U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

2 Ocean Observation and Navigation

Powering the Blue Economy: Exploring Opportunities
for Marine Renewable Energy in Martime Markets

April 2019

2. Ocean Observation and Navigation

Key Findings

- The oceans are being actively investigated, yet almost 80% have not been mapped or explored. Active development of new instruments, platforms, and tools is underway to support further exploration.
- The use of ocean instrumentation is often limited by battery capacity, data storage, and transmission to shore. Weather buoys, profiling instruments, tsunami warning devices, and other systems are limited in the amount of data they can collect and transmit, and the time they can remain at sea unattended.
- Marine energy could meet power needs for surface sensors, especially if integrated with solar power and battery storage. Subsurface instrument needs could be met by marine energy coupled with energy storage systems, such as batteries.
- Marine energy provides unique advantages for at-sea power generation including colocation with ocean observation sensors, navigation markers, and subsea inspection vehicles; continuous power generation when coupled with energy storage; stealth characteristics for defense applications; and designs that are tailored to the marine environment.
- The world market for navigational and survey instruments more than doubled between 2001 and 2011, from $7.5 billion to $16 billion (Maritime Technology News 2012). Many of these instruments are used for ocean observation and navigation purposes, indicating a growing need for power at sea to supply these systems.

Opportunity Summary

The use of maritime sensors and navigation aids is widespread and growing rapidly worldwide as new technologies enable multiple networked tools to economically monitor the ocean and often provide greater coverage than traditional shipboard methods (Venkatesan et al. 2018). Common marine buoys include surface ocean observation buoys with sensors that measure meteorological data, subsurface nodes for tsunami or submarine monitoring, and surface navigation buoys for maritime traffic. Some ocean observation sensors are cabled to shore power, whereas others are powered locally with solar panels or batteries. As the need and capability to measure our oceans advances, more sensors will be deployed with their own unique power needs as wireless data telemetry technologies become more commonplace (Venkatesan et al. 2018).

Battery life limits the useful duration of most observation and navigation equipment, making locally extracted ocean energy a feasible option for recharging these devices (Ayers and Richter 2016). As an alternative solution to solar and wind, marine energy devices could provide longer-term and more continuous power by taking advantage of the very environment the sensors measure, allowing for nighttime and high-latitude winter charging; areas where some other renewable sources may not be optimal. Ocean observation systems have been limited by material fatigue, biofouling, and instrument calibration drift (Brian Polagye, personal communication, August 2018). These challenges will continue even if marine energy devices provided power on a more continuous basis; however, the maintenance and automated systems used to mitigate these challenges would also benefit from power availability.

Although difficult to size, the international ocean observation market size is estimated to be greater than $16 billion (Maritime Technology News 2012) and growing. Overall, the per-unit-sensor power consumption is decreasing because of technological advances, and the total number of sensors on platforms is increasing, resulting in a net power increase. High-power devices (including active acoustics [e.g., scanning sonar]; video cameras; underwater lights; mobile, motorized sensor platforms) continue to need an external power supply (Delory and Pearlman 2018). Recent trends indicate that production of navigational and survey instruments has increased substantially in recent years (Maritime Technology News 2012), many of which may be used for ocean observation and navigation purposes. If more of these instruments are being used for maritime-related purposes, more power will be needed, and marine energy could be used to supplement the power for these instruments, or even enable new, higher-power applications.

Application

Description of Application

Integrated networks of ocean sensors and navigation aids exist in the United States and international waters to provide monitoring and forecasting of oceanographic and meteorological data and ensure safe navigation, respectively (Figure 2.1). Oceanographic and meteorological sensors monitor the environment in near real time, improving our ability to understand and predict events, such as hurricanes, waves, sea level changes, and tsunamis. Navigation aids assist commercial and recreational ship traffic, marking areas of danger and zones for safe passage. This improves maritime safety by reducing the risks of collisions, allisions, or groundings.

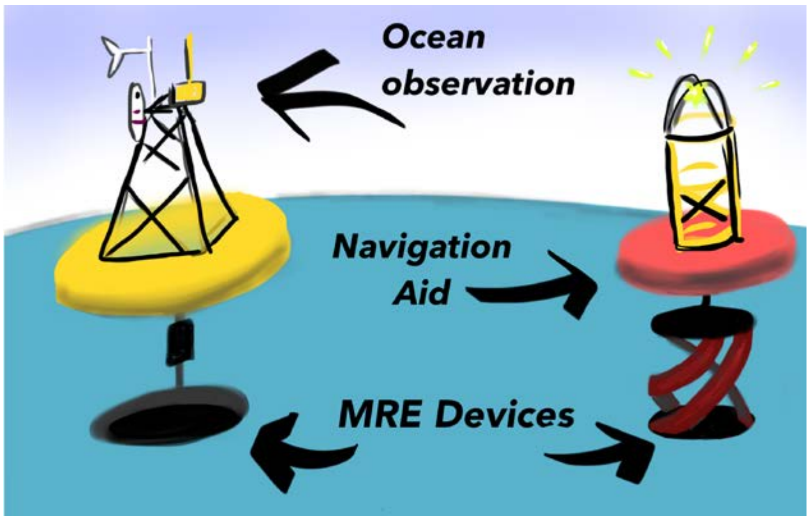

Figure 2.1. Marine renewable energy (MRE) application overview for ocean observation. *Image courtesy of Molly Grear, Pacific Northwest National Laboratory*

