Hydrokinetic Energy in the United States - Resources, Challenges and Opportunities

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Abstract

Renewable energy sources in the U.S. account for about 8.5% of the electricity produced nationwide, 6.5% of which comes from conventional hydropower plants. The total U.S. generation potential of emerging marine renewable energy sources, including wave, tidal, ocean currents and river hydrokinetic power, could provide a significant contribution to the U.S. renewable energy mix. This paper discusses the resource potential for power generation within different geographic regions and addresses current initiatives and barriers to development in the U.S.

Research by the Electric Power Research Institute (EPRI) suggests that the total recoverable resource is equal to about 10% of the present U.S. electricity consumption. While these initial assessments provide a good first order indication of the resource potential, it is important to understand that many factors, such as electrical transmission capabilities, economic viability, environmental concerns and socio-economic considerations, impose additional limits onto these resources that may substantially alter the recoverable resources. Given the present technical, environmental and economic uncertainties, it is important to pursue all of these marine hydrokinetic resources in a sensible and strategic manner.

While the U.S. lags behind Europe in research, development and demonstration (RD&D) activities in the sectors of hydrokinetic energy conversion, interest in the U.S. is emerging: project developers, the states and the federal government are turning their attention to marine renewable technology. For example, the Department of Energy has begun active research in this area with an initial funding level for FY2008 of $10 million, in addition to many state initiatives that are strategically pursuing these emerging generation resources.

Significant technical, economic, environmental and regulatory barriers remain to be addressed in order

for this emerging industry to move forward with large-scale commercial development. Experience with hydrokinetic energy conversion is thus far limited to a few prototype installations and provides a limited understanding of these issues. As such, it will be critical for the success of this industry to gain a full understanding of potential issues over a project lifecycle. Such understanding can only be gained in a sensible way from developer demonstration projects and early commercial adopters. Both market push (R&D) and market pull mechanisms (financial deployment incentives) will be required to successfully move this technology sector forward and develop the capabilities to sustainably tap into the enormous potential of ocean energy.

Keywords: United States, Resources, Programs, Policy

1 The Resources

The two main characteristics of quantifying these marine renewable resources are power density and the size of the recoverable resource. The power density is a good indicator of how cost-effectively the power from a resource can be extracted (i.e., higher power densities yielding lower cost of electricity); the recoverable resource size provides an understanding of the potential impact the resource can have on meeting future energy needs, and is therefore important in determining if substantial investments into the sector are warranted. This paper focuses on the resources available for large-scale generation of power which could thus meet a significant portion of future U.S. electricity demand.

EPRI studies [1,2] showed that ocean wave energy with suitable power densities can be found primarily on the U.S. West Coast (California, Oregon, Washington), as well as Alaska and Hawaii. Power densities on the U.S. East Coast are not likely to become economically competitive in the near future. The total deep water resource is estimated to be about 2,100 TWh/year. If 15% of the resource is extracted and converted into electricity using wave power conversion machines with 90% power conversion efficiency and 90% availability, wave power could provide about 252 TWh/year of electricity.

Suitable power densities for tidal power conversion are localized to specific sites, where a naturally occurring geographic restriction focuses the fluid flow, therefore creating fluid power densities that are suitable for economic extraction of power. These tidal sites can be found in Maine, Puget Sound in Washington State, and Alaska. A number of site-specific studies by EPRI [1,2] revealed the recoverable potential to be about 0.5TWh/year on the East Coast, 4 TWh/year for eight sites studied in the Puget Sound, and about 100 TWh/year in a few dozen sites studied in Southeast Alaska, the Aleutian Islands and Cook Inlet, Alaska.

Initial measurements of the Gulf Stream show power densities of > 2kW/m^2 on the transect between Florida and the Bahamas. About one quarter of the Gulf Stream's water volume moves through this area. Florida Atlantic University [2] has an active ocean energy program in place, and initial estimates suggest an average recoverable resource of between 4 and 10 GW from that site. This results in an energy extraction potential of about 50TWh/year from this single deployment area.

