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Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

The Contribution of Environmental Siting and Permitting Requirements to the Cost of Energy for Oscillating Water Column Wave Energy Devices

Reference Model #6

AE Copping
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September 2013

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Summary

Responsible deployment of marine and hydrokinetic (MHK) devices in estuaries, coastal areas, and major rivers requires that biological resources and ecosystems be protected through siting and permitting (consenting) processes. Scoping appropriate deployment locations, collecting pre-installation (baseline) and post-installation data all add to the cost of developing MHK projects, and hence to the cost of energy. Under the direction of the U.S. Department of Energy, Pacific Northwest National Laboratory scientists have developed logic models that describe studies and processes for environmental siting and permitting. Each study and environmental permitting process has been assigned a cost derived from existing and proposed tidal, wave, and riverine MHK projects, as well as expert opinion of marine environmental research professionals. Cost estimates have been developed at the pilot and commercial scale.

The reference model described in this document is an oscillating water column device deployed in Northern California at approximately 50 meters water depth.

Acknowledgments

We appreciate the assistance of the engineers and scientists from Sandia National Laboratory, National Renewable Energy Laboratory, Oak Ridge National Laboratory, Advanced Research Laboratory at Penn State University and ReVision for their input and assistance in determining the designs that will affect the marine environment. We would also like to thank Brian Polagye from the University of Washington NNMREC and Sharon Kramer from H.T. Harvey and Associates for their thoughtful input on the reference model studies and costs.

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1.0 Introduction

Responsible deployment of marine and hydrokinetic (MHK) energy devices in estuaries, coastal areas, and rivers requires that biological resources and ecosystems be protected through siting and permitting processes (Bohlert et al. 2008, Dehlsen Associates 2012). Scoping appropriate deployment locations, collecting environmental baseline data, working with permitting agencies and providing the necessary analysis and documentation, conducting post-installation monitoring information, and mitigating for impacts add to the cost of developing each MHK installation, and hence to the cost of energy (COE) generated. The success of the MHK industry in the U.S. depends on a favorable comparison of COE with that of other renewable energy sources (Polagye et al. 2011).

As provided for the first four reference models (tidal, riverine, wave, and ocean current), Pacific Northwest National Laboratory (PNNL) has undertaken the task of determining the preliminary costs for the major categories of environmental and site specific studies that can be expected to be needed for reference model # 6, described in Table 1 below. PNNL's approach develops logic models that describe the expected studies for siting and permitting MHK devices, driven by the siting and regulatory processes that require those studies. Each study and environmental permitting process has been assigned a cost derived from data from existing and proposed MHK projects, scaling factors, projections for future post-installation monitoring costs, and expert opinion. Cost estimates have been prepared for a pilot scale (1 device), small commercial (10 devices), and large commercial (100 devices) project. A range of costs is presented for each type of study and regulatory requirement to reflect the significant uncertainty that results from the generic nature of the reference model site and device. Cost estimates were reviewed by agency staff, researchers, and consultants familiar with environmental permitting processes.

Table 1.Description of Reference Model #6

Reference Model	Technology	Water Body	Marine Receptors of Importance
Oscillating Water Column (OWC) Wave Energy Converter (WEC)	Large floating structure with an air chamber and air turbine generator	Located in ~50 m of water off the coast of Northern California.	Marine mammals, turtles, and fish. Seabirds. Nearfield and farfield habitat. ESA listed,

The goals for costing the contribution to the cost of energy (COE) from siting and permitting include:

1. Determine information needs, study requirements, and costs for each reference model for 1) scoping; 2) pre-installation; and 3) monitoring and mitigation phases, in order to assign costs to each.
2. Organize costs by major regulatory drivers—determine which regulations (and required studies) are highest cost drivers.
3. Engage regulatory agencies in the flow of studies, permitting pathways, to smooth pathway to siting and permitting.
4. Create a logic-model to allow comparison of real world sites to reference model sites and determine total contribution of siting and permitting costs to COE.

This report addresses the first two goals; additional funds would be required to address goals #3 and #4.

2.0 Methods

The process for costing the siting permitting contribution for COE was divided into three phases for reference model #6: 1) siting and scoping; 2) pre-installation information collection; and 3) post-installation monitoring. Costs for developing NEPA and other regulatory processes and deliverables were developed independent of the three phases.

While the specific sites and technologies will have a major influence on the costs for any project, there are many commonalities driven by regulatory requirements and information needs across projects. For the first three reference models (RM#1, RM#2, and RM#3), PNNL researchers derived cost ranges from the best available information on existing and planned MHK projects by consulting with developers and the consultants supporting them and also relied on the best professional judgment of researchers and natural resource management agency staff. Cost ranges for RM#4, RM#5, and RM#6 were extrapolated from the first three models due to the lack of understanding of the cost associated with siting and permitting these technologies. For reference model #6, the basis for costs of environmental studies and processes were developed through extrapolation from the previous three models, relying heavily on costing for RM#3 (WEC point absorber). Both RM#3 and RM#6 are wave energy converters with some potential for commonalities in interactions with receptors of concern. The impact of anchors and mooring lines on marine habitats are somewhat analogous for both RM#3 and RM#6. The ocean space occupied for RM#6 is similar to RM#3 and NEPA processes and study costs can be extrapolated using PNNL staff knowledge of other MHK projects and consultation with experts in the area (Polagye et al. 2011). In the context of potential environmental interactions and thus study costs, the primary differences between RM#3 and RM#6 are in the much larger surface expression of RM#6 (30.5 m length, 27 m width, rising 10 m above the water line), the presence of large air chambers below the surface (27 m height, 34 m width), and the use of an air turbine for the power take off (Copeland and Bull 2013).

Costs for each of the RM#6 studies and processes have been developed for a pilot project, as described. From the pilot, costs were extrapolated for small commercial (10-50 devices) and large commercial (> 50 devices) development arrays. While the size of a pilot project differs from one technology and location to another, we have assumed that the RM#6 pilot project consists of one device, totaling less than 5MW generation capacity, and could be deployed for up to 5 years. PNNL researchers developed a set of scaling rules for the first four reference models to extrapolate from pilot project costs to those of small commercial scale and large scale commercial. For the first three reference models, costing information was developed for the early stage of pilot projects based on information from ongoing expenditures from U.S. projects; post-installation monitoring costs are also more speculative as no monitoring programs have been fully implemented to date. Reliance on scaling from other technology-dependent reference models to RM#6 adds to the uncertainty surrounding the cost estimates.