Power Requirements

The range of power requirements for ocean observation buoys and navigation aids, per installation, is estimated to be 10–600 kilowatts (Brasseur 2009), whereas many buoys operated by the National Oceanic and Atmospheric Administration (NOAA) require power that ranges from 40 to 200 watts. There are no accurate power estimates for overall ocean observation systems (Dana Manalang, personal communication, December 2017), as the systems are changing rapidly, although we know power requirements for specific individual instruments. It is likely that any additional power that can be generated at sea can and will be used to power additional sensors, nodes, and data communications for ocean observation systems (Ayers and Richter 2016).

Many important patterns of biological, chemical, and physical processes in the ocean happen at long timescales, from seasons to years or more, and can only be identified through long time series ocean observations (e.g., Edwards et al. 2010; Riser et al. 2016). For decades, long time series ocean observations were costly and required repeated visits to sites of interest, as well as periodic maintenance. To collect continuous time series, battery-powered instruments were left behind. Therefore, ocean instrumentation development was often limited by battery capacity and data storage.

In recent years, cabled ocean observing systems have been developed that deliver ample continuous power and communications, when coupled with energy storage, to remote ocean sites, enabling the development of new types of sophisticated and higher power in-situ devices that were not previously possible. Some examples include:

- High-definition camera systems[5]
- Mass spectrometers[6]
- Environmental sampling processors[7]
- Robotic systems.[8]

With the possibility of marine renewable energy devices delivering power at sea, there are similar opportunities for noncabled ocean observations. A variety of systems and subsystems could use marine energy, including electricity, as outlined in Figure 2.2. Although Figure 2.2 presents potential uses of marine energy to power various systems, not all potential uses will be practical to be powered by marine energy, as the presence and operation of a marine energy device could alter the intended measurements/observations (e.g., presence of marine energy device could alter behavior, community, composition, and so on).

[5] http://oceanobservatories.org/instrument-class/camhd/
[6] https://girguislab.oeb.harvard.edu/isms
[7] https://www.mbari.org/technology/emerging-current-tools/instruments/environmental-sample-processor-esp/
[8] https://www.oceannetworks.ca/groups/wally-benthic-crawler