A high-level study carried out by NYU in 1986 suggested that about 110 TWh/year could be extracted from rivers using in-stream hydrokinetic energy conversion. Initial feasibility studies revealed that this may be a feasible resource option for remote village electrification in places like Alaska.

While the U.S. has substantial offshore wind and Ocean Thermal (OTEC) resources, these resources are not discussed in this paper.

2 Active Programs and Projects

While the U.S. lags behind Europe in R&D activities in these hydrokinetic energy sectors, project developers, the states and the federal government have expressed considerable interest. The following section outlines the major programs and projects that are actively moving forward.

Department of Energy

In 2009, the U.S. Department of Energy (DOE) was appropriated 40 million USD to conduct research and development on advanced water power energy generation technologies, including both marine and hydrokinetic technologies (wave, tidal, ocean current, in-stream hydrokinetic and ocean thermal), as well as conventional hydropower (any technology that uses a dam or diversionary structure). This marks a significant increase in funding from the 10 million USD appropriated in 2008, which was the first year wave and tidal power research was supported by the Department.

DOE's wave and tidal power research is focused on assessing the potential recoverable energy from these resources in the U.S. and facilitating the development and deployment of technologies to fully realize this potential. Marine and hydrokinetic technologies represent a substantial opportunity for the U.S. to engage directly in an emerging area of energy science and discovery, while developing an entirely new suite of renewable technologies available to reduce emissions, revitalize stagnant sectors of the economy, and help states meet RPS targets.

The Department's priorities for wave and tidal power include 1) facilitating the deployment of prototypes and collecting data on their energy conversion performance and their environmental, navigational and competing-use impacts; 2) determining the available, extractable and cost-effective resources in the U.S; 3) characterizing and comparing the wide variety of existing marine and hydrokinetic technologies; 4) improving technology performance and reliability and reducing technology development costs; and 5) minimizing the cost, time and negative impacts associated with siting projects.

In 2008, the majority of DOE funding for wave and tidal power was awarded to specific technology and project development efforts, selected through a competitive process. These awarded efforts included: the preparation of detailed design, manufacturing and installation drawings of a bi-directional air turbine for application in a floating Oceanlinx oscillating water column; engineering design, baseline environmental studies, and license construction and operation applications to help Pacific Gas and Electric, the largest investor-owned utility in California, develop a hub to deploy wave energy converters and connect them to the grid; the design, fabrication and testing of an improved turbine blade design structure for Verdant Power, Inc; and a program to conduct in-water testing and demonstration of tidal flow technology as a first step toward the deployment of a commercial tidal power facility by the Snohomish Public Utility District, a municipal utility in Washington State. In addition, the Department selected and funded two National Marine Renewable Energy Centers, one at the University of Hawaii, and a second run jointly by Oregon State University and the University of Washington.

Further, the DoE funded a market acceleration program, consisting of nationwide resource assessments (wave and tidal) and a collaborative project to address navigation, and environmental issues as well as clarify the permitting process. The latter project is a collaborative between re vision consulting, PCCI and Pacific Ventures.

Electric Power Research Institute

The Electric Power Research Institute (EPRI) has conducted wave, tidal in-stream and river in-stream system definition and feasibility studies over the past five years. The purpose of the EPRI studies was to determine the technical and economic feasibility of applying hydrokinetic technology at potential U.S. sites so that the nation can decide whether this technology ought to be developed as a potential alternative to add to our national portfolio of energy supply options. The EPRI studies have resulted in unprecedented, nationwide momentum toward investigating the technology in question. EPRI continues to support many of the active programs and projects.

EPRI has, in the past, made preliminary estimates of the available and recoverable ocean wave energy resources for the entire U.S., and is now beginning a new project under DOE sponsorship to more accurately determine the naturally available and recoverable resource base. The final product will include a geospatial database, verified and validated by the National Renewable Energy Laboratory (NREL) that displays power densities for specific geographic information system (GIS) coordinates. The expected users of this product include policymakers, wave energy project developers, wave energy device and technology developers, investors and universities.