Each stage of study development (scoping and siting; pre-installation assessment; post-installation monitoring) requires documentation and adherence to processes designed to meet regulatory

requirements. These include conducting public meetings, filing necessary permitting paperwork, and performing periodic checks with government agencies. Each of these processes has a cost associated with it, and has been accounted for in our costing estimates. It is assumed that many of the siting and permitting processes that drive costs are included under the broad umbrella of the *National Environmental Policy Act of 1969* (NEPA). Other regulatory drivers include: *Endangered Species Act of 1973, Clean Water Act of 1977, Marine Mammal Protection Act of 1972 As Amended, Magnuson-Stevens Fishery Conservation and Management Act*, and the *Migratory Bird Treaty Act of 1918*.

2.1 Pre-installation Studies, Analysis and Documentation

Pre-installation studies (also frequently referred to as baseline assessments) for specific wave energy projects or other similar ocean energy projects located in the nearshore environment, will have site- and technology-specific differences, as well as a range of siting and permitting needs. However, in almost all cases, addressing the environmental concerns listed in Table 2 will be required by federal and state statutes. Environmental sample collection, observation, and analysis; data management and interpretation; quality assurance and quality control; and documentation for regulatory purposes, will be needed for each study.

Table 2. Pre-installation and Environmental Concerns that are Likely to Require Studies and Analysis to meet Regulatory Needs

Environmental Concern	Elements of Concern/Studies Needed	U.S. Regulatory Driver
Species under special protection	Marine animals under threat of extinction	Endangered Species Act
Marine mammals	Concern and special societal value afforded to specific groups of animals	Marine Mammal Protection Act
Migratory birds	Birds that migrate across regions and continents and considered at risk	Migratory Bird Treaty Act (international treaty)
Important fish and shellfish populations	Fish populations of commercial, recreational, or cultural importance	Magnuson-Stevens Fishery Conservation and Management Act (protects critical habitats and fish populations)
Habitats	Need to assess quantity and quality of habitat, due to important role in supporting marine species	Magnuson-Stevens Fishery Conservation and Management Act, other federal and state regulations
Water quality	Cumulative degradation of water quality (dissolved oxygen (DO), nutrients, human benefits), changes in sediment transport (affecting benthic habitats and shore forms)	Clean Water Act and state equivalents

2.2 Post-installation Studies, Analysis and Documentation

Post-installation monitoring studies should be derived from the findings of pre-installation studies and other published information from relevant field and laboratory studies. For small (pilot) projects, most concerns center on the wave device (nearfield), including on the potential for animals colliding with the device or its mooring systems, or disruption of the nearfield benthic habitat. As the size of the installment grows, regulations are likely to require that studies include those focused further from the devices (farfield), including assessments of biological processes such as food web effects, effects on marine populations and communities, and altered large scale processes that drive water quality, sediment processes, and maintain drift cells. While site- and technology-specific differences will drive the details of such studies, in general there is likely to be a common set of requirements (Table 3). As for pre-installation studies, sample collection, observation, and analysis; data management and interpretation; quality assurance and quality control; and documentation for regulatory purposes, have all been costed for post-installation monitoring.

Table 3. Post-installation Monitoring Studies for Nearshore OWC WEC Project Development

Target of Study	**Project Scale**	**Type of Study**	**Reason for the Study**
Marine mammals	Pilot and Commercial	Nearfield monitoring	Strike, entanglement, aggregation effects, avoidance effects.
Fish, pelagic invertebrates	Pilot and Commercial	Nearfield monitoring	
Migratory birds	Pilot and Commercial	Nearfield monitoring	
Sea turtles	Pilot and Commercial	Nearfield monitoring	
Benthic invertebrates	Pilot and Commercial	Underwater survey	Periodic survey and sampling to determine effects
Acoustics of the device	Pilot and Commercial	Noise coming off device	Change in acoustics over time: damage, harassment of marine mammals, sea turtles, fish, diving birds.
Migratory birds	Commercial	Ecosystem effects	Changes to pre-installation population status, fitness, food availability and preference, reproductive success
Marine mammals	Commercial	Ecosystem effects	
Fish, pelagic invertebrates	Commercial	Ecosystem effects	
Sea turtles	Commercial	Ecosystem effects	

3.0 Results

The overall costs for environmental studies and associated processes required for RM#6 are summarized in Table 4. Detailed spreadsheets, references, standardized protocols, and in-depth

explanation of costing is available for all parts of the environmental costing process for RM#6 (Appendix A). It should be noted that the costs listed here are not intended to make recommendations for which studies should be carried out or how much they should cost, but rather to reflect cost data representative of projects carried out to date, coupled with professional judgment on how costs associated with RM#6 may differ over project scales. Project-specific costs may be significantly lower or higher depending on the project's specific site characteristics, regulatory concerns, and stakeholder dynamics. Costs are also expected to come down over time. Numbers here represent a conservative estimate, and are not intended to inform study plan negotiations between developers and regulatory agencies.

Table 4. Nearshore Oscillating Water Column WEC summary tables

	Pilot		**Small Scale Commercial**		**Large Scale Commercial**	
Information Need	Low	High	Low	High	Low	High
Siting & Scoping	$240,000	$390,000	$330,000	$530,000	$330,000	$530,000
Pre-Installation Studies	$1,218,000	$2,047,000	$1,753,000	$3,452,000	$2,233,000	$4,537,000
Post-Installation	$660,000	$1,050,000	$9,355,000	$19,800,000	$10,705,000	$24,150,000
NEPA & Process	$800,000	$1,400,000	$1,100,000	$2,300,000	$1,300,000	$2,550,000
Total	$2,918,000	$4,887,000	$12,538,000	$26,082,000	$14,568,000	$31,767,000

Costs shown here summarize **total** costs expected at pilot and each commercial phase. As described more fully below, commercial costs were extrapolated from pilot costs under the assumption that information collected during permitting at the pilot scale will be used for permitting at the commercial phase as well, thereby achieving cost savings. Commercial costs have been calculated as incremental costs above those incurred in the pilot; to construct Table 4, commercial costs were added to the pilot costs to produce the total cost for both small-scale and large-scale commercial phases.

