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10 Other Applications

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

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10. Other Applications

This chapter identifies opportunities for future exploration that were not studied in-depth in other chapters of this report. Additional applications for marine energy cover various topics, including electrified and hydrogen-fueled marine transportation (e.g., boats and aircraft, as shown in Figure 10.1), off-grid charging for industrial and consumer applications, ocean pollution cleanup and marine conservation, subsea communications, and offshore data centers. These different applications cover a range of technology readiness levels, from those that are in the conceptual-only stage to others with demonstrated pilot projects and paths to commercialization.

Key Findings

- Global pressures to reduce greenhouse gas emissions and improve local air quality are causing vessel operators and ports to modify engine systems. Modifications include using cleaner-burning fuels (e.g., liquid natural gas), diesel-electric hybrids, converting to fully electric operation, or incorporating hydrogen fuel cells. Demand for these technologies, as well as the fuel and energy to power and charge them, respectively, will increase. Marine energy's obvious colocation benefits may make them well-suited as an energy provider.

- Portable electronic devices have created a global market for charging technologies, especially in areas without access to the electrical grid. The two primary off-grid charging solutions are portable battery packs and small transportable solar photovoltaic (PV) panels. Opportunities exist for marine energy to develop small charging systems using river or ocean resources.

- There are potential markets for marine renewable energy technologies within the marine conservation space; including ocean pollution cleanup, oil spill cleanup, and coral reef restoration. Applications for marine energy within these markets are limited at the moment and presently more concentrated nearshore.

- Data centers, in aggregate, are becoming one of the largest consumers of electricity in the world. As site development area for data centers diminishes on shore, some companies will look to deploy server farms offshore. Microsoft has even begun investigating subsea data centers enclosed in watertight containers. The ocean provides free cooling, historically one of the greatest costs in operating a data center, as well as the potential to receive locally sourced power from marine energy.

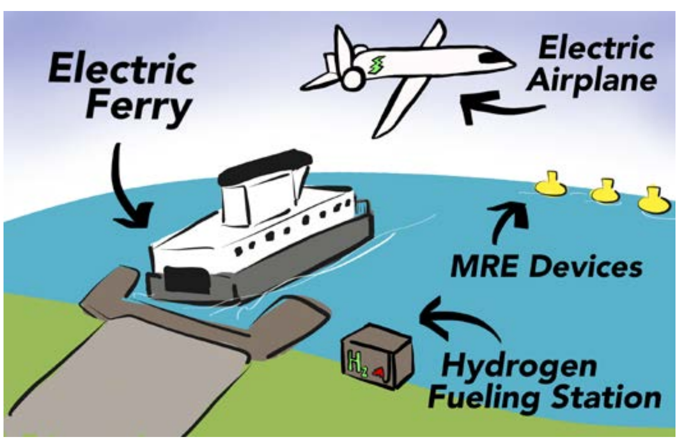

Figure 10.1. Marine renewable energy (MRE) applications for electric and hydrogen-fueled marine transportation. *Image courtesy of Molly Grear, Pacific Northwest National Laboratory*

Marine Transportation: Powering Boats and Aircraft

Potential Marine Energy Application and Market

There are several different opportunities for using marine energy. Similar to providing energy to a storage system for charging underwater vehicles, marine energy could provide energy to charging stations for electric boats and aircraft. On a much smaller scale, charging could also be used for moored recreational power boats, which use batteries to start their engines, and for remotely operated or semiautonomous work boats (e.g., ASV Global's unmanned marine systems). Concepts also exist for integrating wave energy technologies directly into boat hulls, thus circumventing the need for charging stations (The Maritime Executive 2017). If charging stations are grid-connected, the opportunities and challenges for marine energy are similar to remote electricity markets or high-cost electricity markets, as noted in those respective chapters. However, opportunities could exist off grid, such as charging stations in remote terrestrial locations or locations without grid accessibility, or at sea (e.g., moored, station kept, or floating unmoored) for water surface and airborne craft to use for recharging to "hop" and extend useful ranges. As discussed in Chapter 6, another opportunity for powering vessels from marine energy would be through the production of hydrogen from seawater and the subsequent fueling of vessels with hydrogen-powered propulsion systems.