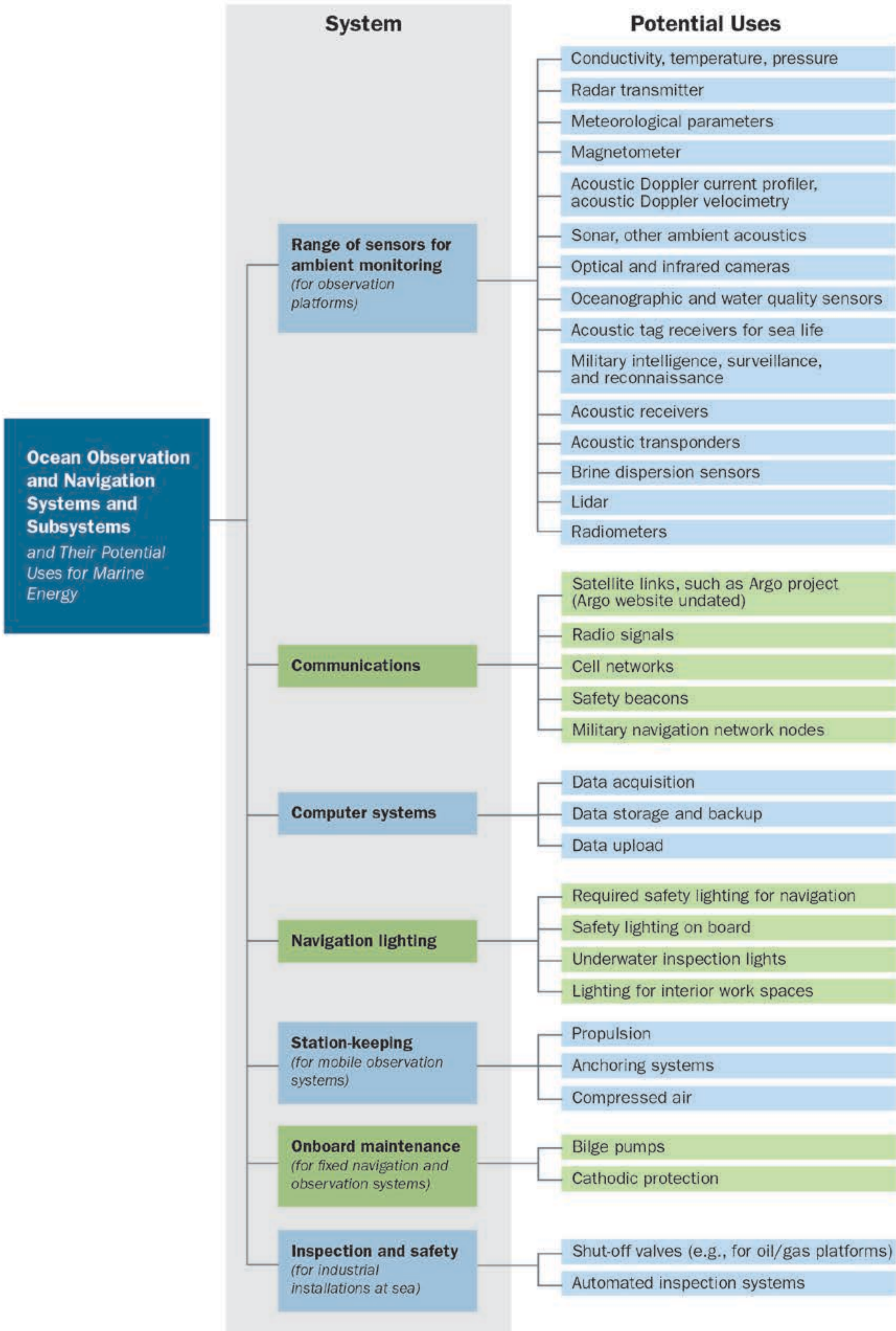

Figure 2.2. Ocean observation and navigation systems and subsystems and their potential uses for marine energy

Navigation Aids

Navigation aids generally include buoys, floats, air horns, and lights on the surface of navigable waterways (Figure 2.3). Power is needed for a variety of uses, such as lights, air horns, radar reflectors, air and water sensors, and data transmission (U.S. Coast Guard 2017a, 2017b). These navigation aids are found in all major bodies of water and near all ports and shipping lanes. The U.S. Coast Guard manages many of these systems in U.S. waters.

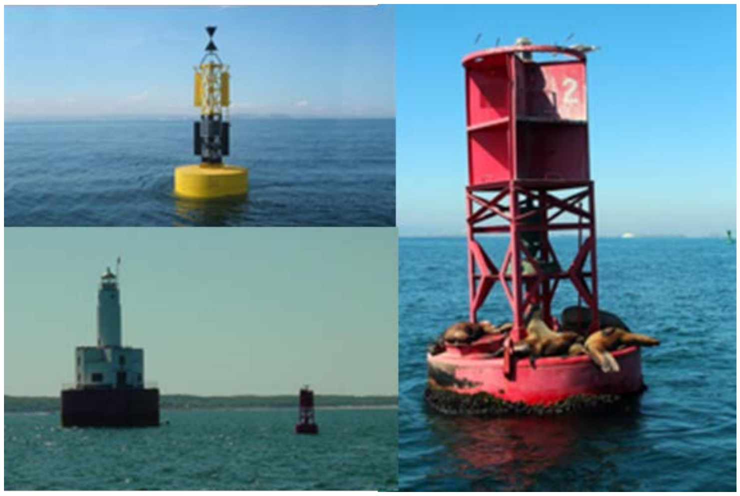

Figure 2.3. Navigation markers. *Photos courtesy of Polliechrome (bottom left) and Creative Commons (upper left, right)*

Ocean Observation

Ocean observation sites are located along coastlines, on continental shelves, along the margin of oceanic plates, along the equator and other convergence zones, and standing off coastlines for tsunami and storm early warning systems. Most ocean observation devices are subsurface, including oil and gas transmitters and acoustic listening posts, whereas others may be on the surface, including meteorological buoys. Key systems for civilian ocean observation in the United States include the U.S. Integrated Ocean Observing System (IOOS) and the related regional system of Ocean Observing Systems (IOOS 2017; Figure 2.4), including the Neptune array in the Pacific (Interactive Oceans 2017), the Canadian Venus array in the Pacific waters between the United States and Canada (Ocean Networks Canada 2019), the Taos array along the equator, tsunami warning systems off U.S. coastlines (NOAA 2017b, 2017c), and the array of profiling Argo floats (Argo undated).