3.1 Pilot Project Costs

Using data from representative pilot project study plans, the studies that are likely to be required were derived for each reference model stage (Table 5); costs were then estimated for each study. The required studies and associated costs were based on assumptions derived from project experience and expert opinion; examples of the studies and the assumptions driving these costs are shown in Table 6. Cost ranges were used to represent the breadth of studies that may be required, depending on the specific animals and habitats encountered in the deployment area, as well as the range of materials, personnel, and equipment available. For example, if no endangered small cetaceans (i.e., dolphins, porpoises, killer whales) were found near the project site, the marine mammal surveys costs would be reduced to focus only on the presence of large cetaceans (i.e., the great whales). If a university partner or non-profit were capable of carrying out the work, costs might be less than those to employ a private firm. Conversely, if new instrumentation must be developed and tested expressly for the projects, costs may be higher.

Table 5. Environmental Studies that are Likely to be Required for each Reference Model Stage

Siting and Scoping	**Pre-Installation Studies**	**Post-Installation Studies**	**NEPA Process**
Preliminary resource assessment-feasibility	Detailed resource assessment	Marine mammals	NEPA document preparation

Environmental scoping	Seabed survey, mapping and bottom composition	Fish	Monitoring and study plans
Community outreach	Marine mammals	Benthos	
Regulatory outreach	Fish and invertebrates	Seabirds	
	Seabirds	Acoustic characterization monitoring	
	Turtles		
	Water quality		
	Habitat		
	Cultural resources		
	Navigation		

Table 6. Examples of Pilot Scale Study Assumptions — Pre-installation (Baseline) Studies for Fish, Marine Mammals, Seabirds, and Turtles

Information Need	Specific Studies	Key Assumptions
Marine mammals	Baseline—species abundance distribution, and behavior: acoustic monitoring; and literature review.	One year study. Large vessel for gray whale surveys in spring and winter; small vessel surveys for resident gray and humpbacks in summer and fall; acoustic monitoring with autonomous recorders for other species (i.e., dolphins and porpoises). This includes boat time to set and retrieve recorders.
Fish and invertebrates	Baseline—species abundance, distribution, and behavior for sturgeon, invertebrates (including crabs), and fish.	Two years of pre-installation monitoring as required by agencies; 1) Telemetry receivers to detect tagged ESA-listed sturgeon; 2) Grab sampling to assess benthic invertebrates; 3) Trapping to assess Dungeness crab; 4) Trawling to assess demersal fish and benthic invertebrates
Birds	Baseline—species abundance, distribution, and behavior	Small boat surveys and line transects for 1 year; Low estimate: assumes 6 surveys done in conjunction with marine mammal surveys, 6 done independently. High estimate: assumes 24 surveys/year done independently.
Sea turtles	Baseline— species abundance, distribution, and behavior for ESA-protected turtles in project area	One year of surveys. Low estimate: surveys done in conjunction with marine mammal and seabird boat surveys, no equipment charges; High estimate- surveys done from small aircraft

3.1.1 Uncertainties in Cost Estimates for Pilot Projects

There are several uncertainties in the cost estimates for pilot projects that cannot be quantified at this time. These are:

- **Monitoring Costs**. Costs for post-installation monitoring are less accurate than those for pre-installation studies because only pre-installation studies have been carried out at existing pilot projects. Costs for post-installation monitoring were estimated based on professional judgment and published studies from related projects. Yearly monitoring costs were estimated and extended to the proposed 5-year term of a FERC pilot license.

- **Mitigation Costs.** Mitigation costs have not been factored into the cost estimates, although mitigation for impacts to marine animals, habitats or ecosystem processes is likely to be required for most MHK projects. These costs could be added to post-installation monitoring costs, but we cannot accurately estimate the magnitude of those costs at this time.

- **Costs for Regulatory Documentation and Interaction.** There is considerable uncertainty associated with the costs for complying with NEPA and other U.S. federal and state regulatory mandates; meeting these mandates will require concentrated effort at each stage of MHK projects. The magnitude of these costs are dependent on the length of time these process require. While some applicable laws and regulations have established timelines for processing permits, these timelines are often exceeded to achieve alignment between the parties involved.

3.2 Commercial Scale Costs

Cost estimates for permitting and siting at a small (10 to 50 devices) and large (greater than 50 devices) commercial scale were extrapolated from costs determined for pilot-scale projects. Cost estimates assume that a pilot permitting process, associated studies, and short-term deployment have already taken place in the project area prior to development at the commercial scale. Cost estimates for commercial scale are for **additional costs** beyond the pilot study. If a developer does not follow the pilot process but goes directly to a commercial scale project (which is allowed under the FERC regulatory process), an estimate of the commercial costs for environmental siting and permitting can be derived by summing the pilot and commercial estimates.

Translating costs from pilot to commercial scale followed a number of assumptions:

- Pre-installation environmental studies carried out at the pilot scale focus on population and behavioral assessments to measure potential **direct** effects to species of concern (e.g. fish, seabirds, sea turtles, marine mammals), in order to establish a baseline for post-installation monitoring. Information gathered from these pilot studies will inform the commercial scale and studies **may not have to be** repeated; supplemental baseline information may be needed as the project footprint increases.

- At commercial scale, additional pre-installation studies may focus on understanding **ecosystem effects** from arrays. These would be **additional studies** beyond those carried out at the pilot scale.

- The threshold between a small and large commercial array cannot be viewed as absolute and must be determined on a site-specific basis. We have chosen thresholds appropriate for the reference sites we are working at, based on overall guidance of the DOE reference model team.

3.2.1 Scaling Rules

In addition to the assumptions that lead from pilot to commercial scale cost estimates, PNNL developed a set of "scaling rules" (Table 7) to allow for consistent comparison between changes in study costs from pilot to commercial scale. This consistency allows for relative comparison, which is useful considering the uncertainty in cost estimates.