Global pressures to reduce greenhouse gas emissions and increase local air quality are causing significant changes to the shipping sector. According to the International Maritime Organization, the United Nations body that regulates the shipping industry, shipping accounts for approximately 3.1% of annual global CO_2 emissions and 15% of annual global NO_x emissions (International Maritime Organization 2014). The organization has set requirements for cutting greenhouse gas emissions—including a 2020 global 0.5% sulfur cap affecting up to 70,000 ships, which has created significant pressure for adaptation and innovation. Some strict emissions limits are already in place in specific emission control areas, partially in response to local air and noise pollution, along with evolving global requirements.

To comply with these evolving objectives and requirements, companies are adapting or retrofitting engine systems to run with cleaner-burning fuels (e.g., liquid natural gas) by using diesel-electric hybrids, converting to fully electric vessels, or incorporating hydrogen fuel cells. One company, Wärtsilä, has developed a wireless charging system for easy transfer of power from the shore to a docked vessel. This inductive charging technology is particularly suitable for fully electric vessels using batteries that spend little time at the dock, such as ferries.

Figure 10.2. The first all-electric ferry operating in Noray, the MF Ampere (left) and the Port-Liner fully electric canal cargo vessel in development and capable of autonomous operation (right). *Sources: www.siemens.com/press and Port-Liner*

A ramp-up of research, development, and implementation of electrification and automation in global shipping fleets is occurring, but it lags behind terrestrial transportation and focuses on short-distance trips. Some companies are developing, and customers are using, fully electric vessels for passenger ferries and short-haul cargo transport in canals and rivers, along with recreational craft (DNV GL 2017a, 2017b; Guarnieri 2018). Electric ferries are presently in operation in Norway, and the first fully electric barges will soon be launched in the ports of Amsterdam, Antwerp, and Rotterdam (Figure 10.2), with more than 4 megawatt-hours of battery packs inside the largest ships. Recently, a 600-passenger electric hybrid ferry, the Enhydra, was put into service in San Francisco Bay, using lithium-ion battery packs, an electric traction motor, and a biodiesel-powered engine. In 2017, the Washington State Department of Commerce launched an initiative called Washington Maritime Blue, with a vision to convert the state ferry system to electric propulsion, including electrification of the state's three largest ferries as a priority demonstration project.

A Norwegian delegation was invited to Washington to share best practices on cluster formation and electrification in support of the state's Maritime Blue strategy (The Maritime Executive 2018). As part of the strategy, DNV GL conducted a global benchmarking of Washington against global maritime capitals of the world. Another concept has also been presented for integrating wave power systems directly into a ship's hull to convert wave energy into compressed air, which could be used as potential energy or on demand to generate electricity (The Maritime Executive 2017). Similarly, it is possible that wave-dampening systems used on recreational boats that are anchored or moored could be designed to capture this wave energy and use the energy to charge batteries and store power for electric propulsion.

The world's first fully electric and potentially autonomous container barges are expected to be operating soon in the Netherlands. Five barges able to carry twenty-four 20-foot containers weighing up to 425 tonnes for 15 hours will be in operation, with six larger 110-meter-long barges, carrying 270 containers capable of running for 35 hours in development (Holter and Hodges 2018). Also in 2018, 185 battery-powered ships will be operational or scheduled for delivery worldwide, most in Norway and France (DNV GL 2017b). A total of 7,300 inland ships in Europe are anticipated to eventually be electric (Holter and Hodges 2018).

A significant number of electric vessels are forecast to be operational by 2040 and 2050. The DNV GL (DNV GL 2017a) analysis supporting this forecast assumes that batteries will only be capable of powering small vessels for short-haul operations, presumably because of energy density and battery costs (Figure 10.3). Short-haul sea shipping will use 37% of the total energy, or 4.3 exajoules, and in this sector, electricity can constitute a significant share (9%) of energy use, comprising 0.4 exajoules (DNV GL 2017b) (Figure 10.3).