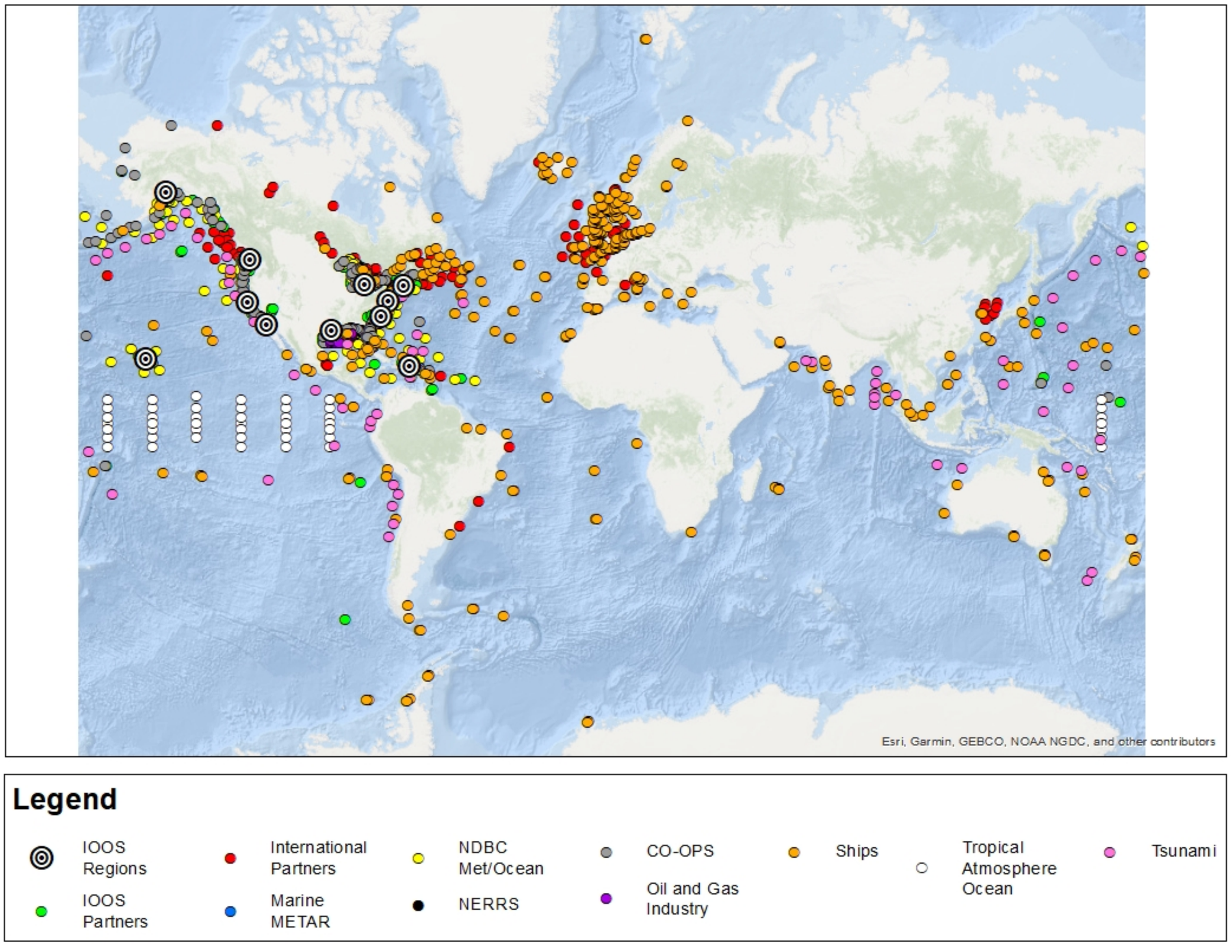

Figure 2.4. IOOS region and NOAA buoy/observation location map. *Image courtesy of Alicia Gorton, Pacific Northwest National Laboratory*

NOAA's Chesapeake Bay Interpretive Buoy System is a network of buoys within Chesapeake Bay that collect meteorological, oceanographic, and water quality data (NOAA 2018). These "smart" buoys relay information wirelessly and interpret points within the bay. The latest data are available online, by calling toll-free, or via applications developed for smartphones. Analogous systems operate internationally, with most tied into the Global Ocean Observation System (United Nations Educational, Scientific, and Cultural Organization [UNESCO] 2017) and the European Earth Observation System (UNESCO 2009).

The oil and gas industry makes extensive use of marine sensors, ocean observation systems, and relevant data and information provided by these sensors/systems. Oil and gas operations make use of marine and ocean observation sensors to conduct environmental monitoring throughout the lifetime of an oil field, from preinstallation surveys/baseline studies to construction and installation, drilling and production, and decommissioning (Kongsberg 2013). Additionally, oil and gas operations make use of established ocean observation systems and networks for further environmental monitoring, forecasting, and to ensure safe operations. For example, one of the five general focus areas of the Gulf of Mexico Coastal Ocean Observing System focuses on safe and efficient marine operations, which include oil and gas operations (Gulf of Mexico Coastal Ocean Observing System 2016). Additionally, military and security uses of ocean observations include systems for port security, surveillance, and tracking, such as submarine tracking systems like the decommissioned sound surveillance system array (NOAA 2017a) and the Deep Reliable Acoustic Path Exploitation System under development (The Diplomat 2016).

