Description of document: Department of Energy (DOE) Report to Congress: Techno-economic Assessment of Marine and Hydrokinetic Technologies, September 2013

Requested date: 2015

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FOIA Requester Service Center
1000 Independence Avenue, SW
Mail Stop MA-90
Washington, DC 20585
Fax: (202) 586-0575
Online DOE Headquarters FOIA Request Form

Department of Energy
Washington, DC 20585

March 27, 2015

Via email

Re: HQ-2015-00224-F

This is the final response to the request for information that you submitted to the Department of Energy (DOE) under the Freedom of Information Act (FOIA), 5 U.S.C. § 552. You requested a "copy of the most recent Quinquennial Report, on the Technical and Economic Viability of Marine and Hydrokinetic Energy Technologies."

In a letter dated December 1, 2014, you were advised that your request had been assigned to the Office of Energy Efficiency and Renewable Energy (EE) to conduct a search of its files for responsive documents. EE started its search on December 18, 2014, which is the cutoff date for responsive documents.

EE has completed its search and located one document responsive to your request. The document is being provided to you as described in the accompanying index.

The DOE has determined that certain information in the document should be withheld pursuant to Exemption 5 of the FOIA, 5 U.S.C. § 552(b)(5).

Exemption 5 protects "inter-agency or intra-agency memorandums or letters which would not be available by law to a party other than an agency in litigation with the agency." 5 U.S.C. § 552(b)(5). This exemption has been construed to exempt those documents normally privileged in the civil discovery context, such as attorney-client communications, attorney work-product documents, and deliberative process material.

The information in the document withheld under Exemption 5 is protected by the deliberative process privilege. Some withheld portions of the document are pre-decisional. The DOE considered these preliminary views as part of the process that will lead to the agency's final policy decision about these matters. The withheld portions do not represent a final agency position, and their release would compromise the deliberative process by which the government makes its decision.

With respect to the discretionary disclosure of deliberative information, the quality of agency decisions would be adversely affected if frank, written discussion of policy matters were inhibited by the knowledge that the content of such discussion might be made public. For this reason, DOE has determined that discretionary disclosure of the deliberative material is not in the public interest because foreseeable harm could result from such disclosure.

This satisfies the standard set forth in the Attorney General's March 19, 2009, memorandum that when a FOIA request is denied, agencies will be defended and justified in not releasing the material on a discretionary basis "if (1) the agency reasonably foresees that disclosure will harm an interest protected by one of the statutory exemptions, or (2) disclosure is prohibited by law." The Attorney General's memorandum also provides that whenever full disclosure of a record is not possible, agencies "must consider whether they can make a partial disclosure." Thus, we have determined that, in certain instances, a partial disclosure is proper.

Pursuant to 10 C.F.R. § 1004.7(b)(2), I am the individual responsible for the determination to withhold the information described above. The FOIA requires that "any reasonably segregable portion of a record shall be provided to any person requesting such record after deletion of the portions which are exempt," 5 U.S.C. § 552(b). As a result, a redacted version of the document is being released to you in accordance with 10 C.F.R. § 1004.7(b)(3).

This decision, as well as the adequacy of the search, may be appealed within 30 calendar days from your receipt of this letter pursuant to 10 C.F.R. § 1004.8. Appeals should be addressed to Director, Office of Hearings and Appeals, HG-1, L'Enfant Plaza, U.S. Department of Energy, 1000 Independence Avenue, S.W., Washington, D.C. 20585-1615. The written appeal, including the envelope, must clearly indicate that a FOIA appeal is being made. The appeal must contain all the elements required by 10 C.F.R. § 1004.8, including a copy of the determination letter. Thereafter, judicial review will be available to you in the Federal District Court either (1) in the district where you reside, (2) where you have your principal place of business, (3) where the DOE's records are situated, or (4) in the District of Columbia.

The FOIA provides for the assessment of fees for the processing of requests. *See* 5 U.S.C. § 552(a)(4)(A)(i); *see also* 10 C.F.R. § 1004.9(a). In our letter of December 1, 2014, you were advised that your request was placed in the "other" category for fee purposes, which provides for two (2) free hours of search time and 100 free pages. You will not be assessed any fees since the search time did not exceed two (2) hours and the responsive document did not exceed 100 pages.

If you have any questions about the processing of the request or this letter, you may contact Mr. Michael Schierloh or me at:

MA-90/ Forrestal Building
1000 Independence Avenue, SW
Washington, DC 20585
(202)586-5955

I appreciate the opportunity to assist you with this matter.

Sincerely,

Alexander C. Morris
FOIA Officer
Office of Information Resources

Enclosures

U.S. DEPARTMENT OF ENERGY

Techno-economic Assessment of Marine and Hydrokinetic Technologies

Report to Congress
September, 2013

United States Department of Energy
Washington, DC 20585

Message from the Secretary

Use this space for the introductory language that would generally go in a transmittal letter, followed by a list of those Members of Congress to whom the report will be sent.