For cutting greenhouse gas emissions, hydrogen-powered vessels can provide another zero-emissions alternative, if the hydrogen is produced from renewable energy, such as from seawater electrolysis using marine energy. Hydrogen is considered by some shipping industry executives and energy experts to be the fuel of the future for cruise liners, ferries, and container ships (Tullis 2018). This presents an opportunity for marine energy to produce the hydrogen for fueling these vessels and make it locally available, such as at port refueling stations. For example, the European Marine Energy Center is producing hydrogen gas to store unused renewable energy produced from tidal and wind energy (European Marine Energy Centre 2017). The hydrogen is then transported to the main Orkney island for use in the intraisland ferry system and land transport.

Figure 10.3. DNV GL forecasts a shipping energy mix by 2050 with 37% of total shipping energy use (4.3 exajoules) in short-sea shipping, and in this sector, electricity constitutes a significant share (9%) of energy use. Note: HFO = heavy fuel oil and MGO = marine gas oil. *Source: DNV GL (2017b)*

Several factors are likely to drive transition to hydrogen-fueled vessels, including increased environmental regulations around carbon emissions, the ability to generate hydrogen locally from electrolyzers, and the anticipated decreases in the costs of fuel cells. Several pilot projects are underway using hydrogen as a transportation fuel, including for towboats, passenger ships, ferries, and short-haul truck routes, as discussed in Chapter 6. Construction of the first hydrogen cell boat, dubbed Water-Go-Round, is expected to be completed by September 2019 and operate as a passenger ferry in San Francisco Bay. Although never turned into a working prototype, a fuel-cell vessel was previously considered for the San Francisco Bay Area through a feasibility study conducted by Sandia National Laboratories on a high-speed, 150-passenger design, called SF-BREEZE (Pratt and Klebanoff 2016). For longer distance travel, a recent Sandia National Laboratories report demonstrated the technical and economic feasibility of a hydrogen-powered research vessel (dubbed the ZERO-V), which would need to go at least 2,400 miles, or 15 days, before requiring a refuel, which is enough to get from San Diego to Hawaii (Klebanoff et al. 2018).

Aircraft

The use of autonomous and remotely operated electric-propelled aircraft is rapidly growing for commercial purposes, emergency management, military operations, and environmental monitoring. Fully electric passenger aircraft are in development, including autonomous vertical takeoff or landing crafts, such as Cora from Kitty Hawk, with stated speeds of more than 150 kilometers per hour and a range in excess of 100 kilometers (Kitty Hawk 2018). The National Aeronautics and Space Administration (NASA) has an active program, X-57, developing an electric aircraft with a speed of 172 miles per hour (mph), 140 kilowatts continuous, 300 kilowatts maximum, 69.1 kilowatt-hours (47 kilowatt-hours usable) (NASA 2017; Figure 10.4). Other examples include Lilium's first electric vertical takeoff and landing jet and Airbus' development of a flight demonstrator testing a 2-megawatt hybrid-electric propulsion system.

Numerous companies are also developing short transport air taxis, including Joby Aviation, which is designing an aircraft to hold five people with a range of more than 150 miles on one charge and that is "100 times quieter during takeoff and landing than a helicopter and near-silent during flyovers" (Vance and Stone 2018). Further, aerial drones are being used for a variety of coastal and offshore applications, including delivery of shipments to maritime industries (e.g., Wilhelmsen Ship Services), and are currently limited by range and duration.

Figure 10.4. NASA X-57 aircraft. *Source: NASA Langley/Advanced Concepts Lab, AMA, Inc.*

In the future, it is possible that strategically located landing platforms with integrated charging ports and batteries could enable extended travel over large bodies of water. Extended utilization of both electric and autonomous craft could serve multiple applications, including scientific missions, weather monitoring, military and homeland security, and passenger travel. These charge stations could also be combined with underwater vehicle charge stations, and in locations where this dual purpose could be useful.