Table 7. Rules for Scaling Environmental Study Costs from Pilot to Commercial Scale Projects

Scaling Rules	Explanation	Example
Covered in pilot	Information need was covered under the pilot project licensing process. Additional funds are likely not needed for studies at the commercial scale.	Desktop studies for initial determination of economic and environmental feasibility. This information would carry over directly into commercial scale.
Continuing costs	Recurring costs that continue from pilot into commercial scale permitting processes.	Nearfield monitoring studies may continue from pilot to commercial scale, though the expectation is that pilot nearfield monitoring studies may answer many of the questions required for commercial installation, so commercial costs may be at a lower level.
Incremental increase	Additional costs associated with larger footprint of a commercial scale project. Cost increase likely to be marginal, incremental, and linear.	Resource assessment—larger project footprint may require procurement and deployment of additional Acoustic Doppler Current Profilers (ADCPs), Acoustic Doppler Velocimeter (ADVs), or other instruments, incrementally higher equipment costs and additional ship days above what would be expected for a pilot-scale project.
Multiplicative cost increase	Significant study cost increases as scale of project goes from pilot to commercial, and regulators require greater understanding of system or basin effects. Cost increase likely to be more than double the cost at the pilot scale and may increase in a non-linear fashion.	Habitat surveys and mapping may be expected to have a multiplicative cost increase if there is a large increase in footprint from pilot to commercial scale, or if a farfield habitat baseline survey is required.
Additional study	Larger scale projects may require studies that are in addition to	Farfield or ecosystem monitoring— Preinstallation

	those required for a pilot project.	studies that characterize valued species (fish, birds, marine mammals) will be needed at up to the basin-scale. If effects of a commercial project are considered to extend beyond the nearfield, or if regulators require "Before After Control Impact" (BACI)- style monitoring in the post-installation phase, completely new studies may be required.

Siting and scoping costs at commercial scale will increase incrementally over pilot scale costs, as the footprint of the OWC farm increases. However these costs will remain a relatively small fraction of total costs.

Pilot scale pre-installation studies may satisfy many of the regulatory needs at the commercial scale. However commercial scale projects may raise new questions about farfield or ecosystem effects, and as a result, additive studies may be necessary to assess baseline health for species of concern. Detailed hydrodynamic modeling may also be needed to inform array siting and to understand potential water quality and sediment transport effects. Finally, habitat mapping costs could increase multiplicatively when device numbers cross a threshold where farfield effects might be expected; this could lead to regulatory requirements for habitat mapping and assessment of a much larger area than that immediately adjacent to the array and associated infrastructure.

As with the pilot-scale assessment, there is considerable uncertainty in costs associated with post-installation monitoring for commercial developments. Some of the post-installation studies carried out at the pilot scale are likely to continue. However, information collected during monitoring of pilot scale devices may satisfy a number of regulatory questions, particularly the risk of direct effects of devices on animals. As with pre-installation studies, increases in post-installation monitoring costs may be related to additional studies to understand farfield or ecosystem effects resulting from large arrays of devices.

3.3 Profile of Post Installation Monitoring Costs

Until sufficient data exist to anticipate interactions of OWC devices with marine animals and habitats, extensive monitoring is likely to be required during the initial years of deployment at the commercial scale, resulting in front-loading of costs in the first five years. These costs are expected to reduce sharply to an annual baseline level, with periodic increases in activity to validate the trends seen in the first five years, and to address new questions or concerns as they arise. Figure 1 shows a cost profile over the course of a thirty-year license term for the large commercial OWC project. Note the general shape of this graph would be identical to the monitoring costs for a small commercial OWC, but has higher costs at the larger scale.

Monitoring Costs Per Year for Large Commercial OWC Project

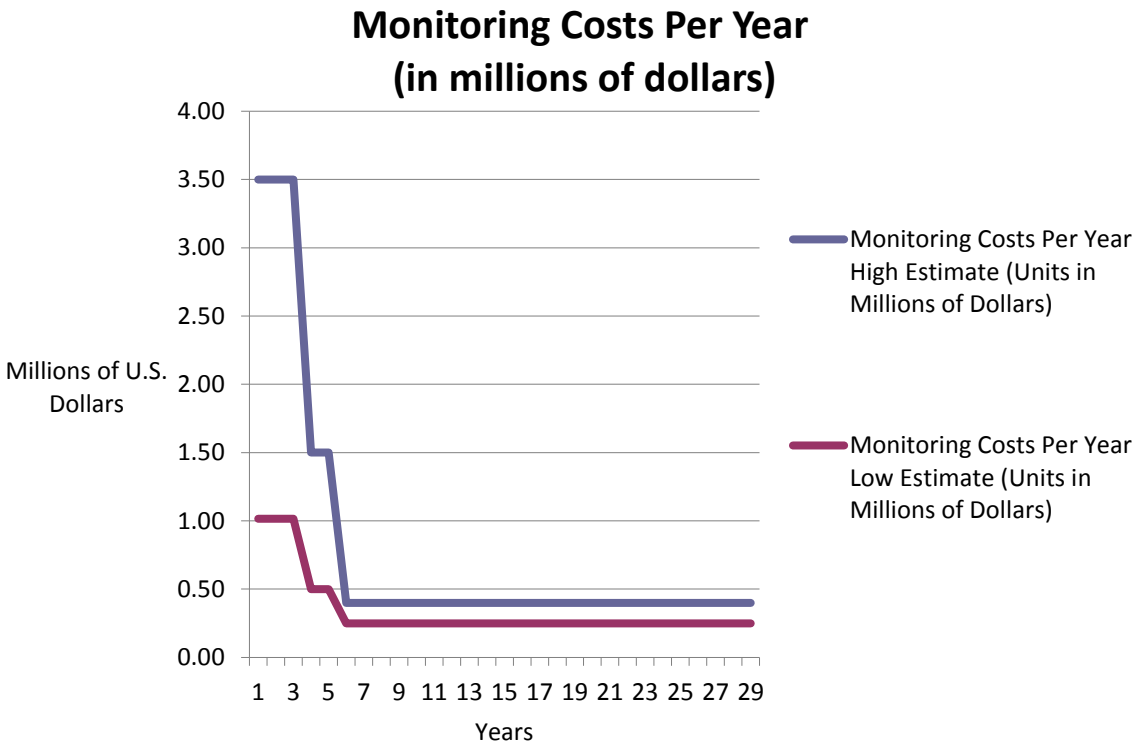

Figure 1. Hypothetical cost profile for monitoring costs over a thirty-year license term for the large commercial-scale OWC farm

3.4 Potential for Cost Savings and Refined Estimates

The process PNNL used to estimate costs of environmental studies and permitting relied heavily on information from developers, researchers and consultants involved in facilitating deployment of MHK devices in the U.S. The variability of cost estimates shown for environmental studies and permitting are large, as reflected by the cost ranges (low estimate, high estimate) shown, and represent preliminary answers that require more investigation before they can be seen as reliable contributors to the COE. Each major study has been costed independently; in reality there may be considerable cost savings if baseline and monitoring studies for various organisms are combined. For example, combining shore-based observer assessments of marine mammals and sea birds will reduce the costs of monitoring; similarly, acoustic monitoring for aquatic mammals and fish can be conducted during the same cruise, using an array of acoustic imaging devices and hydrophones. Where possible, these potential efficiencies were captured in low cost estimates and described in the assumptions, but considerable variability can still be expected. With a limited number of U.S. MHK projects approaching deployment, there have been limited sources of cost data available during this study. Future iterations of this process will help hone the costs of studies and permitting, as well as determine the proportionate contributions to the COE.