Northwest National Marine Renewable Energy Center

Oregon State University (OSU) and the University of Washington (UW) have partnered to develop the Northwest National Marine Renewable Energy Center (NNMREC) with a full range of capabilities to support wave and tidal energy development in the United States. The NNMREC is supported at the national level by the United States Department of Energy for up to five years. Center activities are structured to facilitate device commercialization, inform regulatory and policy decisions, and close key gaps in understanding. The NNMREC leverages the considerable marine energy expertise, facilities and programs for the partner institutions to address the following key themes:

Testing. Wave efforts include the development of “mobile” test berths for full-scale devices. Testing and evaluation will identify best practices for maintenance and quality control of wave energy systems, and refine wave energy power measurements. Tidal efforts initially focus on the development of “mobile” instrumentation packages for site and device characterization. The packages will leverage the expertise of industry partners to address the needs of all stakeholders in a cost-effective manner.

Environmental impacts. Environmental and ecosystem impacts are evaluated through numerical models of devices operating in coastal and estuarine environments, validated by observational data from pilot testing. The focus is on the effects of large-scale device deployments.

Device and array optimization. These are addressed using detailed numerical models of devices and arrays, calibrated against observational data from pilot tests. Models are initially focused on individual devices and then will be scaled up to arrays of devices for investigation of both near- and far-field dynamics.

Resource forecasting. Wave energy forecasting is being improved for offshore locations and extended to the near-shore environment where wave energy devices will be deployed.

Survivability and reliability. These are being enhanced by the development of survivability standards,evaluation methodologies, and the application of corrosion and bio-fouling resistant materials, including new structural composites.

Results of key findings and research programs are being disseminated to all stakeholders and interested parties through workshops, conferences, publications and an online portal. To this end, the NNMREC is establish plans for intellectual property management and is coordinating activities with the other national centers.

Snohomish Public Utility District

Snohomish County Public Utility District No. 1 (PUD) is located near Seattle, Washington, and is the second largest publicly-owned utility in the Pacific Northwest, and the twelfth largest in the United States in terms of customers served. The PUD has a rapidly growing service load and is required by the Washington State Renewable Portfolio Standard (RPS) to supply 15% of its load from new, renewable energy resources by 2020. As a result of these factors, an approximate average of 140 MW of renewable energy resources needs to be added to the District's portfolio over the next twelve years. The PUD believes that tidal energy from the Puget Sound estuary has the potential to contribute significantly toward meeting this challenge, but that in-water testing is required to address uncertainties in performance, cost and environmental effects.

The PUD is partnering with OpenHydro to conduct the deployment, demonstration and testing of tidal in-stream energy conversion (TISEC) technology in the Admiralty Inlet region of the Puget Sound. The PUD currently envisions a ~1 MW pilot plant consisting of two to three OpenHydro turbines.

The PUD intends to leverage learning and experience from the Admiralty Inlet Pilot Plant project to evaluate the feasibility of tidal energy generation at four other sites of interest in the Puget Sound, for which the PUD holds preliminary permits from the Federal Energy Regulatory Administration (FERC).

The project has received funding from the Bonneville Power Administration (~500K), a grant from the U.S. Department of Energy Advanced Water Power Projects program (~$1.2 million), and additional funding via federal appropriations (~$465K). Key project partners include the University of Washington (Depts. of Mechanical Engineering and Oceanography, the Applied Physics Laboratory, and the new Northwest National Marine Renewable Energy Center); the Electric Power Research Institute; the National Renewable Energy Laboratory; and Pacific Northwest National Laboratory.

The PUD is currently consulting with local Tribal Governments and federal/state regulatory agencies regarding permitting activities and baseline/monitoring environmental studies. Puget Sound is an extremely productive marine environment which is subject to a number of environment stressors, so understanding the effects of tidal energy activities on the ecology and fish/marine mammals of the Sound is of primary importance.

The PUD will submit a draft license application for the Admiralty pilot plant to FERC in December of 2009 and envisions plant construction beginning in 2011.

Alaska Activities

Alaska possesses 95% of U.S. tidal energy resource and about 50% of the U.S. wave energy resource. A key limitation to the extraction of these resources is that most of the resource is found in remote areas and not adjacent to any electric transmission infrastructure necessary to provide power export capabilities at significant scales.

