRI
[1. R. Bedard_Day 1 Overview of Techs.pdf]

Axial Flow Machines – Trey Taylor, Verdant Power
[2. T.Taylor Presentation_Day 1.pdf]

Open Center Turbine – Herbert Williams, OpenHydro
[3. H.Williams Tech Presentation.pdf]

Ducted Turbine – Simon Meade, Lunar Energy
[4. S.Meade Tech Presentation.pdf]

Turbine Matrix/Hydromatrix – Alexander Bihlmayer, VA Tech
[5. A.Bihlmayer Tech Pres-1.pdf]

Cross-Flow / Helical Turbine – Alexander Gorlov, Northeastern University
[6. A. Gorlov Presentation.pdf]

Venturi – NO PRESENTATION

Heave Wave Devices – Alla Weinstein, AquaEnergy Group
[7. A.Weinstein Presentation.pdf]

Heave Wave Devices – George Taylor, Ocean Power Technologies
[8. G.Taylor Presentation-revised.pdf]

Heave-Surge Wave Devices – Max Carcas, Pelamis
[9. M.Carcas Tech Presentation.pdf]

Overtopping Wave Devices – Erik Friis-Madsen, Wave Dragon
[10. Erik F-M Tech Presentation.pdf]

Oscillating Water Column – Cynthia Rudge, Energetech
[NO SLIDES]

Day 2 – Resource Area Presentations

Environmental Concerns Associated with Natural Streams – Glenn Cada, ORNL
[1. Cada and Meyer - Natural Streams.pdf]

Environmental Concerns Associated with Estuaries – Tina Swanson, Bay Institute of San Francisco [2. T. Swanson - Estuaries.pdf]

Environmental Concerns Associated with Near-Shore Environments – Jim Gibson, Devine Tarbell & Associates [3. J.Gibson - Near Shore.pdf]

Environmental Concerns Associated with Off-Shore Environment – John Ogden, Florida Institute of Oceanography [4. J.Ogden - Offshore (Bigford).pdf]

Day 2 – Technology Presentations (Known Environmental Concerns)

Turbine Matrix/Hydromatrix Environmental Concerns– Alexander Bihlmayer, VA Tech
[1. A. Bihlmayer Hydromatrix Envr Info.pdf]

Axial Flow Machines Environmental Concerns – Trey Taylor, Verdant Power
[2. J.Gibson - Free Flow Axial Turbines Envr Info.pdf]

Heave-Surge Wave Device Environmental Concerns – Max Carcas, Pelamis
[3. M.Carcas - Pelamis Envr Concerns.pdf]

Heave Wave Devices Environmental Concerns – George Taylor, Ocean Power Technologies
[4. G.Taylor - OPT Envr Concerns.pdf]

Heave Wave Devices Environmental Concerns – Alla Weinstein, AquaEnergy Group
[Weinstein-051027_DOE_HW_workshop_ea.pdf]

NOTE: Gorlov re-used slides from Day 1 presentation.

Day 3 – Next Steps Presentations

Future of EPRI – Roger Bedard, EPRI
[1. R.Bedard EPRI Future.pdf]

Overview of EMEC – John Griffiths, EMEC
[2. J.Griffiths EMEC Overview.pdf]
[PO4-037-002 Final EMEC EIA procedure.pdf]

Overview of Oregon State University Activities – Ken Rhinefrank, Oregon State University
[3. K.Rhinefrank - Oregon St Activities.pdf]