Path Forward

Opportunities could exist off grid, such as charging stations in remote terrestrial locations or locations without grid accessibility, or at sea (e.g., moored, station kept, or floating unmoored) for craft to use recharge and extend ranges. The requirements of these recharge stations should be compared with the costs and value of appropriate marine energy-, wind-, and/or PV-energized charging stations, or hybrid systems inclusive of multiple renewable energy technologies, depending on planned ship volume, timing, and loads to be serviced. Extended usage of electric- and hydrogen-powered vessels will depend on evolving regulations, fuel costs, battery energy densities and costs, and fuel cell commercialization and costs. System life cycle cost and value analyses should be conducted for different shipping use cases to assess the utility, limitations, and key hurdles for electrified and hydrogen-powered water transport across areas without feasible grid connection. Marine energy's relative or collaborative potential contribution to charging station power and hydrogen refueling stations can then be assessed from this perspective.

Off-Grid Small Device Consumer and Industrial Charging

Potential Marine Energy Application and Market

The rapid adoption of portable electronic devices has created a global market for charging technologies, especially in areas without access to grid power (Genesis Market Insights 2017; Research Nester 2018). At present, the two primary off-grid charging solutions are portable battery packs and small transportable solar PV panels (Figure 10.5). The majority of off-grid charging of small personal electronic devices is accomplished with portable battery packs, typically in the 5,000–50,000 milliampere hour (mAh) range. Larger-scale battery packs are also available, serving applications such as buildings or townships, and an early pilot project between Tesla and Nova Innovation has demonstrated integration of tidal power and battery storage. Personal-use battery packs are now inexpensive, reliable, convenient to carry, easy to use, and can operate independent of local resources. They are available commercially at around $4/ampere hour, or about $40 for a battery that can charge three smartphones with one charge.

Figure 10.5. Pocket Power 15K Power Bank, Belkin, the connected things division of Foxconn Interconnect Technology, and solar PV charger (Goal Zero Nomad 14 $150, 14-W Peak). *Sources: Belkin and Goal Zero*

However, these personal chargers are not sufficient for all applications. For extended or higher energy use, off-grid personal, industrial, or military activities, portable consumer solar PV panel systems in the 5- to 50-watt (W) range are more suitable. These PV-battery systems have seen increased adoption as prices have decreased within recent years (Wu et al. 2017; World Bank 2018). These smaller PV systems are now available commercially around $12/W or $80 for a 7-W peak panel that can charge one phone in a few hours with decent solar irradiance. Panels are also now more flexible and can be incorporated into clothing, packs, and other equipment (Wu et al. 2017).

In addition, small wind turbines are available for off-grid charging and are a competitor on the scale of watts to kilowatts. New portable consumer wind generators are commercially available, including the MiniWiz

HYmini, which has a capacity of 1-W peak with a 1,500-mAh battery at a price of around $50. These wind systems are naturally dependent on wind speeds and can reliably generate power in 9–40 mph winds. Microwind turbines are available in the 20- to 500-W range (U.S. Department of Energy 2018), with several commercially available and some portable. For example, in 2011, Arista Power introduced a line of human-portable, three-bladed microwind turbines designed to provide battery charging capability at remote and off-grid locations for military and other applications. These operate in wind speeds of 7–45 mph. Primus Wind Power also sells a series of off-grid, small-scale wind turbines for both marine- and land-based applications. These wind systems fill a small niche market that could be competitive with marine energy applications.

New hybrid technologies combine the ability to produce power from both wind and water. For example, the flexible WaterLily wind and water turbine system has recently been released, which generates a 15-W peak and operates in winds of 7–55 mph and current speeds of 0.5–3 meters per second (Figure 10.6). The turbine is anchored with a supplied cord in the current, and a power cable is run to shore to charge devices directly or to the included 2,600-mAh battery pack. This system is available for $199. If it is assumed that the 2,600-mAh battery is about $15, this system is comparable to a PV system at $12/W.

Figure 10.6. WaterLily—A water and wind turbine for charging personal electronics (www.waterlilyturbine.com). *Source: WaterLily*

Turbine systems for charging batteries on boats have been available commercially for some time (e.g., Watt and Sea Hydrogenerators, Eclectic Energy Sail-Gen, and Save Marine Hydrogenerator). For instance, the Watt and Sea Hydrogenerator 300-W 12-volt (V) Cruising 24", which operates off the side of a boat at boat (or current) speeds of 1–10 meters per second, is around $4,000, or $13/W (Figure 10.7).