The cost ranges shown for the OWC technology reflect choices among the studies, as indicated by the logic models. As we learn more about the conditions found at proposed MHK sites, the potential effects of these devices on marine animals, habitats and ecosystem processes, and the studies required to understand and address these effects, the logic models could be revisited, with further refinement of the list of studies and associated costs for each stage of development.

3.5 Cost Differences among MHK Technologies

Factors such as waterbody characteristics, MHK technologies, and the marine animals and habitats indigenous to the site will be reflected in differences among permitting and siting costs for MHK projects in the U.S. As more MHK sites are chosen for development, additional permitting requirements and siting complexities may arise causing even greater divergence in permitting and siting costs.

The reference site for the OWC RM#6 is located in approximately 50 meters of water in a coastal northern California location, similar to RM#3. Extensive pre- and post- installation monitoring will be needed to better understand the interaction between this device and migratory marine mammals, fish and reptiles; endangered species like the gray whale, Stellar sea lion, Chinook salmon, and green sturgeon will inhabit this coastal environment during their migratory routes and for feeding. RM#6 differs from RM#3 (WEC Point Absorber) in several significant ways: the very large superstructure of the OWC may act as an attraction to birds; the air turbine above the water may have acoustic impacts (105-140 dB) on wildlife or potentially present a nuisance to recreational users of the area; the presence of large air chambers beneath the device could potentially present an entrainment risk to fish, marine mammals, or diving birds; and finally, long mooring lines (two 810-meter lines port and starboard, and one 200-meter line aft, arranged in a three-point mooring) may present a greater risk to habitat from dragging or present a risk of fishing gear entanglement, that may in turn endanger fish, marine mammals, diving birds, sea turtles and some invertebrates. Finally, the devices are much larger than a typical point absorber buoy, and an array of 50+ devices would require considerably more space than a similar sized array of RM#3 devices. Greater site dimensions are likely to increase the area of potential environmental effects and drive higher survey and monitoring costs.

4.0 Conclusions

Estimating costs of environmental studies and permitting provides input to the COE, and also serves other purposes. These estimates may assist developers in determining upfront and ongoing costs of developing projects, as well as planning linked studies from pre-installation assessment to post installation monitoring, and developing mitigation strategies. Probably most important, the process of determining appropriate studies to meet regulatory needs can assist the standardization of a pathway for installing MHK projects in the water and expanding towards commercial production of power.

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Appendix A—Costing Tables

Summary Table of Reference Model # 6 (OWC WEC)

Information Need	Pilot		Small Scale Commercial		Large Scale Commercial	
	Low	High	Low	High	Low	High
Siting & Scoping	$240,000	$390,000	$330,000	$530,000	$330,000	$530,000
Pre-Installation Studies	$1,218,000	$2,047,000	$1,753,000	$3,452,000	$2,233,000	$4,537,000
Post-Installation	$660,000	$1,050,000	$9,355,000	$19,800,000	$10,705,000	$24,150,000
NEPA & Process	$800,000	$1,400,000	$1,100,000	$2,300,000	$1,300,000	$2,550,000
Total	$2,918,000	$4,887,000	$12,538,000	$26,082,000	$14,568,000	$31,767,000

Pilot Siting and Scoping

Information Need	Specific Studies	Low Cost (USD)	High Cost (USD)	Key Assumptions
Resource Assessment—Maximum Available Power	Assessment of waves heights, lengths, periods over seasons	90,000	90,000	Access to NCEP-NOPP Wavewach III 30-yr hindcast dataset. 1) obtain wave climate parameters; 2) construct wave spectra (and calibrated spectral shape coefficients if data available); 3) calculated wave power density and estimate wave energy flux; 4) report
Environmental Scoping	Desktop study—review existing information on key species and habitats as well as competing uses.	50,000	100,000	Used for preliminary NEPA scoping and to identify key information needs for pre-installation studies.
Community Outreach	Targeted information delivery, community meetings, workshops	50,000	80,000	Development of materials and information to address anticipated stakeholder concerns and frame the value of the project to the community, attending or hosting 3-4 meetings with existing organizations. Would inform NEPA process.
Regulatory Outreach	Policy and regulatory analysis, reach out to regulators for future NEPA process	50,000	120,000	Low: 6 meetings total with agency personnel (FERC, USFWS, NMFS, CDFG, FERC); High: 12 meetings total with agency personnel; Assumes all meetings are local and no travel costs
Total		**240,000**	**390,000**	

Pilot Pre-Installation Studies

Information Need	Specific Studies	Low Cost (USD)	High Cost (USD)	Key Assumptions
Seabed Survey and Mapping	Side-scan survey of site area, ROV survey at site, compile data and create georeferenced site maps.	110,000	110,000	Cost for field work + equipment; includes 2 days to survey project site and cable route ($47 k). Mapping assumes lab work, data enter, analysis, and report writing ($62 K)
Marine Mammals	Baseline—distribution, speciation, and behavioral analysis: acoustic monitoring, vessel-based observation, and literature review.	485,000	620,000	1 year study. Large vessel for gray whale surveys in spring and winter; small vessel surveys for resident gray and humpbacks in summer and fall; acoustic monitoring with autonomous recorders for other species (i.e., dolphins and porpoises)- includes boat time to set and retrieve recorders.
Fish and Invertebrates	Baseline—distribution, speciation, and behavioral analysis: Telemetery and tagging for sturgeon, grab samples for invertebrates, trapping for crabs, trawling and for midwater fish, purse seine/plankton tow/gill net for surface pelagics.	469,000	765,000	1-2 years of pre-installation monitoring as required by agencies; 1) Telemetry receivers to detect tagged ESA-listed sturge on; 2) Grab sampling to assess benthic inverts; 3) Trapping to assess Dungeness crab; 4) Trawling to assess demersal fish and benthic invertebrates; 5) surface pelagics may be sampled with purse seine, gill nets, or plankton tow.
Seabirds	Baseline—distribution, speciation, and behavioral analysis: small boat surveys and line transects	37,000	150,000	1 year of surveys; Low: assumes 6 surveys done in conjunction with marine mammal surveys, 6 done independently. High: assumes 24 surveys/year done independently.
Turtles	Baseline—distribution, speciation, and behavioral analysis of T&E turtles in project area	12,000	38,000	1 year of surveys. Low: surveys done in conjunction with marine mammal and seabird boat surveys, no equipment charges; High- surveys done from small aircraft
Water Quality	Water quality meter point casts from boat; contaminants analysis in lab. Also includes characterization used to assess sediment transport	40,000	54,000	Low estimate is if paired with fish and invertebrate studies (no boat charges); High is to conduct separate water quality measurements.

