

Overview of Wave Energy Activities at Oregon State University

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1. Introduction

The solutions to today's energy challenges need to be explored through alternative, renewable and clean energy sources to enable a diverse national energy resource plan. An extremely abundant and promising source of energy exists in the world's oceans. Ocean energy exists in the forms of wave, tidal, marine current, thermal (temperature gradient) and salinity. Among these forms, significant opportunities and benefits have been identified in the area of wave energy extraction. Waves have several advantages over other forms of renewable energy such as wind and solar, in that the waves are more available (seasonal, but more constant) and more predictable with better demand matching. Wave energy also offers higher energy densities, enabling devices to extract more power from a smaller volume at consequent lower costs and reduced visual impact. However, many research and development challenges exist including issues of survivability, maintainability, efficiency, cost reduction, identification of suitable sites, reliable interconnection with the utility grid, better understanding of potential environmental/marine impacts, and wave resource measurement methodologies for reliable wave energy forecasting and scheduling. Optimizing wave energy technologies requires a multi-disciplinary team from areas such as Electrical, Ocean, Chemical, Materials, Civil, Mechanical and Bio Engineering, in addition to the critical Marine Sciences disciplines to enable innovative systems-level research, and successful and responsible development.

2. Wave Energy Developments at Oregon State University

A multidisciplinary wave energy team at Oregon State University (OSU) has been pursuing wave energy developments in four thrust areas: 1) researching novel direct-drive wave energy generators, 2) developing an action plan for a National Wave Energy Research and Demonstration Center in Oregon, 3) working closely with the Oregon Department of Energy (ODOE) and a variety of stakeholders to promote Oregon as the optimal location for the nation's first commercial wave parks, and 4) examining the biological and ecosystem effects of wave energy systems.

OSU's direct-drive research focuses on a simplification of processes, i.e. replacing systems employing intermediate hydraulics or pneumatics with direct-drive approaches to allow generators to respond directly to the movement of the ocean by employing magnetic fields for contact-less mechanical energy transmission, and power electronics for efficient electrical energy extraction. The term "direct" drive describes the direct coupling of the buoy's velocity and force to the generator without the use of hydraulic fluid or air.

The Oregon State Wave Energy team's research and development goals are driven by the important issues of survivability, reliability and maintainability, in addition to efficient and high quality power take-off systems. OSU is a prime location to conduct ocean wave energy research, noting the following strategic facilities:

- OSU is the home of the nation’s highest power university-based energy systems laboratory, the Motor Systems Resource Facility (MSRF) with a 750kVA dedicated power supply and full capabilities to regenerate back onto the grid. (see Fig. 1)
- OSU is the home of the O. H. Hinsdale Wave Research Lab (WRL) with world-class wave tank facilities including a 342 ft. wave flume. (see Fig. 2)
- OSU is the home of the Hatfield Marine Science Center (HMSC) with a 40 year history of marine research, education, and outreach from a 49 acre site on Yaquina Bay in Newport, and the ability to rapidly access the coastal ocean for instrument deployment and retrieval.

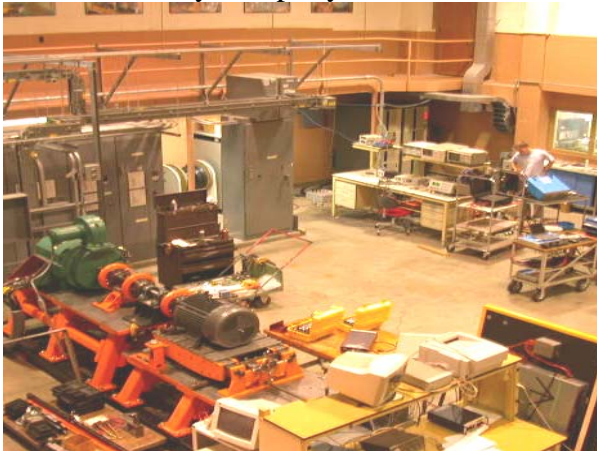


Fig. 1 OSU’s MSRF.



Fig. 2 OSU’s O. H. Hinsdale WRL.