Pursuant to statutory requirements, this report is being provided to the following Members of Congress:

- The Honorable Member of Congress

Title, House or Senate Committee

- The Honorable Member of Congress

Title, House or Senate Committee

- The Honorable Member of Congress

Title, House or Senate Committee

- The Honorable Member of Congress

Title, House or Senate Committee

If you have any questions or need additional information, please contact me or Mr. Jeff Lane, Assistant Secretary for Congressional and Intergovernmental Affairs, at (202) 586-5450.

Sincerely,

Ernest Moniz

Executive Summary

This report presents a techno-economic assessment of Marine and Hydrokinetic (MHK) technologies that was prepared utilizing recent resource assessment studies sponsored by the US Department of Energy, published cost and performance data, and economic impact analyses conducted at the national laboratories. The results provide cost projections and extraction potentials from domestic ocean wave, ocean current, tidal current, and river current renewable energy resources. (b) (5) [redacted]

[redacted]

[redacted]

The page numbered iii, of a document totaling forty-two (42) pages, *is being withheld in part pursuant to Exemption (b)(5)*.

Techno-economic Assessment of Marine Hydrokinetic Technologies

Table of Contents

I. Introduction

Legislative Language

This report responds to legislative language set forth in H.R. Rep. No. 111-278 on page 103, wherein it is stated:

> *… "Within available funds, the conferees further direct the Department to validate the economic and technical viability of a variety of technologies and to provide a written report to the House and Senate Committees on Appropriations on the prospect of each of the technologies. This report shall include the Department's research and development priorities and goals for the program for the next five years"*

Approach

This document presents a techno-economic assessment (TEA) of ocean wave, ocean current, tidal current, and river current technologies, referred to herein as Marine Hydrokinetic (MHK) technologies. The objectives of the TEA include summarizing MHK resource potentials, reviewing existing MHK generation technology options, and providing cost, deployment and contribution estimates for MHK projects to contribute to the US electricity demand. Inputs for the TEA were derived from recent resource assessment studies sponsored by the US Department of Energy, analysis of the resource potential and wave energy technologies performed by the National Renewable Energy Laboratory, R&D driven cost reductions, published cost and performance data, and a resulting Regional Energy Deployment Systems (ReEDS) analysis performed by the National Renewable Energy Laboratory.

II. MHK National Strategic Resource Potentials

Background

The relative magnitudes of renewable energy resources ultimately determine their maximum strategic contribution potential to the US electricity energy demand. The US Department of Energy[1] recently sponsored a series of resource assessment studies that estimated the **Theoretical Resource** potential of Ocean Wave [1][2], Ocean Current [3], Ocean Tidal [4], and River Current [5] energy in the Unites States. Figure II-1 presents the magnitudes and locations of the MHK resources, and shows that the wave energy is the most abundant resource. Following completion of the DOE sponsored resource assessment studies, the National Academy of Sciences (NAS) performed an impartial third-party review on the methods used in the studies, major findings and analysis limitations [6].

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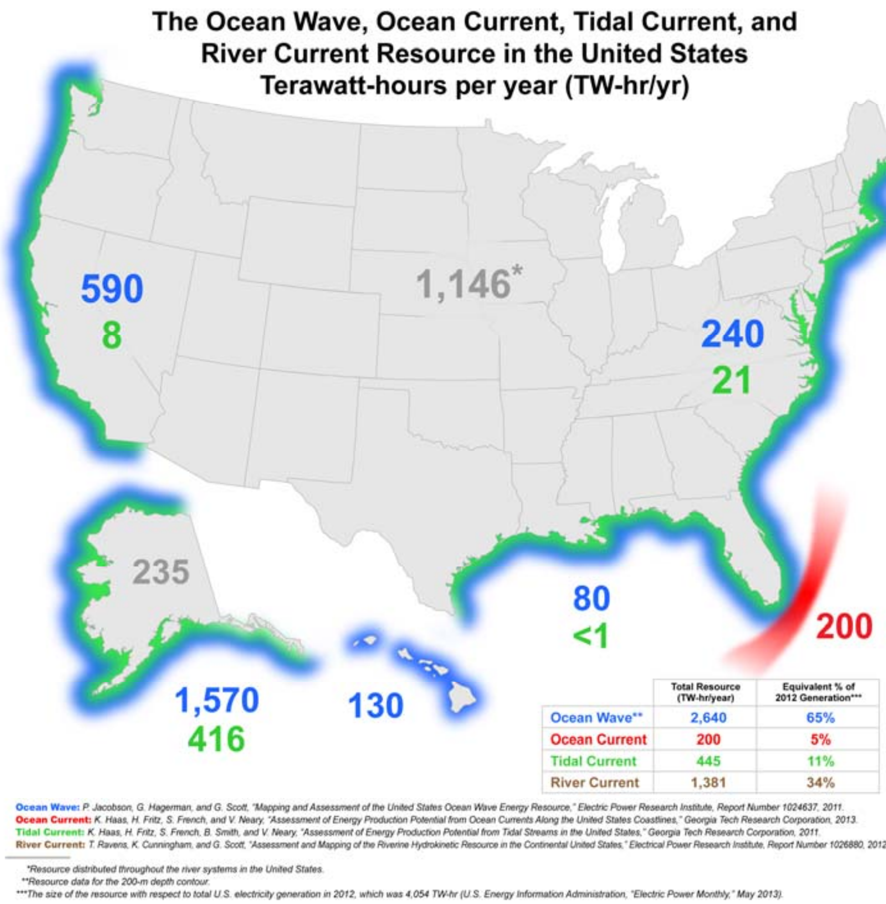
[1] US Department of Energy | Energy Efficiency and Renewable Energy Office | Wind and Water Technology Office (DOE/EERE/WWTO)



	Total Resource (TW-hr/year)	Equivalent % of 2012 Generation***
Ocean Wave**	2,640	65%
Ocean Current	200	5%
Tidal Current	445	11%
River Current	1,381	34%

Figure II-1. The theoretical MHK resources in the United States.