Markets

Description of Markets

The world's sales of navigational and survey instruments nearly doubled between 2001 and 2011, from $7.5 billion to $16 billion (Maritime Technology News 2012). Sixty-three percent of the sales ($10.1 billion) in 2011 were for surveying, hydrographic, oceanographic, hydrological, meteorological, or geophysical instruments and appliances, whereas navigational instruments totaled 37% ($5.8 billion) (Maritime Technology News 2012). These trends indicate that production of navigational and survey instruments has increased substantially in recent years, many of which can be used for ocean observation and navigation purposes. If more of these instruments are being used for maritime-related purposes, more charging power will be needed, and marine energy could be used to supplement the power for these instruments.

In 2012, the Duke University Center on Globalization, Governance & Competitiveness completed a study on the global value chains of ocean technologies, including underwater sensors and observation. The study found that technology and manufacturing advances have led to the miniaturization and increased energy efficiency of instruments. Although this would imply reduced energy needs on an individual platform basis, more devices are being integrated and deployed on single platforms to increase functionality and reduce operating costs, resulting in a net increase in energy needs (National Academies of Sciences, Engineering, and Medicine 2017). In addition, increased activity in the Arctic Ocean and remote locations has increased the demand for sensors that can withstand extreme conditions (Maritime Technology News 2012).

The domestic and international ocean observation and subsea inspection markets are growing, driven largely by increasing needs for early-warning systems for tsunami generation, weather patterns, climate variables, and other scientific questions (National Academies of Sciences, Engineering, and Medicine 2017). There are also defense applications for ocean observation sensors and systems, including air, surface, and subsurface intelligence gathering, surveillance, and reconnaissance.

There has been a growing consolidation of the market for ocean observation instruments and equipment, with large firms buying smaller firms in an effort to provide a wide range of products for many different end markets. Recent examples of this consolidation include the purchase of Liquid Robotics by The Boeing Company, the acquisition of Bluefin Robotics by General Dynamics, and the acquisition of Hydroid by Kongsberg Maritime. This market consolidation enables technological acquisition and helps firms attain scales of economy in research and development (R&D), marketing, and end-market coverage that may provide a way for large firms to acquire innovative technology (Maritime Technology News 2012).

Governmental and private organizations that develop and support navigation aids and ocean observatories could be likely customers and partners for co-developing marine energy systems. Navigation aids are almost always publicly owned and financed through governments around the world. There is a small market for private surface markers that require power (e.g., lights, active radar reflectors, satellite transceivers, Global Positioning Systems, low power radio), often in conjunction with marinas and ports (U.S. Lighthouse Society 2018). The U.S. Coast Guard is the main authority in the United States that oversees these navigation buoys. However, many ports could also be potential investors and customers for marine energy systems to power navigation aids.

Ocean observation systems are commonly financed by government entities (e.g., the National Science Foundation via university consortia in the United States) or by NOAA, the U.S. Department of Defense, Office of Naval Research, or the U.S. Department of Homeland Security. Government investments in ocean observation are critical for weather forecasting, marine resource management, maritime navigation, and climate change analyses (National Academies of Sciences, Engineering, and Medicine 2017). Furthermore, federal defense and security organizations invest in ocean observation for national security and ocean surveillance purposes. For example, the U.S. Department of Homeland Security has invested in the Autonomous PowerBuoy, coupling long-duration maritime vessel detection with wave power generation (Homeland Security News Wire 2012). Private foundations are also important funding partners for equipment and data collection capabilities. Similar governmental organizations in other nations, as well as some private foundations and international aid and finance organizations, presently fund and are expected to continue funding ocean observations.

Offshore manned industrial facilities, such as oil and gas platforms, require power for a range of operations including inspection of underwater systems, and the emergency shutdown of valves and other equipment. The need to meet increasingly stringent clean air and water regulations is moving petroleum producers to use alternate sources of power, which could include site-based marine energy. Similarly, unmanned offshore facilities require power that could be compatible with marine energy generation.

Power Options

Navigation aids and (noncabled) ocean observation installations are commonly powered by diesel generators, solar panels, or batteries. At present, wave energy provides only a small contribution to the ocean observation industry from companies such as Ocean Power Technologies and Resen Wave (Naval Today 2018). However, marine energy—particularly wave power—could be highly competitive for supplying power to ocean observation instruments and nodes, especially at depth, at night, in high latitudes, and during the winter. The energy density of moving water is much greater than other renewable sources, such as wind or solar, and marine energy devices could provide efficient power generation at sea. Solar is likely to have a short-term competitive advantage through photovoltaic (PV) panels used for surface ocean observation and navigation markers, except at high latitudes and for applications where placement of PV panels is limited by available surface area. PV panels placed close to the sea surface may need more frequent maintenance and cleaning because of corrosion, biofouling, and bird droppings. Large offshore wind is generally location-dependent and provides power outputs that are unnecessarily large for supplying ocean observations and navigation needs. Small buoy or platform-mounted wind turbines could provide an appropriate power source but will be at risk from waves and salt. Offshore wind turbines also require a stable platform for operation, which cannot be provided by offshore buoys. Diesel generators are impractical in remote locations in the middle of the ocean for many reasons, chief among them the need for refueling and maintenance. Backup storage may be required to match renewable generation with power needs for stand-alone or hybrid systems.