The Oregon State University Wave Energy team is developing several novel direct-drive prototypes including a Permanent Magnet Linear Generator Buoy, a Permanent Magnet Rack and Pinion Generator Buoy, and a Contact-less Force Transmission Generator Buoy. These buoys are designed to be anchored one to three miles offshore, in typical water depths of greater than 100 feet, where the buoys will experience gradual, repetitive ocean swells. Inside the Permanent Magnet Linear Generator Buoy, the wave motion causes specially designed electrical coils to move through a magnetic field, inducing voltages and generating electricity. In the Permanent Magnet Rack and Pinion Generator Buoy, linear to rotary conversion is being developed as an extension of the concept of permanent magnet gears. The Contact-less Force Transmission Generator Buoy exhibits linear force transmission using large, high-strength permanent magnets configured in a “piston.” The motion of the piston is then transformed to rotation using a ball screw to drive a permanent magnet rotary generator. Advanced designs of these prototypes are also being developed to achieve higher efficiencies and power output performance. The OSU researchers are also interested in small scale wave energy generators, which could be integrated into boat anchor systems to power a variety of small craft electronic devices. These similar small-scale systems could enable ocean data collection and monitoring buoys to become self-powered. To comprehensively test, evaluate and advance wave energy conversion devices, OSU is also designing and building a Linear Test Bed in their MSRF, which is discussed in more detail in Section 3.

The combination of key facilities, ongoing successful wave energy research and collaboration, and the tremendous wave potentials and well-suited coastline off the Oregon coast has led the OSU Wave Energy team to propose the formation of a National Wave Energy Research and Demonstration Center in Oregon. This Center is strategically necessary for the U.S. to

successfully develop renewable wave energy resources in what is projected to become a rapidly developing new set of industries. The center would be strategically located at OSU for research and development (through the MSRF and the WRL), with a proposed research/demonstration site off Lincoln County/Newport, OR, where land-based facilities could be integrated with the ongoing activities at the Hatfield Marine Science Center (HMSC). The National Center could advance wave energy developments through a number of initiatives including: explore and compare existing ocean energy extraction technologies, research and develop advanced systems, investigate efficient and reliable integration with the utility grid and intermittency issues, advancement of wave forecasting technologies, conduct experimental and numerical modeling for device and wave park array optimization, develop a framework for understanding and evaluating potential environmental and ecosystem impacts of wave energy, establish protocols for how the ocean community best interacts with wave energy devices/parks, develop wave energy power measurement standards, determine wave energy device identification/navigation standards etc.

Fig. 3 shows a conceptual wave park illustration, highlighting OSU's first wave energy prototype of its permanent magnet linear generator. As shown in Fig. 3, each buoy would have a power cable dropping down along the tether to the anchor, which would then be routed to a central junction box located on the seafloor at the front of the wave park. At the central junction box, the unregulated voltages from all of the buoys could be "combined" and conditioned as regulated dc for delivery to the shore through a single submarine cable. At the shore substation, the dc power provided by the wave park could be inverted to ac, and connected to the grid. The Oregon coast has excellent wave energy potentials, where wave heights in the winter average 3.5 meters, which converts to 50kW per meter of crest length (each coastal home is about 1.3 kW). During the summer, average wave heights are 1.5 meters, which converts to 10kW per meter of crest length. Considering an overall average of 30kW/m, and an Oregon coastline of 460km, the total Oregon coast raw Wave Energy potential is in the range of 13,800MW. The average electrical energy consumption in the state is about 5-6000 MW, thus the 13,800 MW of raw wave energy can have a significant impact on Oregon's renewable energy portfolio.

The OSU researchers, along with Oregon Sea Grant, realized the significant need for partnership and collaboration with fishermen and crabbers and formed a Port Liaison Project (PLP) team of commercial fishing industry experts/cooperators to aid in wave park siting and ocean technical expertise. Both input from fishermen and experiences from the Oregon Fishermen's Cable Committee are essential for making the leap from lab to a "real-world scenario" in the ocean. This PLP team has spring-boarded into a Newport Wave Energy team working with OSU to prepare for ocean testing to occur, including determining the best testing site, as well as ocean community interactions, navigation, mooring etc. OSU has also been working closely with Oregon Department of Energy (ODOE) to promote Oregon as an optimal location for the nation's first commercial wave parks. The manufacturing and fabrication would be performed locally, meaning job opportunities for coastal Oregonians. At about one to three miles offshore, the parks would be virtually invisible from the beach, thus preserving views, but close enough to make anchoring and transmission feasible. The buoys would be placed in water depths of 150 - 200feet; before the waves start to break and dissipate their energy.