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The pages numbered 3 through 6, of a document totaling forty-two (42) pages *are being withheld in part pursuant to Exemption (b)(5)*.

(b) (5) [redacted]

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III. Marine and Hydrokinetic Technologies

Introduction

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Wave Energy Converter (WEC) Technologies

WEC Device Descriptions

WEC devices extract energy contained within ocean surface waves and convert it to useful electric power. These devices are typically divided into three categories (point absorbers, terminators, and attenuators) based on their operating principle, as illustrated in Figure III-1 . In addition to these three general categories, there are two other device types, overtopping devices and oscillating water columns, which generate energy through the use of hydro turbines and air turbines, respectively. Figure III-2 shows schematics of the various types of WEC devices and illustrates the mechanism through which the devices extract energy.

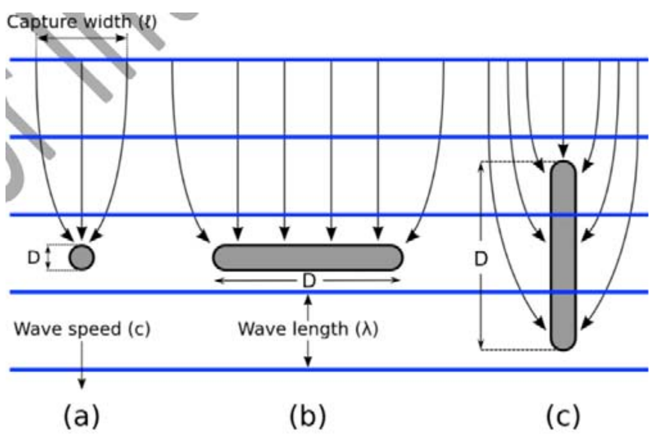

Figure III-1 Three major WEC device archetypes. (a) Point-absorber, (b) terminator, and (c) attenuator.

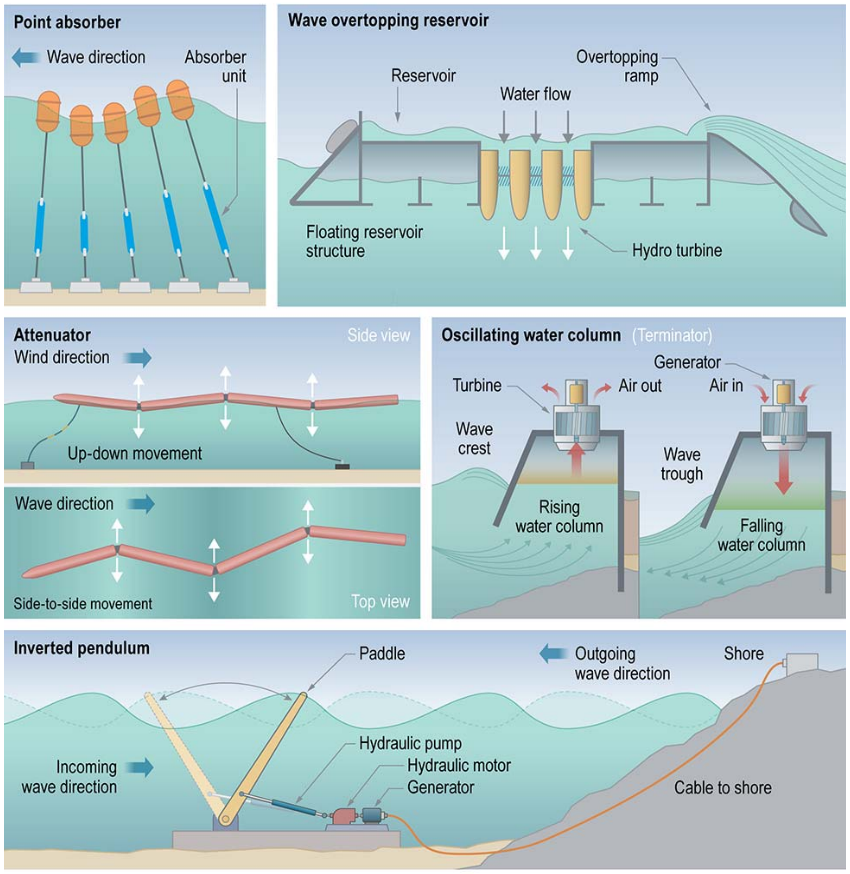

Figure III-2 Types of WEC devices.