A potentially attractive tidal site is in the Cook Inlet, where transmission infrastructure is nearby good tidal resources. The possible threat posed to Cook Inlet beluga whales, listed as an endangered species by the National Marine Fisheries Service in October 2008, is one of the significant potential environmental impacts of tidal energy development in this area. Two studies were completed by EPRI on the tidal potential in the Cook Inlet and Southeast Alaska in 2006 and 2007. The Ocean Renewable Power Company (ORPC) is actively pursuing a Tidal Energy Project in the Cook Inlet and has received a FERC preliminary permit to commence project development.

Yakutat, a coastal village known as the surfing capital of Alaska, has commissioned a wave energy feasibility study which is lead by EPRI and re vision consulting. This remote fishing community is 100% reliant on diesel fuel for generating electricity.

In 2008, EPRI completed an assessment of river hydrokinetic potential for different sites in Alaska. The study included a site assessment and a system level design, performance, cost and economic assessment for representative sites. The study showed that river hydrokinetic energy conversion may be an economically attractive alternative to existing diesel generation systems, if remaining technical issues can be addressed.

The first grid-connected river in-stream project in the United States was operated briefly in August 2008 at Ruby Alaska on the Yukon River. Power output was minimal and the 5kW device was removed before river freeze-up. This project has received funding from the Alaska Renewable Energy Fund for further work and deployment of a 25kW device in 2010.

Numerous FERC preliminary permit applications have been filed for river in-stream projects in Alaska. Among others, the following projects are actively being pursued by various project developers.

A coalition of partners led by the Alaska Center for Energy and Power has received Alaska Renewable Energy Fund grant money for a hydrokinetic test center at Nenana.

The Village of Igiugig is developing a river in-stream project in coordination with the upgrade of its diesel powerhouse. This community receives diesel fuel by air in WWII tanker planes.

The community of Whitestone on the Tanana River received a FERC preliminary permit for a river in-stream project in February of 2008.

The University of Alaska at Anchorage received Alaska Renewable Energy Fund grant money for a statewide assessment of river in-stream resources in 2009.

Pacific Gas & Electric Company

Pacific Gas and Electric Company (PG&E), incorporated in California in 1905, is one of the largest combination natural gas and electric utilities in the United States. Its service territory encompasses all of Northern California, and the company delivers about 80,000 GWh of electricity to its customers annually. PG&E's service territory borders 960km of Pacific coastline with wave power densities of 20-40kW/m, making wave power a renewable energy resource of strategic interest to the utility.

PG&E is developing two sites in Northern California, near the cities of Fort Bragg and Eureka to establish WaveConnect. Similar to the WaveHub in the U.K., WaveConnect will provide the infrastructure to test small arrays of commercial wave power conversion devices in California, and therefore allow the emerging wave power industry to gain a full lifecycle understanding of these technologies deployed in the state.

PG&E has received preliminary permits from the Federal Electric Regulatory Commission (FERC) for the two sites of interest and has received a total of 6 million USD to develop the sites from the U.S. Department of Energy and the California Public Utility Commission. The company is actively moving forward with site development activities.

Florida Atlantic University, Center for Ocean Energy Technology

The Florida Atlantic University (FAU) Center for Ocean Energy Technology (COET) was established in January 2007 to investigate ocean-based solutions to Florida's energy crisis. The State of Florida is working on a suite of alternative energy solutions, and in 2008 the Florida State Legislature and the Governor established the Florida Energy and Climate Commission and the Florida Energy Systems Consortium, of which COET is a member. To date, COET has received USD 13.9M in total funding from the State of Florida and an additional USD 1.19M of Federal funding. COET's research in the area of hydrokinetic energy conversion pertains specifically to open-ocean currents and to associated energy transmission and grid integration issues.

Ocean current energy is the kinetic energy available from moving water. The Gulf Stream flows northward past the southern and eastern shores of Florida, funneling through the Florida Straits with a mass transport greater than thirty times the total freshwater river flows of the world. The ocean current energy resource in Florida has a potential generating capacity of up to 10 GW, equivalent to ten nuclear power plants – approximately one third of Florida's average electricity consumption. The Gulf Stream never stops, and its flow velocity actually increases in the summer, matching well with base-load summer-peaking energy demands. In terms of flow cross-sections, it represents an annual average power density of about 2 kW/m^2, with a summertime power density that exceeds 8 kW/m^2 in the most energy-dense sections of the current.