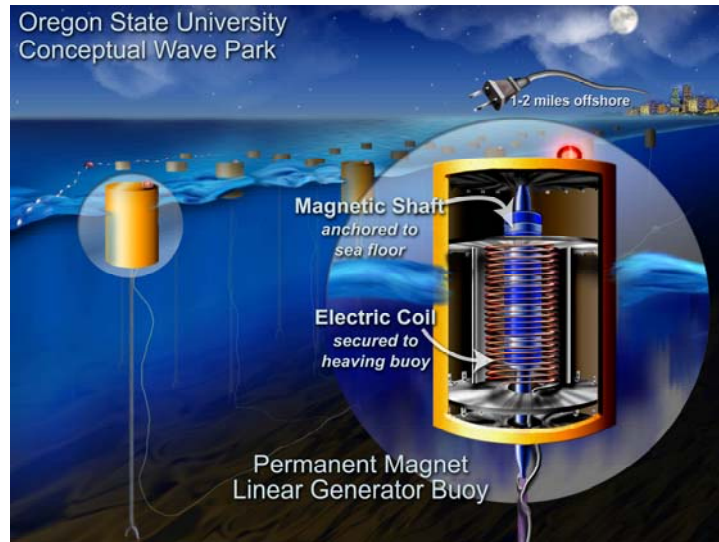


Fig. 3 Oregon State University Conceptual Wave Park.

3. Linear Test Bed Development

OSU's Wave Energy team has recognized that in order to advance and optimize wave energy devices, they need to upgrade their Energy Systems lab/facility with Wave Energy Linear Test Bed (LTB) Equipment. The LTB would also significantly increase OSU's Wave Energy research capabilities as they pursue a National Wave Energy Research and Demonstration Center. The National Demonstration Center is planned to be located off Lincoln County (potentially off Newport, OR), with land-based facilities that could be integrated with ongoing activities at the Hatfield Marine Science Center.

The LTB (see Fig. 4) is designed to generate the relative linear motion created by ocean waves to optimize wave energy device technologies. For example, the LTB will create the linear motion between a vertically oriented center "spar" and the active components of a surrounding "float". Thus, the LTB will enable the dynamic and controlled testing of wave energy devices, using captured wave profiles from ocean monitoring buoys, while simulating the actual response of ocean waves. In detail, the mechanical machine oscillations in the vertical axis will simulate sinusoidal vertical velocity, predetermined velocity profiles, or dynamically controlled force interactions to simulate the real response of the buoy in ocean waves. Simulating ocean waves requires very high forces. For this LTB system, driving forces of up to 20,000N (4500 lbs) at speeds of 1m/s are required.

The LTB system will be comprised of one (1) vertical axis (Z) of servo controlled CNC (computer numerically controlled) motion for moving the wave energy Device Under Test (DUT). A servomotor, through timing belts, will be used to move the LTB carriage to drive the active float up and down. The outer active float will be attached through dual load cells to the driving arm of the LTB, with servo loop integration. Rollers on a steel track will provide guidance for the carriage. The base has a gimbal mounting for the center spar and a removable pallet for loading and unloading the DUT. An upper gimbal mount will be used to attach the top of the DUT to the Z carriage. (Note, the active float of the buoy is mounted with a gimbal mount to tolerate dimensional and alignment variation of the DUT). Adapter plates will be used for different size wave energy devices. A versatile PC-based motion controller will be used to

control all motion. A Graphical User Interface (GUI) will provide access for setup, motion profiles and overall operation of the machine.