Point-Absorbers are devices that are small with respect to the wavelength of incident waves. Point-absorbers typically extract energy through a heaving or pitching motion, or a combination of both, as illustrated in Figure III-2. The point-absorber is an attractive WEC concept because it is theoretically capable of absorbing energy from a wave front many times greater than the device diameter or width (Figure III-1 a). Figure III-3 shows images of two point absorber devices under development by US WEC technology developers.

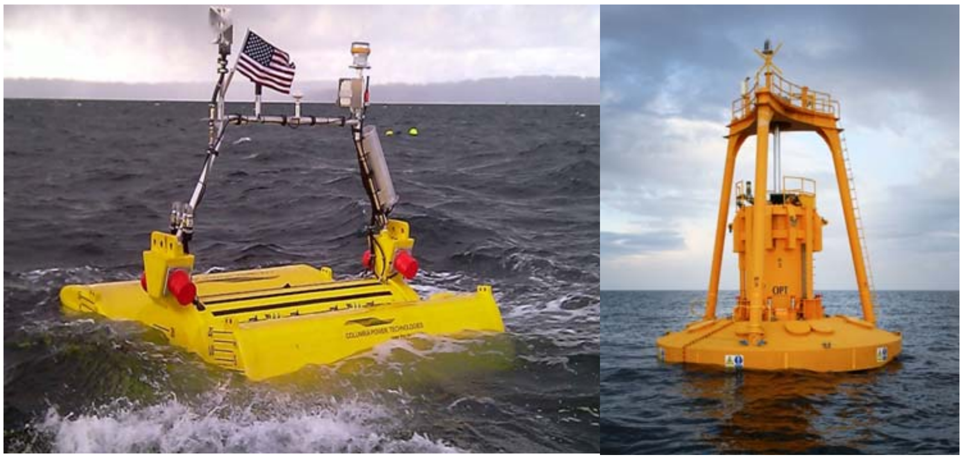

Figure III-3 (Left) 1/7 scale point-absorber developed by Columbia Power Technologies undergoing testing in the Puget Sound, WA. (Right) Ocean Power Technologies PowerBuoy point-absorber in open-ocean testing. Note that for both point-absorber devices shown above, the majority of device structure is below the water level, as Figure III-2 shows.

Terminators and Attenuators have dimensions that are on the same order of magnitude as the wavelength and have one dominant dimension (see Figure III-1). Terminators and attenuators are oriented with their dominant dimensions parallel and perpendicular to the incoming wave front, respectively. A terminator can theoretically absorb 100% of incoming wave energy [11], while an attenuator captures wave energy along its length from a large wave front length. Several companies are developing these types of technologies, as exemplified in Figure III-4.

Figure III-4. (Left) Resolute Marine's terminator prototype being prepared for a test deployment, courtesy of Resolute Marine Energy. (Right) Aquamarine's Pelamis attenuator device in open-ocean testing, courtesy of Pelamis Wave Power.

Overtopping and Oscillating Water Column devices use turbines to generate electricity as shown in Figure III-2. Overtopping devices gather water in a reservoir at a height higher than the mean free surface as waves pass over the top of the device. The resulting hydrostatic pressure difference that is created between the reservoir and the open ocean is used to drive a turbine that is similar to those used in conventional hydropower applications (i.e. dams). Oscillating Water Column (OWC) devices consist of a confined air chamber whose pressure varies with water height within the chamber. As the water level rises and falls, air is driven into and out of an air turbine, which generates power. Figure III-5 shows examples of an OWC and an overtopping device that are currently under development.

Figure III-5. (Left) Ocean Energy Limited's AWS oscillating water column device showing the air turbine that is used to generate energy. (Right) The Wave Dragon overtopping device undergoing open-ocean testing.

WEC Efficiencies

In order to objectively evaluate the power absorption performance of WEC devices, the WEC community has adopted the concept of a capture width ratio (C_{WR}), which is defined as,

$$C_{WR} = \frac{P_{absorbed}}{D \times J_{wave}} = \frac{\text{Capture width}}{D}$$

where $P_{absorbed}$ is the wave power absorbed by the device, D is the characteristic dimension of the WEC, and J_{wave} is the wave power density (in the unit of W/m). Appendix A provides more detail and discussion on the theoretical maximum C_{WR} for different device archetypes.

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The Cost of WEC Energy and Cost Reduction Pathways

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[redacted]

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

Current Energy Converter (CEC) Technologies

Device Descriptions

Technologies that extract energy from ocean, tidal, and river currents are collectively called current energy converters (CECs). Today, these technologies are significantly more advanced than WECs because their designs draw on decades of research and development experience from the wind energy industry. Accordingly, most CECs under development today resemble wind turbines that have been adapted to operate in the marine environment, as shown in Figure III-6.

Figure III-6. (Left) Verdant Power's axial-flow turbine CEC, similar in design to today's commercial-scale wind turbines, being deployed in the East River near New York City [21]. (Right) A cross-flow turbine developed by Ocean Renewable Power Company being prepared for an open water test [22].