Habitat	Benthic surveys covered in seabed analysis above. Nearshore surveys conducted by plant ecologists	20,000	20,000	Botanical surveys, dune surveys. 1 week (5 d), assumes no new transmission line. Does not include wetland delineation.
Cultural Resources	Three phases: Inventory, testing, data recovery	15,000	195,000	Low estimate is for historic properties inventory only. High estimate reflects testing and data recovery that would only be necessary if sites are found that cannot be avoided. Estimates are for shoreline sites only; seabed survey would identify submerged cultural resources that could be avoided through siting.
Navigation	Establish vessel traffic baseline, risk assessment.	10,000	15,000	AIS transponder near project to record ship tracks; data used in Coast Guard consultation.
Recreation	Recreation overview and initial impact assessment	20,000	80,000	Focus on boat and shore based fishing, sail and powerboat navigation and access, surfing, shore-based use in viewshed. 3-9 month study, interviews, site visit, meetings with developer and staff, summary of existing data, summary report.
Total		**1,218,000**	**2,047,000**	

Pilot Post-Installation Studies

Information Need	Specific Studies	Low Cost (USD)	High Cost (USD)	Key Assumptions
Marine Mammals, Sea Turtles, and Fish	Monitoring—Strike, entanglement, aggregation effects, avoidance effects.	300,000	425,000	(costs are for one year of monitoring—multiple years may be required) Equipment costs includes lights and camera package (above and below water), hydrophones, active acoustics (150-275k). Operating costs are recurring yearly and include surveys of lines for entanglement (100-150k). Tremendous uncertainty here—costs could be much higher depending on agency needs.
Seabirds	Monitoring—Strike, aggregation effects, avoidance effects.	150,000	250,000	(costs are for one year of monitoring—multiple years may be required) Above water cameras to assess bird behavior and strike. Radar and infrared detection. Roosting on deck of device a primary concern. Costs could be much higher depending on agency needs.
Benthos	Periodic survey and sampling to determine effects on benthic organisms and community	150,000	300,000	(costs are for one year of monitoring—multiple years may be required) ROV surveys, six surveys over three years.

Acoustic Characterization Monitoring	Sound produced by WECs and air turbines (above and below water)	60,000	75,000	(costs are for one year of monitoring—multiple years may be required) Monitoring devices above and below water, equipment costs 50-65k, recurring costs for analysis of 10k per year.
Total		660,000	1,050,000	

Pilot NEPA and Process

Information Need	Specific Studies	Low Cost (USD)	High Cost (USD)	Key Assumptions
NEPA Document Preparation	Consulting firm contract	600,000	1,000,000	Agency consultation, Biological Assessment, MMPA permits, 404 water quality permit, CZMA, draft and final EIS, draft and final license agreement.
Monitoring and Study Plans	Consultants or research partners	200,000	400,000	Separate study plans prepared for 1) marine mammals & sea turtles, 2) fish, invertebrates, & water quality, 3) seabirds. Also, preparation of adaptive management plan if needed. Assumes several iterations for each study plan needed to satisfy agency concerns.
Total		**800,000**	**1,400,000**	

Pilot Total

	Pilot	
Information Need	**Low**	**High**
Siting & Scoping	**$240,000**	**$390,000**
Pre-Installation Studies	**$1,218,000**	**$2,047,000**
Post-Installation	**$660,000**	**$1,050,000**
NEPA & Process	**$800,000**	**$1,400,000**
Total	**$2,918,000**	**$4,887,000**

Commercial Siting and Scoping for OWC

Information Need	Specific Studies	Small Scale Commercial (Low Estimate, USD)	Small Scale Commercial (High Estimate, USD)	Large Scale Commercial (Low Estimate, USD)	Large Scale Commercial (High Estimate, USD)	Scaling Rules—Scaling up from pilot
Preliminary Resource Assessment—Feasibility	Desktop feasibility—max flow rate, cross sectional area, length of channel: Theoretical resource	0	0	0	0	**Covered in Pilot—**Study at pilot scale directly applicable to small- and large-scale commercial.
Environmental Scoping	Desktop study—review existing information	10,000	10,000	10,000	10,000	**Incremental Increase—**Pilot study $50k-$100k provides most of the necessary information, will need to be updated for the commercial process.
Community Outreach (Note: Community outreach continues through all project phases)	Targeted information delivery, community meetings, workshops	50,000	80,000	50,000	80,000	**Continuing Cost, Incremental Increase—**Pilot costs: $50k-$80k: Outreach budget may double for commercial scale, based on the difference in length of permitting process—anticipated at 1.5 years for a pilot, 5 years for a commercial project. Longer process will required more in-depth outreach, more public meetings, greater need for facilitated stakeholder interactions. Potential for broader stakeholder group.
Regulatory Outreach	Policy and regulatory analysis, reach out to regulators for future NEPA process	30,000	50000	30,000	50000	**Continuing Cost, Incremental Increase—**Pilot costs: $50k-160k: Regulatory analysis completed during pilot, however, additional agency interaction around project scoping likely needed at small and large commercial scale. Majority of costs associated with agency interactions and studies are accounted for under NEPA and Process phases.
Total		**90,000**	**140,000**	**90,000**	**140,000**	