Geographic Relevance

NOAA’s National Data Buoy Center (NDBC) operates and maintains more than 1,300 buoys (Figure 2.5) that provide ocean and environmental observations to support the understanding of and predictions for changes in weather, climate, oceans, and the coast. These systems collect valuable meteorological and ocean data that support numerous industries, from airlines to fisheries. In the United States, NDBC buoys are located along the coast and offshore of the East Coast, West Coast, Gulf of Mexico, Alaska, and Hawaii. In addition to these NDBC buoys, navigation aids are used along all U.S. coastlines to support vessel traffic, with an increase in these navigation aids most likely congregated around major ports. The top U.S. container ports are Los Angeles, Long Beach, New York, New Jersey, Savannah, Brunswick, Seattle-Tacoma, Virginia, Houston, Charleston, Georgetown, Oakland, and Miami (iContainers 2017). The U.S. Department of Energy (2013) estimated the wave energy resources along the East Coast, West Coast, Gulf of Mexico, Alaska, and Hawaii to be 240 terawatt-hours per year (TWh/yr), 590 TWh/yr, 80 TWh/yr, 1,570 TWh/yr, and 130 TWh/yr, respectively. With the significant number of buoys and U.S. container ports located along the East and West Coasts, marine energy along these coasts could potentially be used to supplement power to these buoys and navigation aids.

Buoys in western boundary currents like the Gulf Stream may offer better pairing potential with ocean current devices. U.S. wave resources are optimal off the coasts of Hawaii and Alaska, the mainland West Coast, and the Northeast, which overlaps well with tsunami nodes. Tidal resources are most common in inland waters, in shallow constrictions where navigation buoys are likely to be most prevalent.