CEC Efficiencies

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The Cost of CEC Energy

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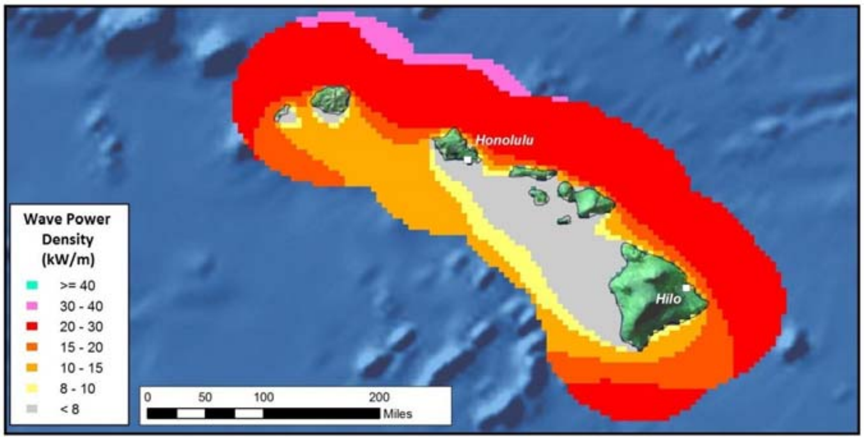

Figure V-3 Wave resource at 100m water depth [2]

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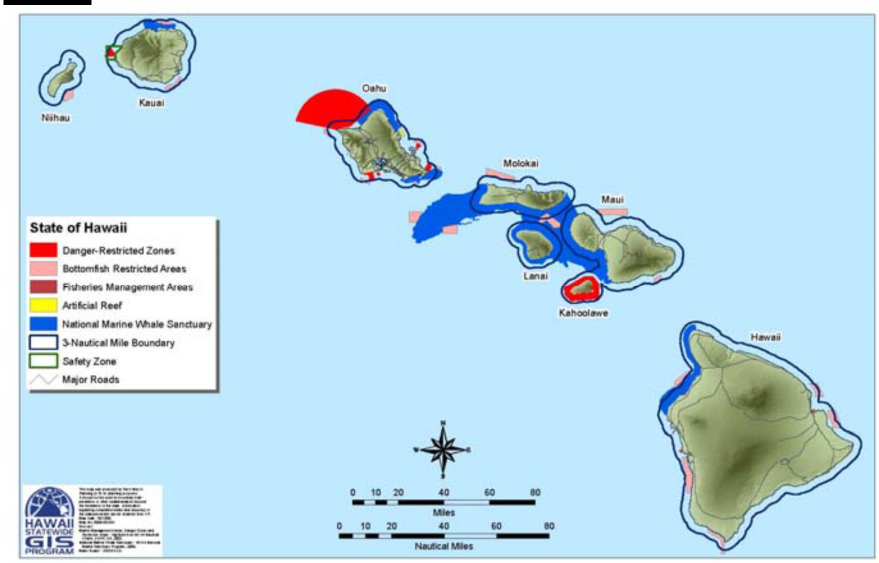

Figure V-4 State of Hawaii with marine exclusion zones indicated [36]

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VI. DOE Contributions to Achieve Deployment Goals

DOE's Water Power Program strategic investment objectives for MHK are to reduce the costs of MHK technologies and facilitate utility-scale deployment and the growth of a domestic MHK industry that is competitive both within the U.S. and internationally. Being in its infancy, the MHK industry has not converged upon the final designs for wave, tidal, or current devices. Unlike established industries that may have difficulty changing course and incorporating new technologies, the early stage of the MHK sector allows the Program to explore revolutionary system concepts and apply existing DOE-funded basic knowledge, research, and tools to realize significant reductions in LCOE with relatively modest investment.

The Program concentrates its strategic investments through four MHK focus areas that are comprehensive and enduring: technology advancement and demonstration; testing infrastructure and instrumentation; resource characterization; and market acceleration and deployment (see Box 1). This cost reduction and deployment strategy is based on the Programs' resource assessments[6,7,8,9,10]; baseline costs from reference modeling[11]; and LCOE reduction opportunities as identified through industry webinars,[12] LCOE reporting guideline development,

[6] EPRI, Mapping and Assessment of the United States Wave energy Resource, 2011.

[7] Georgia Tech Research Corporation, Assessment of Energy Production Potential from Tidal Streams in the United States, 2011.

[8] EPRI, Assessment and Mapping of the Riverine Hydrokinetic Resource in the Continental United States, 2012.

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[10] Georgia Tech Research Corporation, Assessment of Energy Production Potential from Ocean Currents Along the United States Coastline, 2013.

[11] Neary, V. et, al. Methodology for Design and Economic Analysis of Four Marine Energy Conversion Technology Reference Model Archetypes. 2013. https://collaborate.sandia.gov/sites/DOE_Reference_Model_Project

[12] Axial Flow turbine webinar: http://prod.sandia.gov/sand_doc/2013/137203.pdf
Attenuator webinar: http://prod.sandia.gov/sand_doc/2013/137207.pdf
Point absorber webinar: http://prod.sandia.gov/sand_doc/2013/137204.pdf
OWC webinar: http://prod.sandia.gov/sand_doc/2013/137205.pdf

[13] modeling and instrumentation workshops[14], and Requests for Information (RFIs) on manufacturing[15] and resource characterization[16].