Figure 10.7. Watt and Sea Hydrogenerator 300-W 12-V Cruising 24". *Source: Watt and Sea*

This technology would probably be costlier per watt at smaller capacities. Although this generator system has been commercially available, utilization in smaller capacities in portable nonboat-mounted applications is unknown.

Path Forward

Charging of small electronic devices from river and other water currents may be a small subset of the off-grid personal charging sector. Adoption of the new WaterLily turbine system should be followed closely to assess the potential of the personal charging market (e.g., reliability and market traction). A cheap, easily deployed, marine renewable energy charger would likely be useful to hikers, recreational boaters, and off-grid coastal communities. It could also have potential application for survival craft, such as lifeboats and life rafts, that have limited available sources of energy.

Ocean Pollution Cleanup and Marine Conservation

Potential Marine Energy Application and Market

There are potential markets for the application of marine renewable energy technologies to marine conservation topics, including ocean pollution cleanup, oil spill cleanup, and coral reef restoration. Plastic debris and contaminants in the ocean are pervasive and physically harmful to wildlife and the environment. Marine plastic has even been found in seafood destined for human consumption (Rochman et al. 2013a, 2013b; Browne et al. 2008; Lithner, Larsson, and Dave 2011; Teuten et al. 2009). No one knows exactly how much plastic is in the ocean today, but best estimates place the amount around 150 million tons. If we continue with business as usual, by 2025 the amount will increase to the point that for every 3 tons of fish in the sea there will be 1 ton of plastic. By 2050, the ratio will be 1:1 (GOV.UK 2018; Rochman et al. 2013b).

The scale and complexity of ocean plastic pollution is not well understood, but it is of growing concern to many nations. It is likely that as true scale and impacts of marine pollution are realized, we will see more solutions proposed. In addition to the collection of plastics, marine energy potentially adds a method to collect surface slicks of spilled petroleum and other contaminants, having the additional benefit of cleaning the environment and protecting wave power and desalination equipment from hydrocarbon fouling. An additional marine conservation application that could potentially utilize marine energy includes the restoration of coral reefs, such as using wave energy to support reef restoration via electrolysis of seawater to produce limestone.

Most debris that makes it to the ocean eventually winds up in an ocean gyre, which is a large circular current near the center of ocean basins. These gyres have become known as maritime “garbage patches” because of the prevalence of trash (Figure 10.8). There are five major gyres in the world’s oceans, and each contains plastic debris. When it comes to cleanup efforts, the best solutions are those that prevent trash from reaching the ocean. However, there is an immense amount of plastic already in the ocean, and it needs to be removed before it degrades into dangerous microplastics.

Figure 10.8. Illustration of Pacific Ocean garbage patches. *Image from National Oceanic and Atmospheric Administration*

Although there are many proposed technical solutions to address ocean plastic pollution, three popular examples include:

1. The Seabin Project to passively collect floating debris (Seabin Project)
2. The Waterfront Partnership of Baltimore’s Trash Wheel powered by currents and solar PV (The Waterfront Partnership of Baltimore’s Mr. Trash Wheel)
3. The passive moored Ocean Cleanup Project.

The Seabin and the Trash Wheel solutions are examples of coastal cleanup efforts; they attempt to remove trash and debris from the water before it reaches a major body of water. Some of these devices are within easy access of a grid connection, but for other applications, marine energy provides the best power option due to proximity to strong currents or waves. For example, the Trash Wheel converts river currents into mechanical energy to power its conveyor belt for trash collection.

The Ocean Cleanup Project device is designed to use solar energy to power its sensors and navigation lights. However, given the limitations of solar in maritime applications, especially in ultraremote locations far out at sea, this device may be an excellent candidate for marine renewable energy. Moreover, if the pilot device proves successful, the intent is to build dozens of these cleanup devices for each of the major gyres.

In addition to marine plastics, various other types of contaminants in the marine environment can impact marine life and human health, including oil spills. According to the National Oceanic and Atmospheric Administration’s (NOAA’s) Office of Response and Restoration, oil spills of varying size happen along U.S. coasts, the Great Lakes, and rivers almost every day, with involvement of federal agencies in more than 100 responses to spills or vessel groundings each year (NOAA 2018a). Given the frequency of spills, development of methods for efficient oil-water separation has been of global interest. The environmental and economic demands highlight the urgent need for functional materials that can achieve oil/water separation efficiently. In ocean settings, oil spills can spread over large distances and persist for weeks to months, with associated response cleanup methods requiring sustained power over the course of a spill. Although largely unexplored, ocean energy could potentially power the oil-water separators, skimmers, and other cleanup methods used to collect surface contaminations of spilled petroleum and other pollutants.