4. Conclusions

Recent advances demonstrate that there is reason to hope that ocean wave power may become a new, reliable and clean source of affordable renewable energy. OSU's Wave Energy program is advancing direct-drive wave energy devices, while proposing the establishment of a National Wave Energy Research and Demonstration Center in Oregon. This strategic Center will spring-board off the expertise developed through tremendous collaboration including university, industry, utility and community support.

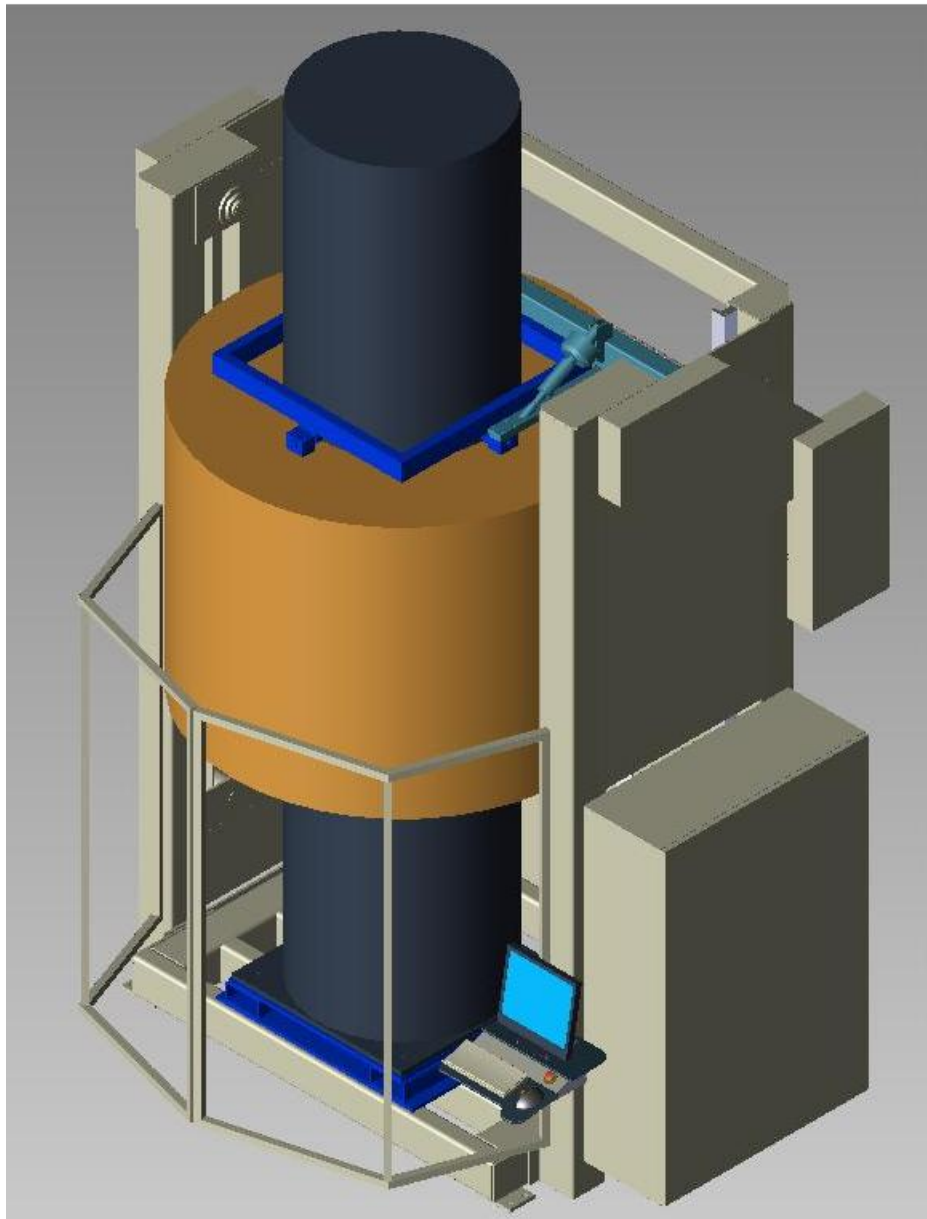


Fig. 4 OSU's Planned Wave Energy Linear Test Bed.