The Program is focused on leading development of high-impact MHK technologies. DOE does this by investing in high-risk, early-stage technologies that, due to market considerations, the private sector is unable to address on its own. These high-risk, high-impact R&D efforts will result in next generation MHK systems that will overcome the technical and cost challenges that the current generation of devices face. Program activities are also targeted to compress design cycle timelines by alleviating industry development burdens by providing publically accessible tools, data, and infrastructure. Finally, deployment will be accelerated by reducing market barriers, for example through ensuring environmentally responsible development.

While the MHK industry is rightly focused on near-term operational devices and in-water demonstrations, the Program provides leadership by focusing on the long-range objective of competitive LCOE without subsidies. This role is exemplified by recent Program R&D efforts to increase performance, increase reliability and device lifetimes through component and system R&D, and address environmental effects. Program efforts include the recent FY13 System Performance Advancement FOA and Environmental Effects Assessment and Monitoring FOA, as well as the planned FY14 Wave Energy Conversion Prize initiative.

In addition to advanced component and system R&D and environmental efforts, the Program provides leadership through development of high-performance open-source numerical design code to enable the rapid optimization of WEC devices in operational and extreme conditions and to support wave tank facilities for open-water and controlled conditions deep-water tests. All of these support deployment of a commercial array that will clearly demonstrate the ability of next-generation wave devices to be efficiently permitted and deployed, as well as perform reliably at utility scale.

Box 1: Program Focus Areas

DOE's MHK Program concentrates its strategic investments in four comprehensive and enduring focus areas that are designed to move the industry from its nascent state and low TRL development to higher TRL levels and to remove technical, market, and finance barriers and risks, thereby allowing an effective and vibrant domestic MHK industry to unfold. The four Program focus areas are as follows:

Technology Advancement and Demonstration

The goal of Program investment in MHK technology advancement and demonstration is to drive innovation to develop next generation systems that are cost-competitive, compress the design cycle for MHK technologies through world-class design and simulation tool development, and demonstrate the technical readiness of U.S.

[13] MHK LCOE Reporting Guidance Draft. http://en.openei.org/community/document/mhk-lcoe-reporting-guidance-draft

[14] Marine and Hydrokinetic Technology (MHK) Instrumentation, Measurment and Computer Modeling Workshop. http://www.nrel.gov/water/workshop_mhk_2012.html.

[15] Manufacturing Barriers and Opportunities for Water Power Technologies. http://www1.eere.energy.gov/water/financial_opps_detail.html?sol_id=617

[16] Improving Marine and Hydrokinetic and Offshore Wind Energy Resource Data. https://eere-exchange.energy.gov/Default.aspx#FoaIdb3be5b49-9122-4673-a2ba-7e77d234915a.

MHK systems. The Program will leverage existing data management architectures to assemble and provide real data to advance and validate numerical tools, inform R&D efforts, and provide certainty to the investor community that MHK projects are following the predicted cost reduction trajectory.

Testing Infrastructure and Instrumentation
The goal of Program investment in MHK testing infrastructure and instrumentation is developing, and providing affordable access to a comprehensive set of facilities capable of testing innovative MHK devices across the entire TRL spectrum. While many existing assets (i.e., wave tanks and basins, and water tunnels) are being used, there remain significant gaps that must be filled in order to adequately support this emerging industry. Because ocean energy systems must survive harsh marine environments, testing infrastructure in real ocean environments is required. Testing infrastructure and instrumentation complements the technology advancement and demonstration focus area by providing the facilities and equipment to evaluate technology innovations. This infrastructure and instrumentation would also be beneficial to the resource characterization focus area by helping to provide data for through model validation.

Resource Characterization
The goal of Program investment in MHK resource characterization is to optimize siting of MHK devices in order to reduce LCOE and market risk. Activities include national scale resource assessments, understanding physical phenomena that determine resource characteristics, developing methodology and best practices for resource characterization, and model and tool development to predict wave energy at fine (site-specific) spatial scales. Resource characterization complements other Program focus areas by developing knowledge of the physical conditions experienced by MHK devices and arrays and how those conditions impact power production, device reliability and survivability, and levelized cost of energy.

Market Acceleration and Deployment
The goal of Program investment in MHK market acceleration and deployment (MA&D) is to minimize key risks to deployment to reduce the cost and time associated with permitting MHK projects. The Program's MA&D work focuses on addressing non-technical barriers to the development, deployment, and evaluation of these systems. This includes undertaking research and developing tools to identify, mitigate, and prioritize environmental risks; providing data to accelerate permitting timeframes and drive down costs; increasing educational opportunities for next generation MHK scientists; and engaging in ocean planning to ensure that MHK is considered in the nation's marine spatial plans. The market acceleration and deployment focus area is complemented by monitoring technologies developed under the testing infrastructure and instrumentation focus area and data gathered through the technology advancement and demonstration focus area.

Evolution of DOE Technology Focus

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The pages numbered 30 through 33, of a document totaling forty-two (42) pages, *are being withheld in part pursuant to Exemption (b)(5)*.

