National Hydropower Association

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RE: Potential ARPA-E Programmatic Support for Marine Energy Technology Commercialization

Marine energy (also known as marine hydrokinetics and defined here to include ocean wave and current, tidal, and river current energy technologies) has the potential to become a major source of electricity for the United States. DOE has estimated that the technically extractable marine energy resource potential is almost 900 TWh/year for wave energy and almost 400 TWh/year for tidal and ocean current technologies, which together represents up to 25 percent of projected U.S. electricity generation requirements.

Representatives of the National Hydropower Association's Marine Energy Council, and other stakeholders in the marine energy industry, have engaged ARPA-E officials to discuss potential roles that ARPA-E could play to accelerate the commercialization of this emerging energy generation technology. To build on these engagements, a group of industry stakeholders worked to identify and communicate a potential role for ARPA-E to support the near-term commercialization of marine energy devices.

The result of this effort and our recommendations follow. Also, please note citations throughout the document to the References Section below.

Challenges to Commercialization Already Solved

The marine energy industry is an emerging sector with only a handful of demonstration projects in the U.S. and globally (1, 2). Numerous innovative marine energy system concepts have been supported by DOE's Water Power Program since 2008, through topical funding opportunities, SBIRs, and more recently the DOE- sponsored Wave Energy Prize (5).

To date, proof of concept experiments for numerous marine energy device configurations have been tested and demonstrated at subscale and full scale, and the fundamental theory of operation for marine energy technologies is well understood. In addition, there are simulation models for the analysis and design of marine energy devices, although additional refinements, verification, and validation are needed for these numerical models.

However, only prototype devices have been deployed in demonstration projects. The current state of the industry can be compared to the early stages of the wind energy industry, in that many concepts have been proposed with a wide variety of methods for energy capture and conversion, but with little technology convergence.

As a result, incremental, though measurable and valuable, progress has been made in the following areas:

- Generators
- Power Take-Off systems
- Advanced controls
- Innovative structures
- Advanced materials
- Resource assessments & forecasting

Primary Challenges to Commercialization

Several primary technology challenges to commercialization are presented below in priority order:

- Energy capture efficiency is low compared with theoretical limits for wave energy converters. For wave energy converters, the performance metric is *Capture Width Ratio (CWR) defined as the ratio of energy captured by the device divided by the energy flowing through the device.* Measured annual average CWR is generally in the range of 20 to 40% (see reference (3) by Babarit for a database of capture widths). Energy capture for marine current technologies is generally much closer to the theoretical Betz limit, but could still be improved when compared to the conversion efficiency of wind energy turbines. Most wind turbines have a maximum power coefficient of .45 to .50, whereas marine current turbines are generally less than .40. For both wave and current technologies, control systems are key to improving energy capture. For wave converters, it has been estimated that wave to wave control could at least double energy capture and reduce excessively high peak loads on the power converter and support structure.

- The capital cost of the basic structure is a significant contribution to the overall capital cost of both wave and current marine energy converters. The marine energy reference model studies sponsored by DOE demonstrate the large contribution of basic device structure to the overall system capital cost of marine energy converters (4). Structural optimization and the use of lower cost materials are important areas of innovation that can significantly reduce cost of energy. In addition, the control system will need to be able to employ innovative load shedding strategies to avoid infrequent large loads.

- Although there is little installation or operational experience with arrays of wave or tidal energy facilities, it is generally understood that these facilities will need:

    - Efficient and low cost installation methods;
    - Efficient and cost effective maintenance methods; and,
    - To be highly reliable and/or be fault and failure tolerant.
- Electrical power aggregation is an unconsidered challenge for marine energy, particularly in offshore applications. Most utility scale farms will be in deep water (>50m), with many devices, and there is the expectation that they will share a single power export cable to shore. However, while there are solutions for power aggregation developed for the offshore oil and gas industry, there are no cost-effective solutions suitable for the marine energy industry. Solutions need to be developed that will allow individual power flow control over devices. Additionally, it is important that solutions are developed in conjunction with the marine energy converters that they are developed to support. This development needs to be done in coordination with marine energy developers for compliance with both device and grid requirements to ensure that they are compatible and provide the correct functionality and cost-performance level.
- The DOE has also identified several challenges and opportunities for marine energy in the Quadrennial Technology Review 2015 (6), and the challenges they identify generally parallel those given above.

<u>Additional "Pinch Points" across the Marine Energy Sector</u>

- *Survivability in Extreme Conditions*. One key challenge facing the viability of marine energy conversion, particularly for wave energy convertors, lies in the mitigation of loads resulting from extreme conditions. Extreme loads can, in some cases, be nearly an order of magnitude larger than typical operating loads, and thus necessitate large, costly marine energy converter structures. Despite the challenge, several prototype devices have encountered and successfully survived extreme conditions during testing, giving validity to the industry-held belief that the challenge is not insurmountable. Accelerated research and development in the areas of extreme condition numerical modeling and load mitigation strategies through either mechanical or controls based means would accelerate the pace of learning and lead to broadly applicable design processes, which would lessen the extreme event challenge industry wide.