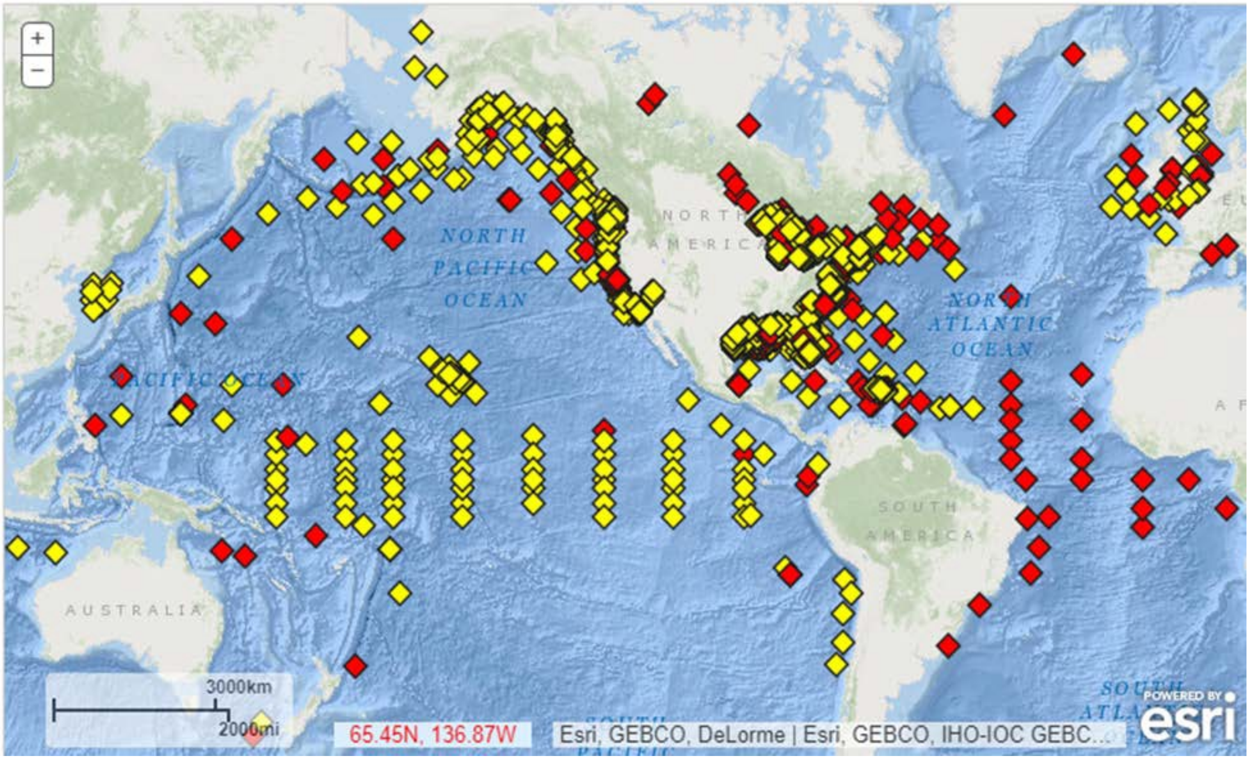

Figure 2.5. Locations of NOAA buoys. *Map courtesy of NOAA*

Marine Energy Potential Value Proposition

The large increase in ocean observation and monitoring systems, combined with the desire to record data in real time, adds new power demands. Because many of these systems are in difficult-to-access locations, marine energy could reduce costly site visits for maintenance and increase system availability. Operational marine energy systems could require less routine maintenance than other renewable systems. For example, individual offshore wind turbines require about five site visits per year, carried out by boat or helicopter (making the visits sea state and weather-dependent) (Röckmann et al. 2017). Additionally, solar installations require cleaning of PV plates to remove salt residue (Atkinson 2016).

Operational marine energy systems could require less routine maintenance than other renewable systems, such as wind turbines (with extensive infrastructure above water that will require lubrication and other maintenance) and solar installations (cleaning of PV plates to remove salt residue) (Rockmann et al. 2017; Atkinson 2016). Presently, marine energy is more expensive than many alternative renewable and traditional power sources; however, with future cost reductions and the availability of marine energy at sea in locations where other sources are less viable, marine energy could meet power needs for surface sensors, especially if integrated with some solar generation and battery storage, whereas undersea needs could be met entirely by marine energy and battery energy storage systems. Marine energy provides unique advantages, including colocation with sensors, markers, and subsea inspection vehicles; continuous power generation when coupled with storage; better stealth characteristics; and designs tailored to the marine environment.

Opportunities for powering ocean observation sensors and navigation aids with marine energy occur throughout the coastal area and open ocean, where sufficient wave or current (tidal or ocean current) resources are present. The U.S. Department of Defense—particularly the U.S. Navy—has a presence in these areas and needs a way to power ocean-observation sensors, navigation aids, and systems across the oceans of the world.

Figure 2.6 highlights the current installed and proposed global seafloor observatories at various stages of development. These observatories are being used for hazard detection and warning, scientific research, coastal/habitat monitoring, or military and security purposes. In the United States, the National Science Foundation's Ocean Observatories Initiative has installed a network of instruments, undersea cables, and instrumented moorings spanning the Western Hemisphere and totaling 830 total sensors (Ocean Observatories Initiative 2018).