COET is addressing ocean energy research and technology development from a systems-level perspective, engaging expertise and knowledge to build the capability, infrastructure, and strategic partnerships necessary for the ultimate demonstration and validation of commercially-viable ocean energy systems. The program plan is phased to accommodate regulatory efforts and the systems perspective, integrating environment, ecology, resource, and energy conversion. The four phases include: (1) ocean observing and monitoring system – data collection, (2) ocean current experimental prototype, (3) cabling of instrumentation, and (4) power trunk line to shore.

COET plans to create a National Open-ocean Energy Laboratory (NOEL) that will include a permanent infrastructure offshore of South Florida to serve as an integrated, standardized testing and research range for advanced marine and hydrokinetic devices. NOEL will provide access to federal and state agencies, technology developers and universities for testing and evaluation of ocean energy systems, from small sub-scale systems to full-scale commercial systems.

Environmental and ecological research for the NOEL is needed to understand fully the open-ocean system and to provide for mitigation of potentially adverse impacts resulting from ocean energy development in the Southeastern United States. Critical research will be conducted throughout all phases of the program to provide the essential knowledge to assist State and Federal agencies in implementing all phases of permitting. COET is developing the necessary assessments required to address the permitting requirements to move on to Phase 2.

Currently, no ocean current turbines have been proven to be capable of operating in sustained ocean current or have been deployed offshore in the Gulf

Stream for more than a few hours. Thus, little, if any, knowledge exists about *in-situ* performance of this technology. To investigate these areas, COET will design, fabricate, deploy and operate a series of small-scale experimental test devices. The initial design, which is in progress, is a 20 kW open-blade axial-flow horizontal underwater turbine, driven by a 3m diameter 3-blade rotor. As knowledge is gained from each generation, design will iteratively progress toward a 300 kW test system. The focus of this research is to perform a technology assessment of the equipment, aimed at identifying gaps that need to be filled for commercial implementation, and to investigate and collect data about potential environmental impacts, providing a better foundation for future studies.

The objectives of research in the areas of energy transmission and grid integration are to provide the scientific and engineering basis for transferring electrical energy harvested offshore from numerous power generation units to shore, with minimal losses, high reliability, and minimum adverse impact on the existing electrical power grid.

In March 2009, a milestone for Phase 1 was achieved with the deployment of four Acoustic Doppler Current Profilers (ADCPs) offshore to measure water current velocities over a range of distances from 7.8 km to 35.9km, at depths from 220m to 645m. The moored ADCPs record the time history of water velocity throughout the water column at single locations with the closest to shore near the shelf break, and the furthest located in near the core on the Miami Terrace. The deployment of the ADCPs will enable researchers at FAU to gather baseline information, which is needed to characterize in detail the spatial and temporal variability of the Gulf Stream for its potential use as an abundant renewable energy source.

Oregon Activities

Wave energy has the potential to play a significant role in Oregon's economic and energy future. The state recognizes that new jobs and clean energy will result from investing in this emerging industry. Oregon has made tremendous strides over the past few years in its wave energy developments, yet it faces intense competition from national and global competitors for the industry's new jobs and economic benefits.

To establish its competitive position, the state's Oregon Innovation Council granted $4.2 million to create the nonprofit Oregon Wave Energy Trust (OWET). It is OWET's mission to establish the state as the preeminent developer of wave energy in the U.S., with the goal of producing 500 MW of clean power from its ocean—about 3-5% of the state's energy—by 2025. To achieve this mission, OWET's strategy is to maintain "technology neutrality" and focus its resources on reducing the barriers hindering the emerging wave energy industry's movement forward toward commercial development.