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[5] T. Ravens, K. Cunningham, and G. Scott, "Assessment and Mapping of the Riverine Hydrokinetic Resource in the Continental United States," Electrical Power Research Institute, Report Number 1026880, 2012.

[6] National Research Council, "An Evaluation of the US Department of Energy's Marine and Hydrokinetic Resource Assessments," The National Academies Press, 2013.

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[9] C. Garrett and P. Cummins, "Limits to Tidal Current Power," *Renew. Energy*, vol. 33, pp. 2485–2490, 2008.

[10] C. Garrett and P. Cummins, "Maximum power from a turbine farm in shallow water," *J. Fluid Mech.*, vol. 714, pp. 634–643, 2013.

[11] J. Falnes, *Ocean Waves and Oscillating Systems*. Cambridge University Press, 2002.

[12] Y.-H. Yu, R. Thresher, Y. Li, E. Nelson, and M. Lawson, "Design and Performance Analysis of a Floating-Point Absorber Wave Energy Convert," National Renewable Energy Laboratory (NREL), Golden, CO, 2013.

[13] A. Babarit, J. Hals, M. J. Muliawan, A. Kurniawan, T. Moan, and J. Krokstad, "Numerical Benchmarking Study of a Selection of Wave Energy Converters," *Renew. Energy*, vol. 41, pp. 44–63, May 2012.

[14] A. Babarit, J. Hals, A. Kurniawan, M. Muliawan, T. Moan, and J. Krokstad, "The NumWEC Project Selection: Numerical Estimation of Energy Delivery from a Selection of Wave Energy Converters," 2011.

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VIII. Appendix A: Wave Energy Converter (WEC) Technologies

Device Efficiency and the Capture Width Ratio

WEC devices absorb energy from the incident wave field by generating radiation waves, which propagate out from the device, and interfere destructively with the incident wave. The result is that wave energy converters extract potential and kinetic energy from oncoming wave fields, as **Error! Reference source not found.**~~Figure A-IX-1~~ shows. The direct result of this phenomenon is that WEC devices have the ability to absorb energy from a wave front larger than their characteristic dimension. In order to systematically evaluate the power absorption performance of WEC devices, the WEC community has adopted the concept of a capture width ratio (C_{WR}), which is defined as,

$$C_{WR}=\frac{P_{absorbed}}{D\times J_{wave}}=\frac{\text{Capture width}}{D}$$

where $P_{absorbed}$ is the wave power absorbed by the device, D is the characteristic dimension of the WEC, and J_{wave} is the wave power density (in the unit of W/m). For example, if a WEC device with a 1 m characteristic dimension is operating in a 5 kW/m wave resource and has a C_{WR} of 2, the device will mechanically absorb 10 kW of power. C_{WR} is typically a function of wave frequency and wave amplitude and may vary for different wave spectrums, depending the specifics of how the device interacts with the wave environment.

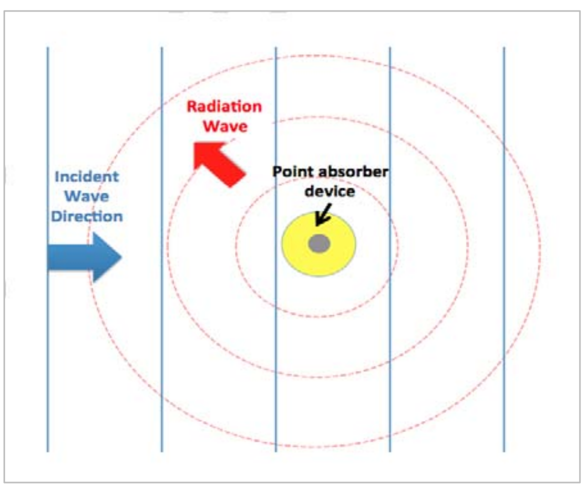

Figure A-VIII-1 Mechanism through which WECs absorb wave energy. The device (point-absorber) oscillates due to wave motion and generates a radiation wave that interferes destructively with the oncoming wave. The result is that there is less wave energy downstream of the device that upstream of the device, and the difference between the two quantities is the amount of energy absorbed by the device.

Point absorbers generally have a large capture width of, λ/2π, where λ is the wavelength . It is interesting to note that the theoretical capture width is not a function of the device size, although practical limitations, such as range of motion and displaced volume constraints, prevent point-absorber devices from reaching the theoretical maximum capture width [38].

Terminators typical extract energy through oscillations in one degree of freedom (e.g. pitch), and the maximum capture width ratio is 0.5 for such a device. If two degrees of motion are allowed (e.g. pitch and surge), terminators have a maximum capture width of 1 and can capture all wave energy flux projected onto the device. The attenuators on the other hand extract energy through oscillations in two-degrees of freedom, and it has been shown that attenuators can have a maximum capture width of 3λ/2π [38] . Artist renditions of terminator and attenuator devices that are under development by WEC industry are shown in Figure III-2.