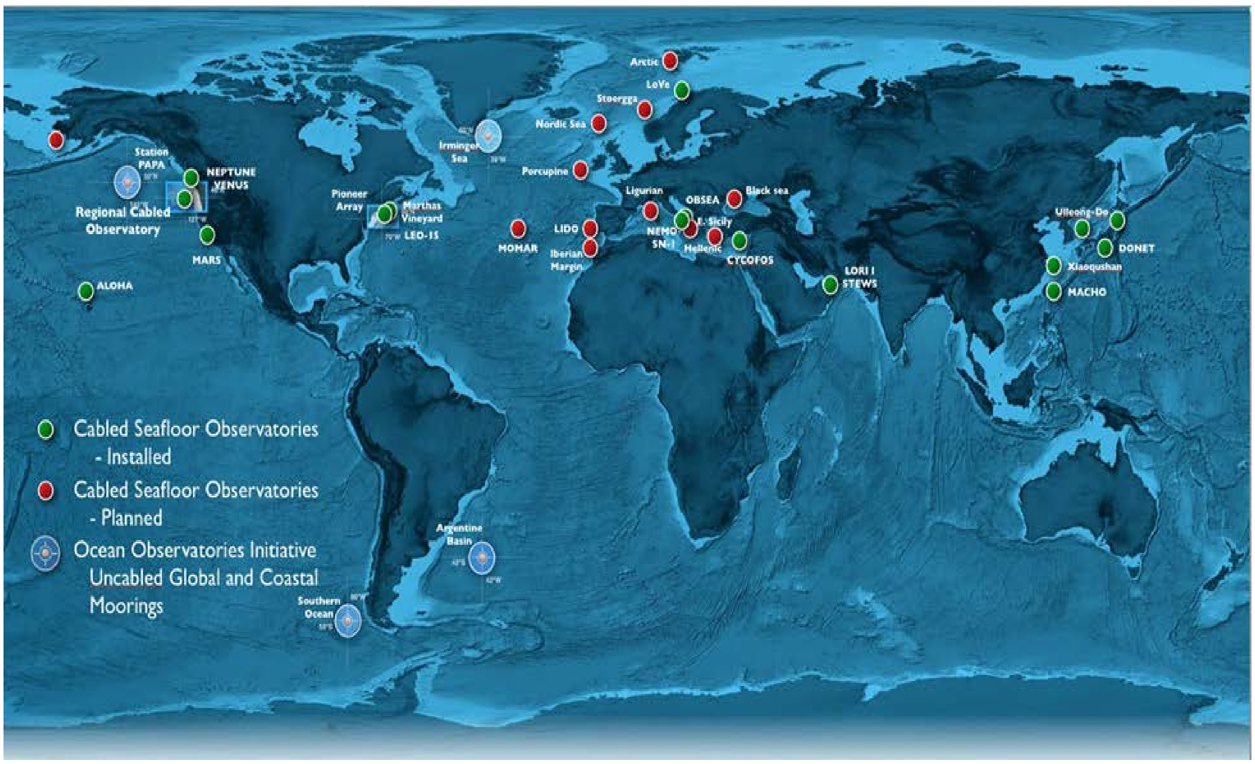

Figure 2.6. Installed and proposed seafloor observatories. *Image courtesy of Deborah Kelly and John Delaney*

Path Forward

Navigation markers and ocean observation systems are a promising point of entry for small wave energy converters and current—tidal, riverine, and ocean—devices. The power needs of these devices are smaller than a grid-scale application, which means they will have a reduced capital expenditure relative to grid-scale applications, allowing earlier initiation of a viable market for ocean observations.

Additionally, the U.S. military funds the continued development of ocean observation sensors, navigation aids, communications systems, and necessary power systems (diesel and/or PV plus battery), with large potential for marine energy to supplant). The military favors systems that are compact (low volume), lightweight, portable, surface expression/signature limiting, and reliable. Working with organizations in this sector may be an expedited path for technology development. Although some of the military observation sensors, for example, may not find their way readily into the marketplace, advances in marine energy systems likely will.

Ongoing government investments are expected for purchasing and upgrading navigation aids, as well as developing, deploying, maintaining, and expanding/upgrading ocean observation systems (National Academies of Sciences, Engineering, and Medicine 2017). NOAA and the U.S. Coast Guard will typically visit their ocean buoys once a year for maintenance, so developers interested in approaching this market should design their systems to operate around this maintenance schedule. To couple marine energy devices and their power output to navigational aids and monitoring systems, government research investment will be needed along with multiple pilot tests. After proving system reliability, it is believed the technology will attract significant private capital. Subsea inspection systems are mostly privately owned; therefore, demonstrating a project without government support will require that industry partners be engaged early. These opportunities present significant potential for innovative marine energy devices to move forward with this market for marine energy companies, including those actively engaged (e.g., Resen Wave, Wave Piston, EC-OG, and Ocean Power Technologies).

Major designs and power needs for navigation aids and markers are relatively well understood. Therefore, R&D in this area should concentrate on the mechanical and electrical integration of marine energy devices into navigation markers and monitoring systems. The newer and more rapidly changing ocean-observing markets for power will require similar R&D for linking marine energy devices to ocean sensors but will also require further co-development with emerging ocean-observation devices to ensure that they co-evolve.

Potential market synergies exist between applying marine energy technologies for ocean observation and navigation aids and applications in underwater recharge, biofuels, and aquaculture, including the need to develop compatible marine energy devices and linkages that will operate independently over long periods of time.

To be successful and ensure marine energy is considered and integrated as a power source, it will be critical to coordinate with ocean-observation systems in the United States as well as internationally as new systems are brought online. For some applications, marine energy devices will need to demonstrate high efficiencies in environments with low resource energy (e.g., a wave energy converter must have high efficiency when transforming wave energy into electrical power in low sea states), will need to demonstrate long-term reliability and low maintenance requirements, and must not affect the environment that is being measured.

Potential Partners

The U.S government has several areas of interest in ocean observing and navigation aids. For ocean observations, these potential mission-driven partners for the marine energy industry include NOAA Coastal Survey's NDBC, NOAA Pacific Marine Environmental Laboratory, IOOS, and the regional ocean observing systems, the U.S. Coast Guard, and the U.S. Department of Defense (e.g., the U.S. Navy and the Defense Advanced Research Projects Agency). For navigation aids, additional partners could include the U.S. Coast Guard, U.S. Army Corps of Engineers, and the NOAA Coastal Survey. Coastal ports, which may be governmental entities or public-private partnerships, also have an interest in navigation aids and may be interested in partnering with marine energy developers.

Academic and research partners in the United States are funded for ocean observation by federal agencies and private foundations. Potential partners include major oceanographic university consortia, such as the University-National Oceanographic Laboratory System, and, potentially, major research universities, such as the University of California San Diego's Scripps Institute of Oceanography, the Woods Hole Oceanographic Institute, the University of Washington, and others. Similar institutions in other nations may have an interest in navigation aids through the Global Ocean Observing System. Potential industry partners may include subsea and observation original equipment manufacturers (including defense), oil and gas rig undersea inspection services, undersea pipeline and subsea cable inspection services, ocean-observation sensor and equipment companies, and navigation and buoy market manufacturers.

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