There are a variety of semiautonomous vehicles being used in ports and harbors to help with cleanup, though nothing at a significant scale yet. For example, the WasteShark is being used to collect plastic, algae, and weeds in marinas and is even capable of collecting oil from the surface of the water. It is an unmanned electric catamaran that primarily gets its power from solar panels and storage in onboard batteries. In addition, Chicago nonprofit Urban Rivers developed a prototype floating robot to help clean up trash from the Chicago River and is developing designs for next-generation models.

An additional marine conservation application that could utilize marine energy technologies includes the restoration of coral reefs, which are being threatened around the world. As temperatures rise, mass coral bleaching events and infectious disease outbreaks are occurring more frequently, and the rising acidity of the oceans threatens reefs by making it harder for corals to build their skeletons (NOAA 2018b). Novel ways are being explored to repair these reefs by using electricity to accelerate coral growth on steel frames. For example, Zyba developed the patented CCell technology, an ultralightweight wave energy converter to generate electricity and grow artificial coral reefs from minerals in the water through an electric process known as Biorock. These techniques are currently being used in various locations to stimulate coral growth, including the Great Barrier Reef and Bali (Smithsonian 2016; New Scientist 2018).

Path Forward

There is a global need in the world's oceans for the development of technologies to efficiently remove marine debris and contaminants from seawater, given their pervasive and destructive nature, and to otherwise aid in marine conservation efforts. Removing plastic debris from the ocean is costly and unregulated. Should cleanup efforts to remove ocean plastic from remote or at-sea locations gain traction and funding, the requirements of cleanup systems should be compared with the costs and value of appropriate marine-energy-, wind-, and/or PV-energized charging stations, or hybrid systems inclusive of multiple renewable energy technologies. With regard to oil spills, federal spill response efforts are triggered for spills of a certain size and use various techniques for minimizing the impacts of hydrocarbons on the marine environment and human health. There may be an opportunity to incorporate marine energy devices into powering oil-water separators, which could be explored in partnership with federal agencies (e.g., NOAA and the United States Coast Guard) and companies and universities actively supporting spill response efforts. In addition, marine energy has the potential to aid in the conservation and restoration of coral reefs, such as has been demonstrated using lightweight wave energy converters to grow artificial reefs off some coastal communities.

Offshore Communications

Potential Marine Energy Application and Market

An expansive network of underwater communications infrastructure plays a critical role in global data transmission. This network comprises submarine communications cables that are laid on the seabed between land-based stations and carry telecommunication signals across the oceans (Figure 10.9). As of early 2018, there were approximately 448 submarine cables in service around the world, equating to more than 1.2 million kilometers of submarine cables in service globally (TeleGeography 2018). A vast majority (99%) of all transoceanic data traffic goes through undersea cables, including internet usage, phone calls, and text messages, at a speed that is up to eightfold faster than satellite transmissions (Starosielski 2015). Modern submarine cables use fiber-optic technology with optical fiber repeaters that are powered by a constant direct current passed down the conductor, near the center of the cable, and power feed equipment is installed at the terminal stations. Marine renewable energy may present an opportunity for powering new cables, as well as the network of environmental sensors that have been proposed for integration into these cables (Lentz and Howe 2018).