OWET's major activities are grouped within four major program areas:

Stakeholder Education and Engagement. Specific activities include: a) Coastal Community Open Houses, b) creating a statewide network of coastal economic and community development advisors, c) facilitating development of organized fishermen groups to participate in wave energy planning, d) showcasing at consumer events, e) producing a wave energy conference, and more.

Regulatory and Policy. Specific activities include development of Regulatory Roadmaps to help wave energy developers navigate the complex network of state and federal permit and license requirements. OWET actively monitors state legislative activities and provides wave energy industry information to legislative representatives and committees.

Market Development. OWET recently launched a *Utility Market Initiative.* This extensive project will produce an effective market strategy to integrate wave energy projects into the electric utility system and establish technical requirements to connect into the grid. OWET hopes to create a utility "pull" and wave energy "push" to help meet the target production goals. In addition to the Utility Market Initiative, an economic assessment of the wave energy industry to Oregon – which will include economic data for the fishing and crabbing industries – is underway.

Research. OWET directs and funds environmental and applied research projects to answer key questions about wave energy development. To date, it has completed baseline assessment studies on seabirds and whale migration at the proposed wave energy project sites. Throughout 2009, OWET will support additional research on seabirds, crab distribution, EMF, sediment transport, and create a planning tool to model cumulative effects of wave energy projects.

There are three projects off the Oregon Coast actively engaged in the FERC licensing process:

Reedsport – Ocean Power Technologies (OPT) is both the technology and project developer. OPT will use their Powerbuoy wave generating system.

Coos Bay – OPT also plans to develop a project off Coos Bay.

Winchester Bay (Reedsport) – Douglas County is the project developer, and Wavegen will be the technology provider.

Additional projects that are being explored along the Oregon Coast, but are not yet in the licensing process, include:

Tillamook Public Utility District and the County of Tillamook are currently evaluating multiple project sites and will serve as the project developer. Their technology is not yet identified.

Columbia Power Technologies (CPT) are aggressively pursuing a new technology and are in the early stages of site identification. They will serve as both project and technology developer.

In addition to these active projects, there have been several serious inquiries by international companies interested in locating a project in Oregon.

Another major opportunity in Oregon is the establishment of a test-berth facility. Oregon State University (OSU) and the University of Washington (UW) were awarded USD 6.25 million by the U.S. Department of Energy to develop the Northwest National Marine Renewable Energy Center (NNMREC). OSU plans to deploy various devices and subsequent environmental measurement devices at a location near Newport to study new technologies and evaluate potential environmental effects.

Hawaii Activities

In October 2008, the University of Hawaii (UH) was selected as one of two national sites for development of a Marine Renewable Energy Center (MREC). The Hawaii MREC is managed by the Hawaii Natural Energy Institute (HNEI) at UH and funded by US DOE at approximately USD 1 million per year with equivalent cost share from UH and industrial partners. The Center will comprise an international partnership between academia, industry, local and federal government agencies, and NGOs. The objectives of the Hawaii project are to facilitate the development and implementation of commercial wave energy systems with one or more systems deployed and supplying power to the local grid at greater than 50% availability within five years, and to assist the private sector to move ocean thermal energy conversion (OTEC) systems beyond proof-of-concept to pre-commercialization.

The MREC will work closely with energy developers to conduct supporting research on system performance and survivability, grid integration and environmental impacts, including completing necessary environmental studies and assisting industrial partners to acquire required permits. Partners include local engineering firms familiar with the permitting process.

The Center proposes to build upon current and proposed marine energy projects in Hawaii to accelerate establishment of up to three field test facilities for hydrokinetic systems and one for OTEC component testing. Proposed wave energy test sites include Pauwela Point on the northeast coast of Maui, building off the announced agreement between Maui Electric Company and Oceanlinx, at the Kaneohe Marine Corps Base on Oahu, where Ocean Power Technologies maintains an ongoing program, and off the Makai Research Pier located west of Makapuu Point on the eastern tip of Oahu. The latter site is proposed for obtaining long-term data series on wave energy resources, research on corrosion and innovative materials, and an easily accessible site for deployment and testing of small wave energy conversion devices and components. The Pier is already permitted for a range of marine research activities. The initial OTEC project, validation of advanced heat exchangers in collaboration with Lockheed Martin, is expected to take place at the Natural Energy Laboratory Hawaii on the island of Hawaii. NELHA has hosted numerous earlier OTEC investigations and can provide large quantities of warm and cold seawater.