Commercial Pre-Installation Studies

Information Need	Specific Studies	Small Scale Commercial (Low Estimate, USD)	Small Scale Commercial (High Estimate, USD)	Large Scale Commercial (Low Estimate, USD)	Large Scale Commercial (High Estimate, USD)	Scaling Rules—Scaling up from pilot
Detailed Resource Assessment—Hydrodynamic Modeling of Maximum Extractable Power	Consider array effects and insert hypothetical MHK device into wave model developed for preliminary assessment.	80,000	200,000	80,000	200,000	**Additive Study—**Would not be likely in pilot-scale, detailed hydrodynamic modeling would be more useful at commercial scale.
Seabed Survey, Mapping and Bottom Composition	Side-scan survey of site area, ROV survey at site, optional survey of bottom composition below seabed	30,000	50,000	100,000	300,000	(Small Commercial) Incremental Increase over Pilot Costs: $110k (Large Commercial) **Incremental Increase—**Larger project footprint would necessitate additional ship time and potentially additional ROV survey to facilitate siting.
Marine Mammals	Baseline Condition—Population analysis, food availability and preference, reproduction—compare to existing data (assuming availability)	30,000	100,000	120,000	250,000	**Additive Study—**Pilot Costs: $485k-$620k. Baseline at pilot scale collected population, distribution, and behavior to assess direct effects. Pilot scale information will be applicable to commercial scale, but additional studies needed to assess system-wide effects on habitat and food supply due to operation of arrays. Could be used in potential BACI-like monitoring studies, if required.
Fish	Baseline Condition—Population analysis, food availability and preference, reproduction—compare to existing data (assuming availability)	30,000	100,000	250,000	370,000	**Additive Study—**Pilot Costs: $469k-$765k. Baseline at pilot scale collected population, distribution, and behavior to assess direct effects. Pilot scale information will be applicable to commercial scale, but additional studies needed to assess system-wide effects on habitat and food supply due to operation of arrays. Could be used in potential BACI-like monitoring studies, if required.

Seabirds	Baseline Condition—Population analysis, food availability and preference, reproduction—compare to existing data (assuming availability)	30,000	100,000	30,000	100,000	**Additive Study—**Pilot Costs: $37k-$150k. Baseline at pilot scale collected population, distribution, and behavior to assess direct effects. Pilot scale information will be applicable to commercial scale, but additional studies needed to assess system-wide effects on habitat and food supply due to operation of arrays. Could be used in potential BACI-like monitoring studies, if required.
Turtles	Baseline Condition—Population analysis, food availability and preference, reproduction—compare to existing data (assuming availability)	30,000	100,000	30,000	100,000	**Additive Study—**Pilot Costs: $12k-$38k. Baseline at pilot scale collected population, distribution, and behavior to assess direct effects. Pilot scale information will be applicable to commercial scale, but additional studies needed to assess system-wide effects on habitat and food supply due to operation of arrays. Could be used in potential BACI-like monitoring studies, if required.
Water Quality/Sediment Transport Modeling	Baseline—CTD point casts; sediment transport modeling to indicate changes to shoreline processes and beach runup	75,000	150,000	100,000	220,000	**Additive Study**—WEC arrays may raise concerns for sediment transport processes and effects to shoreforms. Sediment transport modeling may be required at both small- and large-scale commercial, and validation sampling. CTD casts and sediment traps may also be required.
Habitat	From seabed survey conducted in pilot, development of habitat maps and nearshore survey	30,000	50,000	80,000	375,000	(Small commercial) **Incremental Increase**—Small increase in costs to factor in studies habitat mapping for a slightly larger project footprint. At the small commercial scale, you still do not expect far field effects on habitat from turbine operation. (large commercial) **Multiplicative Increase—**when WEC numbers cross a threshold where you would begin to expect far field effects associated with sediment transport and shoreforms, habitat assessment and mapping would likely be required for a larger area. May require additional surveys and data collection, such as LIDAR.
Acoustic Baseline Modeling and Measurement	Measurement and modeling to assess ambient acoustic environment.	75,000	150,000	75,000	150,000	**Additive Study--**Potential for air turbines to have effects on the acoustic environment may be a regulatory concern. Studies to characterize the baseline undersea acoustic environment are necessary to assess future changes.

Cultural Resources	Three phases: Inventory, testing, data recovery	0	30,000	15,000	30,000	**Incremental Increase**—Increasing the area of potential effect offshore would increase the likelihood that submerged cultural resources would be found requiring documentation or mitigation. This estimate assumes that the nearshore footprint of the cable landing is the same at all project phases. If nearshore or shore-based footprint were to grow, costs would also grow.
Navigation	AIS transponder, risk assessment	0	0	10,000	20,000	(Small Commercial) **Covered in Pilot—**Small commercial, similar footprint to pilot-scale, pilot studies would be applicable. (large Commercial) **Incremental Increase—**larger footprint than pilot and small commercial may require additional studies or data processing.
Recreation and Socio Economic	Additional assessment costs above pilot for more precision, focus groups or panel evaluations, survey based evaluations, descriptive use information study, evaluation of changes to recreational resource. Also surveys to assess effects on recreational and commercial fisheries and other human uses.	125,000	375,000	125,000	375,000	**Additive Studies—**Larger project area, greater potential risk to recreational opportunities, may require more detailed and intensive studies to understand potential effect on recreational resources and mitigation strategies
Total		**535,000**	**1,405,000**	**1,015,000**	**2,490,000**	

Commercial Post-Installation Studies

Information Need	Specific Studies	Small Scale Commercial (Low Estimate, USD)	Small Scale Commercial (High Estimate, USD)	Large Scale Commercial (Low Estimate, USD)	Large Scale Commercial (High Estimate, USD)	Scaling Rules—Scaling up from pilot
Marine Mammals and Turtles	Nearfield Monitoring—Strike, entanglement, aggregation effects, avoidance effects, effects from acoustic output of air turbines.	30,000	325,000	30,000	600,000	**Continuing Costs:** Monitoring at the pilot scale will have established effects at the nearfield; costs for small commercial nearfield monitoring will be lower or remain at the same level per year. At the low end of range, periodic surveys expected. At the high end, continuation of nearfield visual and acoustic monitoring (farfield monitoring is an additive study costed below under "Ecosystem Effects"). Effects of avoidance from large scale commercial array may need to be studied, leading to costs beyond those at pilot scale. Costs are per year—potentially recurring for 2-3 years at high costs, and continuing at a lower level of effort and cost for the term of the license.
Fish	Nearfield Monitoring—Strike, aggregation effects, avoidance effects, effects from acoustic output of air turbines.	30,000	325,000	30,000	600,000	**Continuing Costs:** Monitoring at the pilot scale will have established effects at the nearfield; costs for small commercial nearfield monitoring will be lower or remain at the same level per year. At the low end of range, periodic surveys expected. At the high end, continuation of nearfield visual and acoustic monitoring (farfield monitoring is an additive study costed below under "Ecosystem Effects"). Effects of avoidance from large scale commercial array may need to be studied, leading to costs beyond those at pilot scale. Costs are per year—potentially recurring for 2-3 years at high costs, and continuing at a lower level of effort and cost for the term of the license.