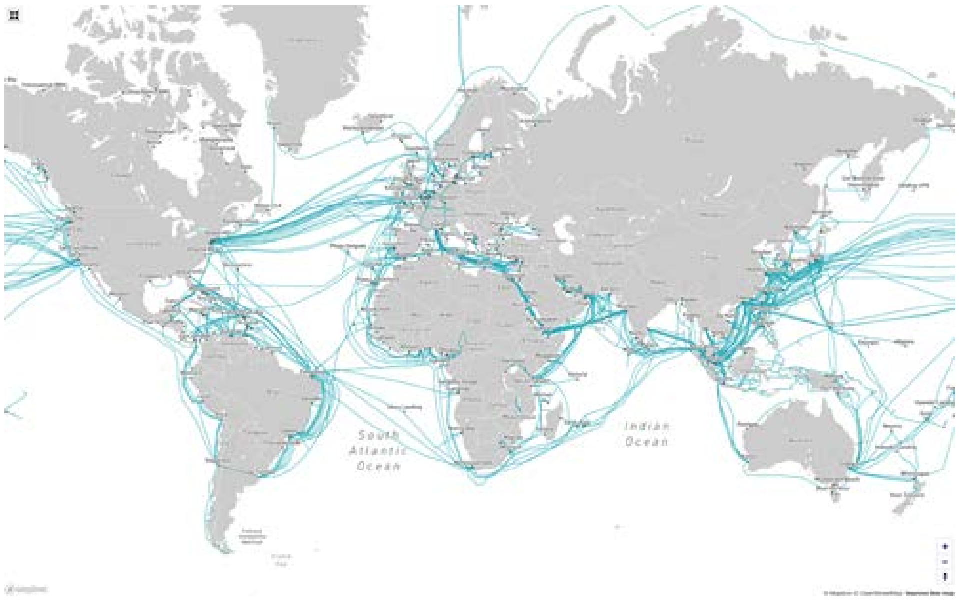

Figure 10.9. Map of global operational submarine cables. *Source: ©Network Atlas (www.networkatlas.com); Image courtesy of Kapany Networks, Inc.*

The International Telecommunication Union; Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization; and the World Meteorological Organization established a joint task force in late 2012 to investigate the use of submarine telecommunications cables for ocean and climate monitoring and disaster warning. Two of the technical challenges for integrating environmental sensors into submarine cables include power consumption limits and delivery of power to external sensors (Lentz and Howe 2018). The additional power required by integrating scientific sensors into cables could be provided by marine renewable energy at each of the nodes where sensors are installed, likely at the optical fiber repeaters.

Another potential underwater communications market for marine energy applications is represented in the underwater acoustics market. According to a recent market research report, the underwater acoustic communication market is expected to grow from $1.31 billion in 2017 to $2.86 billion by 2023 (MarketsandMarkets 2018). Several major factors are identified as driving the growth of this market, including the increase in the adoption of underwater acoustic modems in the oil and gas and naval defense sectors. As discussed in Chapter 3, autonomous underwater vehicles can also be equipped with underwater acoustic modems that are used for communications because they explore the ocean and gather data during monitoring missions. These autonomous underwater vehicles could potentially be recharged at stations powered by marine energy.

Path Forward

Underwater communication networks of both fiber-optic cables and acoustic modems play a critical role in various sectors, including global telecommunications, the energy industry, defense operations, and ocean observing. There are also proposals to couple environmental sensors into submarine cables for ocean and climate monitoring and early disaster warning—an application that would require additional power sources. As these communication networks continue to develop, and environmental monitoring networks are integrated, there may be an opportunity for marine renewable energy to power these systems. For example, marine energy could be integrated at the telecommunication cable repeaters, where it has also been proposed that integration of environmental sensors would occur. Opportunities for partnering include major telecommunications companies, the oil and gas sector, the U.S. Navy, and universities. They also consist of the International Telecommunication Union; Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization; and World Meteorological Organization Joint Task Force.

Offshore Data Centers

Potential Marine Energy Application and Market

The explosion of cloud computing and internet-based content—from movie streaming to cryptocurrency mining—has created significant growth and evolution in the build-out of server centers. These servers have a tremendous electricity demand; in the United States alone it represents 70 terawatt-hours per year, or almost 2% of total U.S. electricity consumption in 2014 (Shehabi et al. 2016). Customers in this market require uninterrupted power and often have 100% renewable energy targets, but they remain price sensitive, which limits the type of renewable energy utilized. Data centers need electricity for powering the computer servers and auxiliary systems, often referred to as "energy overhead." Historically, cooling has represented a large part of a data center's energy overhead, but in recent years this portion has been decreasing because of improved efficiencies in hardware and facility design (Cutler et al. 2017). Still, companies look for opportunities to reduce this cost. For example, companies such as Google, Microsoft, and Nautilus Data Technologies have been experimenting with using water, including seawater, for cooling instead of the more common air-cooling methods (e.g., Figure 10.10). Evolving small "edge caching" data centers, located near coastal population centers, increasingly need rapid paths to deployment and scalability, reduced costs, and access to reliable renewable power (NOAA 2017; Microsoft 2018).