Verdant Project

This paper would not be complete without mentioning the Verdant Power tidal project in the East River, New York. Initiated in 2002, Verdant Power's Roosevelt Island Tidal Energy (RITE) Project is being operated in New York City's East River.

In three phases, the RITE Project will test, demonstrate and deliver commercial electricity from Verdant Power's *Free Flow* Kinetic Hydropower System (tidal). The project is progressing from an initial demonstration array of six turbines to a full field of turbines that could generate up to 10 MW. Over 7,000 operational hours have been logged so far and the company is presently engaged in improving its rotor design in collaboration with NREL.

3 Technology Considerations

The technology landscape in this emerging sector involves technologies at various stages of development. From a programmatic perspective, there are a few important aspects that should be considered when evaluating these emerging technologies.

In the absence of empirical cost data, the projected cost of emerging technologies is largely based on techno-economic models. EPRI's experience with evaluating cost projections for a wide range of different energy technologies shows that there is a tendency to underestimate cost in the early stages of a concept development; as the technology's maturity increases, so does its projected cost. Oftentimes this is due to the fact that unforeseen engineering challenges emerge, increasing the technology's cost. The following figure shows the typical relationship between cost and development stage. The graph illustrates predicted cost between the laboratory and prototype stage and actual cost at later stages of development.

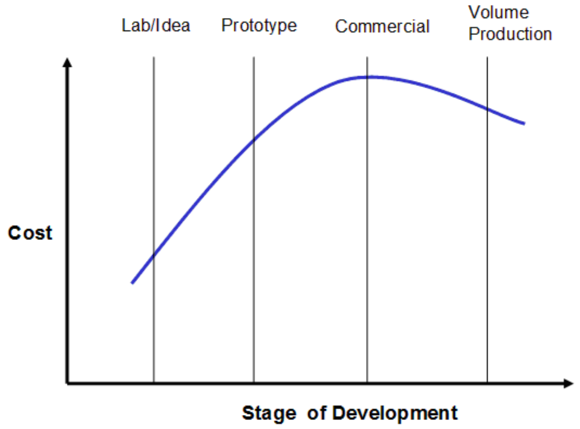

Figure 1: Cost as a Function of Development Stage

Oftentimes, the discrepancy between cost and development stage leads to early stage concepts being viewed as more competitive than more mature technologies that are closer to commercial readiness.

A second important aspect of adopting a novel technology into the market place is the comparative costliness of initial commercial deployments versus other generation options. Experience with other renewables and generation technologies indicates that the cost will reduce exponentially as the learning effects of deployment and continued RD&D drive costs down. Empirically-derived learning curves from wind, solar and other generation technologies suggest that progress ratios are on the order of 80% - 90% [3]. In other words, with every doubling of installed capacity, the generation cost will reduce by 10% - 20%. This means that in the early phases of technology development, significant cost reductions can be attained, while more mature technologies will see smaller cost reductions as a function of additional deployment scale.

A third important aspect of technology development is a phenomenon known as technology lock-in. Typically, a large number of very different concepts are pursued at the outset, and as the industry gains experience, concepts that are not performing well are eliminated. As industry converges on a few viable designs, large-scale manufacturing capabilities will be built up to construct the most promising machines. These investments into manufacturing capabilities and scientific understanding of a particular technical approach create the phenomenon known as technology lock-in. As technology lock-in occurs, it becomes more and more difficult to make radical design changes. Since the hydrokinetic sector is in an early stage of development, such lock-in has not yet occurred.

A fourth important aspect of the ocean energy sector is the relative paucity of commercial-ready designs. While there are a large number of conceptual designs in existence, only a few of them have moved to full-scale. The marine environment is harsh and difficult to work in, and it requires a significant amount of time and capital to move a design from concept to commercial readiness. It has taken Pelamis Wave Power about a decade to move from their 1/7th scale prototype to their first commercial three-unit deployment in Portugal.