Seabirds	Nearfield Monitoring—Strike, aggregation effects, avoidance effects, effects from acoustic output of air turbines.	30,000	150,000	30,000	150,000	**Continuing Costs:** Monitoring at the pilot scale will have established effects at the nearfield; costs for small commercial nearfield monitoring will be lower or remain at the same level per year. Use of cameras (infrared and visible light(used to monitor roosting. (farfield monitoring is an additive study costed below under "Ecosystem Effects"). Costs are per year—potentially recurring for 2-3 years at high costs, and continuing at a lower level of effort and cost for the term of the license.
Benthos	Periodic survey and sampling to determine effects	200,000	400,000	250,000	500,000	**Continuing Cost/ Incremental Increase:** Monitoring at the pilot scale (if applicable) will have established effects at the nearfield; Due toanchor configuration of device (significant anchor chain with potential to draf on seafloor) benthic monitoring is litely to be a priority, requring quarterly ROV surveys over initial years of monitoring. Larger footprint at large scale commerical increases costs. Costs are per year—potentially recurring for 2-3 and continuing at a lower level of effort and cost for the term of the license.
Ecosystem Effects Seabird	Assess changes to pre-installation population analysis, fitness, food availability and preference, reproduction—compare to existing data (assuming availability)	200,000	500,000	200,000	500,000	**Additive Study—**If there is regulatory concern that the scale of a project is likely to result in food chain or ecosystem effects on species of concern, monitoring may be required to assess changes based on pre-installation baseline studies. Studies may not be required for small-scale commercial deployments. If Before After Control Impact (BACI)-type studies are required for large commercial deployments, cost could be very high and have tremendous effects on project feasibility. Costs are per year — potentially recurring for 3-5 years at high costs, and continuing at a reduced effort and cost for the term of the license. Costs may increase periodically (approximately every five years) for additional survey effort or equipment replacement.

Ecosystem Effects Marine Mammals and Turtles	Assess changes to pre-installation population analysis, fitness, food availability and preference, reproduction—compare to existing data (assuming availability)	200,000	500,000	200,000	500,000	**Additive Study—**If there is regulatory concern that the scale of a project is likely to result in food chain or ecosystem effects on species of concern, monitoring may be required to assess changes based on pre-installation baseline studies. Studies may not be required for small-scale commercial deployments. If Before After Control Impact (BACI)-type studies are required for large commercial deployments, cost could be very high and have tremendous effects on project feasibility. Costs are per year—potentially recurring for 3-5 years at high cost, and continuing at a reduced effort and cost for the term of the license. Costs may increase periodically (approximately every five years) for additional survey effort or equipment replacement.
Acoustic Effects on Human Uses	Assess how air turbine noise affects recreational, cultural, and other uses of project area and surrounding environment.	50,000	100,000	50,000	100,000	**Additive Study--**Monitoring to determine the level and frequency of sound produced by air turbines; and then survey, interviews, and other methods to understand how sound affects human uses of project area and surrounding environment.
Navigation	Assess effects of devices and moorings on surface vessel and submarine navigation	25,000	50,000	25,000	50,000	**Additive Study--**Interviews, surveys, monitoring incident reports to assess navigational changes due to presence of an array.
Ecosystem Effects Fish	Assess changes to pre-installation population analysis, fitness, food availability and preference, reproduction—compare to existing data (assuming availability)	200,000	500,000	200,000	500,000	**Additive Study—**If there is regulatory concern that the scale of a project is likely to result in food chain or ecosystem effects on species of concern, monitoring may be required to assess changes based on pre-installation baseline studies. Studies may not be required for small-scale commercial deployments. If Before After Control Impact (BACI)-type studies are required for large commercial deployments, cost could be very high and have tremendous effects on project feasibility. Costs are per year— potentially recurring for 3-5 years at high costs, and continuing at a reduced effort and cost for the term of the license. Costs may increase periodically

						(approximately every five years) for additional survey effort or equipment replacement.
Total		**965,000**	**2,850,000**	**1,015,000**	**3,500,000**	**(Per Year)**
30 Year Total		**8,695,000**	**18,750,000**	**10,045,000**	**23,100,000**	**(Based on 30-year monitoring cost profile illustrated in chart below)**

Commercial NEPA and Process

Information Need	Specific Studies	Small Scale Commercial (Low Estimate, USD)	Small Scale Commercial (High Estimate, USD)	Large Scale Commercial (Low Estimate, USD)	Large Scale Commercial (High Estimate, USD)	Scaling Rules—Scaling up from pilot
NEPA Document Preparation	Consulting firm contract	100,000	500,000	300,000	750,000	**Incremental Increase**—NEPA documents from pilot project will inform preparation of commercial scale document. But longer process, higher potential for environmental effects, and greater agency scrutiny will likely require additional work.

Monitoring and Study Plans	Consultants or research partners	200,000	400,000	200,000	400,000	**Incremental Increase**—Study plans from pilot project will inform preparation of commercial scale document. But costing of ecosystem-type monitoring studies and additional scope of studies due to longer process, higher potential for environmental risk, and greater agency scrutiny will require Additive Study plan preparation.
Total		**300,000**	**900,000**	**500,000**	**1,150,000**	

Commercial OWC Totals

Information Need	Small Scale Commercial (Low Estimate, USD)	Small Scale Commercial (High Estimate, USD)	Large Scale Commercial (Low Estimate, USD)	Large Scale Commercial (High Estimate, USD)	Notes
Siting and Scoping	90,000	140,000	90,000	140,000	**Preliminary Permit, scoping, and lead up to DLA**
Pre-Installation Studies	535,000	1,405,000	1,015,000	2,490,000	**From final license agreement through baseline data collection phase**
Post-Installation	**8,695,000**	**18,750,000**	**10,045,000**	**23,100,000**	**Over the course of the 30 year license**
NEPA and Process	300,000	900,000	500,000	1,150,000	**Over the course of the FERC licensing process, Preliminary permit to FLA**
Total	**9,620,000**	**21,195,000**	**11,650,000**	**26,880,000**	**(additional costs above those incurred in pilot)**

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