Quantifying Individual Device Performance

A critical step in analyzing the performance of WEC devices is calculating how much energy will be produced in a particular wave climate. The preferred method of estimating device performance is to calculate a device power matrix and multiply it by the wave joint probability distribution (JPD) for the deployment site, as shown in Figure A-VIII-2~~Figure A-IX-2~~. The power matrix defines how a device performs over the range of expected sea state and the JPD gives the probability of a specific sea state (defined by a wave height and peak wave period) occurring at a given location. Accordingly, multiplying the two matrices provides a description of how much power is produced in any give wave condition.

Power matrix
(obtained from last step)

Power Matrix (kW)	Peak Period (s)												
Hs (m)	5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7	13.7	14.7	15.7	16.7	17.7
0.25	0.49	0.58	0.66	0.75	0.84	0.92	1.01	1.10	1.18	1.27	1.35	1.44	1.53
0.75	4.43	5.20	5.98	6.75	7.53	8.31	9.08	9.86	10.64	11.41	12.19	12.97	13.74
1.25	12.29	14.45	16.61	18.76	20.92	23.08	25.23	27.39	29.54	31.70	33.86	36.01	38.17
1.75	24.09	28.32	32.55	36.77	41.00	45.23	49.45	53.68	57.91	62.13	66.36	70.59	74.82
2.25	39.83	46.81	53.80	60.79	67.78	74.76	81.75	88.74	95.73	102.71	109.70	116.69	123.67
2.75	59.50	69.93	80.37	90.81	101.25	111.68	122.12	132.56	143.00	153.43	163.87	174.31	184.75
3.25	83.10	97.67	112.25	126.83	141.41	155.99	170.57	185.14	199.72	214.30	228.88	243.46	258.04
3.75	110.63	130.04	149.45	168.86	188.27	207.68	227.09	246.49	265.90	285.31	304.72	324.13	343.54
4.25	142.10	167.03	191.96	216.89	241.82	266.75	291.68	316.61	341.54	366.47	391.40	416.33	441.26
4.75	177.50	208.64	239.78	270.92	302.06	333.21	364.35	395.49	426.63	457.77	488.91	520.05	551.19
5.25	216.84	254.88	292.92	330.96	369.00	407.05	445.09	483.13	521.17	559.21	597.25	635.30	673.34

X

Wave Scatter Diagram - Joint Probability Plot (%)	Peak Period (s)												
Hs (m)	5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7	13.7	14.7	15.7	16.7	17.7
0.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.75	0.4%	1.1%	1.1%	1.3%	0.4%	0.6%	0.3%	0.2%	0.2%	0.3%	0.4%	0.5%	0.2%
1.25	1.0%	2.8%	2.4%	4.6%	1.8%	2.2%	1.1%	0.9%	0.7%	0.5%	0.4%	0.4%	0.2%
1.75	0.2%	2.5%	2.7%	3.6%	2.1%	3.5%	1.9%	1.4%	1.2%	1.0%	0.5%	0.5%	0.3%
2.25	0.0%	0.6%	2.3%	3.6%	1.7%	3.3%	2.4%	1.9%	1.5%	1.0%	0.6%	0.5%	0.3%
2.75	0.0%	0.2%	0.9%	2.7%	1.0%	2.2%	2.0%	1.5%	1.3%	0.9%	0.5%	0.5%	0.3%
3.25	0.0%	0.0%	0.2%	1.1%	0.7%	1.2%	1.3%	1.2%	1.1%	0.8%	0.5%	0.4%	0.2%
3.75	0.0%	0.0%	0.0%	0.3%	0.3%	0.5%	0.7%	0.7%	0.7%	0.6%	0.3%	0.3%	0.1%
4.25	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.3%	0.3%	0.4%	0.4%	0.2%	0.2%	0.1%
4.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.2%	0.2%	0.1%	0.2%	0.1%
5.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%

Annual Energy Distribution (kW)	Peak Period (s)												
Hs (m)	5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7	13.7	14.7	15.7	16.7	17.7
0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.75	0.02	0.06	0.07	0.09	0.03	0.05	0.03	0.02	0.02	0.03	0.05	0.06	0.03
1.25	0.12	0.40	0.40	0.86	0.38	0.51	0.28	0.25	0.21	0.16	0.14	0.14	0.08
1.75	0.05	0.71	0.88	1.32	0.86	1.58	0.94	0.75	0.69	0.62	0.33	0.35	0.22
2.25	0.00	0.28	1.24	2.19	1.15	2.47	1.96	1.69	1.44	1.03	0.66	0.58	0.37
2.75	0.00	0.14	0.72	2.45	1.01	2.46	2.44	1.99	1.86	1.38	0.82	0.87	0.55
3.25	0.00	0.00	0.22	1.40	0.99	1.87	2.22	2.22	2.20	1.71	1.14	0.97	0.52
3.75	0.00	0.00	0.00	0.51	0.56	1.04	1.59	1.73	1.86	1.71	0.91	0.97	0.34
4.25	0.00	0.00	0.00	0.22	0.24	0.53	0.88	0.95	1.37	1.47	0.78	0.83	0.44
4.75	0.00	0.00	0.00	0.00	0.00	0.33	0.36	0.40	0.85	0.92	0.49	1.04	0.55
5.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.56	0.60	0.64	0.67

Figure A-VIII-2 Standard method of assessing WEC performance.