- *Advanced Device/Array Mooring*. Individual generators and arrays are fully- or partially-submerged and individually fixed to the sea or river floor by foundation or mooring. In the case of an array, the mooring can encompass a significant amount of floor, leading to potential environmental impacts and conflicts with existing industries. Transformative solutions that are cost-effective, easily deployable, and scalable are needed (with benefits for sectors other than marine energy).

- *Supervisory Control and Data Acquisition (SCADA) systems* increase power performance, reliability, and survivability though the monitoring and control of individual generators. The development of

SCADA systems could increase power performance gains, improve device reliability, and increase extreme event survivability of individual marine energy devices and arrays through intelligent and coordinated control. These advances will likely depend heavily upon machine learning, big data management, and advanced and coordinated controls.

- *Automation in Marine Energy Installation, O&M, Decommissioning* (cross-cuts with offshore wind & oil & gas). Being placed in energetic sites distant from shore, along with significant device dynamics, currently presents significant challenges in the operations and maintenance (O&M) of marine energy farms. Robotics-based approaches to O&M of marine energy devices would lower operating expenditures, which currently are estimated to constitute approximately 25% of total wave energy project costs and 15% of total tidal energy project costs. These estimated costs are approximately equal to the fabrication costs of the primary device structures, and well above those of connection, installation, foundations and mooring, or power take off and control. Significant reductions in operating costs may be achieved through innovative, low-cost autonomous solutions. Technological advances are needed in autonomous underwater vehicle (AUV) station-keeping capabilities, situational (optical, acoustic, and non-destructive) sensing and awareness, vehicle robustness, fault resilience and recovery, operation in high current or surge environments, and task flexibility.

  - *Offshore Electricity Delivery Technology Advancement* (cross-cuts with offshore wind and oil & gas). The United States has very little offshore cabling and electrical infrastructure currently installed, which is custom made to order, expensive, and difficult to deploy and repair. In the case of marine energy, use of existing electricity delivery technology would be cost prohibitive. Significant opportunity exists to develop transformational offshore grid technologies (cables, interconnectors, convertors) that are scalable, technology agnostic, easily deployable and retrievable, and capable of cross-cutting offshore renewable energy generation. For example, a 2014 offshore interconnection study by the US DOE highlighted the potential for transformational research and development smaller form-factor high-voltage direct current (HVDC) convertor technology advancement, particularly in reducing the high initial capital costs of offshore renewable energy.

<u>Potential Role for ARPA-E</u>

A focused investment by ARPA-E would accelerate the development of advanced and innovative marine energy technologies and give confidence to investors, thus attracting the private capital needed for commercial deployments. ARPA-E support to develop and prove the technology, together with private sector investments, would help form a U.S. marine energy supply chain, thereby creating high-quality job growth in coastal communities, increase long-term productivity of underutilized shipyards, and development of fleets of vessels for installation and servicing. In summary, it would spark the creation of a new marine energy industry in coastal regions of the U.S.

The envisioned program would address the primary technical challenges that are preventing private sector commercialization of marine energy systems. This program would be designed to develop *breakthrough marine energy converter systems and components* by assessing and developing innovative marine energy concepts that capture more energy, experience lower loading, and that are inherently and dramatically more cost competitive. The concepts need to have the following attributes to address the technical challenges identified:

- High energy capture through:
  - improving hydrodynamic performance;
  - applying innovative control strategies to improve energy capture while restraining peak loads; and,
  - reducing conversion losses.
- Reduced cost of the converter's primary structure by:
  - optimizing the structural design of marine energy converters;
  - utilizing low cost material;
  - limiting peak loads in operation; and ,
  - applying innovative approaches to limit survival and off-design loads.
- Innovative low cost installation and maintenance methods:
  - employing advanced high performance computational design and analysis methods to insure rigorous and robust design and analysis of ultimate and fatigue loads;
  - utilizing laboratory testing to verify design concepts, reliability, and fatigue damage rates at the appropriate scale to prove competing design approaches at the component, subsystem, and full system level;
  - fully tested final system designs in realistic ocean environments for a period of time sufficient to verify reliability and determine wear and fatigue damage rates on critical components and subsystems; and,
  - verify final system costs to develop reliable system cost of energy estimates prior to private sector commercialization.

The envisioned research and development program would identify the most promising technology concepts for development, and then make the necessary investments to shepherd them through design refinement and testing to develop a proven product that the private sector can take through to commercialization. The framework and metrics for the technology assessment and follow-on development process should be holistic in nature and include the following requirements at all stages of evaluation:

- The environmental and social acceptability of the concept;
- The ability of the concept to absorb, convert, and finally deliver electricity to the grid;

- The potential of the concept to be reliable and have high availability;
- The initial capital cost of the concept; and,
- The operating cost of the system.

This type of framework for evaluation of the holistic performance ability of marine energy converters is discussed in more detail by Weber and Laird (7).

References

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