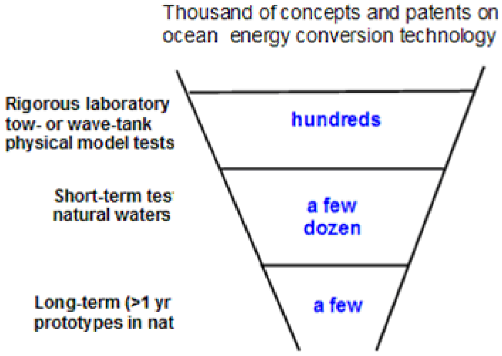

Figure 2: Technology Development Stage

One of the most important needs from an industry-wide perspective is to gain a full lifecycle understanding of these emerging concepts. Such lifecycle understanding needs to include technical, economic, operational, environmental and regulatory aspects. The only way to gain this necessary experience is by deploying technology at a meaningful scale, while conducting targeted R&D to put the accrued lessons into perspective and address relevant issues.

4 ENVIRONMENTAL AND REGULATORY CONSIDERATIONS

In the U.S., most of the projects being proposed are under the regulatory jurisdiction of the Federal Regulatory Commission (FERC), which has permitting and licensing authority in hydropower developments. The first step in the licensing process is to obtain a preliminary permit, which gives the permit holder the first right of refusal to obtain a construction and operation license for the site for the three-year duration of the permit. To date, over one hundred preliminary permit applications have been filed with the FERC.

Research conducted to date indicates that environmental impacts from many of these emerging technologies is minimal; negative socio-economic impacts can be managed; and there are some significant potential economic benefits to these emerging industries. However, regulatory bodies and the general public demand that minimal impacts are demonstrated before proceeding. A gradual scale-up of deployments, following a carefully designed approach, is likely the only way such demands can be satisfied in a sensible way.

While there are some federal and state tax incentives to build renewable power systems, these incentives are insufficient to finance early adopter projects at small scale. As a result, developers will be put in the position of having to push for large commercial installations to drive cost down, and in the process may be forced to assume the significant technical, economic and environmental risks of deploying unproven technologies at large scale.

It is clear that a sensible policy for this emerging industry needs to provide a technology-specific financial support mechanism and encourage technology diversity to spread technology risks. In order to provide optimal support for these emerging technologies, it will be crucial to have technology developers carry the technical risks and reward for the delivery of electricity, possibly through a mechanism such as the European feed-in tariffs.

The infrastructure cost (i.e. subsea electrical collector system and pre-deployment studies) of small-scale ocean energy farms oftentimes exceeds the cost of the technology themselves, and the time horizon to establish them is significant given the present regulatory and environmental uncertainties. Sharing of this infrastructure between different device developers could lower the overall project cost at the small scale required to gain commercial confidence. Decoupling the site development process from the immense challenges technology developers are facing in their technology developments would allow them to focus more of their attention and resources on technological challenges. In addition to the obvious economic advantages of providing such facilities to the industry, it will also provide a controlled environment to reduce operational and environmental risks. In the US, such facilities are encouraged through the establishment of test centers and early commercial adopter sites.

CONCLUSIONS

The recoverable potential to provide electricity from hydrokinetic energy resources is estimated to be about 10% of today's electric consumption in the United States. Initial studies suggest that given sufficient deployment scale, these technologies will be commercially competitive with other forms of renewable power generation. However, significant technical, economic, operational, environmental and regulatory barriers remain to be addressed in order to allow this emerging industry to move forward with commercial development. The experience related to ocean energy is limited to a few prototype installations and provides a limited understanding of the economic, operational, environmental and regulatory issues. It will be critical for the success of this industry to gain a full understanding of all lifecycle-related issues over the coming years to pave the way for larger scale commercial deployments. Such understanding can only be gained in a practical way from the deployment of demonstration and early commercial adopter systems. Early commercial adopter systems will not only address technology related issues, but will also provide confidence to regulators, the general public and investors. Both market push (R&D) and market pull mechanisms (economic incentives to encourage deployment) will be required to successfully move this technology sector forward and develop the capacity to harness energy from the ocean.

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