Figure 10.10. Google data center opened in 2011 in Hamina, Finland (left) with closed-loop water cooling (right). *Source: ©2018 Google LLC, used with permission. Google and the Google logo are registered trademarks of Google LLC*

As costs and reliability of marine energy technologies continue to improve, they have the potential to provide local, renewable power to shore- and sea-based data centers, reduce cooling electrical loads, and share infrastructure and installation and operation and maintenance efforts. These technologies can also be part of a rapidly scalable edge node system at coastal population centers and in remote communities. Other data center types, including temporary data centers for emergency and military management, require extreme ease of deployment and reliability, along with proven integration with storage and backup generation sources. Further, marine energy devices have the potential to replace or extend diesel supplies and operational times for these temporary centers. Combined, this is a potential multibillion-dollar market and is only expected to grow as computing needs increase (Jones Lang LaSalle IP, Inc. 2017; RECAP 2017).

The data center sector is rapidly expanding and evolving, with major players, such as Amazon, Microsoft, Google, and Apple utilizing or targeting 100% of electricity from renewable sources. These centers encompass a rapidly evolving range of sizes and purposes, including large "hyperscale" server centers, in-house or multitenant data centers, edge caching data centers, and temporary data centers (RECAP 2017; Gartner 2016; Cisco 2016; International Data Corporation 2017).

Large Hyperscale Data Centers

Large, rapidly scalable hyperscale server centers have been defined by International Data Corporation as being "...often architected for a homogeneous scale-out greenfield application portfolio using increasingly disaggregated, high-density, and power-optimized infrastructures. They have a minimum of 5,000 servers and are at least 10,000 sq ft in size but generally much larger" (RECAP 2018). Many of these data centers are located in areas with inexpensive, reliable electricity, and some have been located in northern latitudes to leverage lower ambient air temperatures for cooling support. The power load for these data centers may vary from hundreds of kilowatts to hundreds of megawatts.

Edge Caching Data Centers

Data centers located far away from the end user will require long transmission lines to send and receive data packets, but this distance can cause delays and increase data latency. This can be very disruptive for businesses that conduct rapid transactions, such as electronic-traded funds or stream videos. To reduce the disruption of data latency and improve content delivery efficiencies, small local servers are being placed near population centers (i.e., extending close to the customer and possibly even on-site, for both commercial and residential) and will host cached content, known as "edge caching" (Figure 10.11). These small centers could have tens to hundreds of servers and typically have power loads in the tens to hundreds of kilowatts and potentially larger.

Off-grid temporary or "pop-up" data centers for events, emergency response, or military operations are now regularly utilized. These are typically mobile truck-based or container-based systems with only a few servers and power needs in the tens to hundreds of kilowatts range. These pop-up data centers value mobility and the ability to deploy quickly with few resources.

Figure 10.11. Edge data center from Edge Micro. *Photo from edgemicro.com*

Data centers between the temporary and hyperscale data center extremes also exist. This is a highly dynamic sector that is quickly evolving as a result of new computing needs and technology trends like cryptocurrency mining. It is envisioned that marine energy combined with storage and potentially other renewable energy sources could provide the power or partial power for these data centers, with ocean or river water providing server cooling to reduce load.

Small edge caching data server centers have tens of servers that require tens to hundreds of kilowatts of power. These centers also require 100% availability of high-quality power, are typically grid connected, and employ backup storage and power supplies. The Project Natick modular subsea data center recently deployed by Microsoft (and discussed more in the upcoming sections) is a 240-kilowatt data center module with 12 racks containing 864 standard Microsoft data center servers and 27.6 petabytes of disk (Microsoft 2018; Figure 10.12). This data center is as powerful as several thousand high-end consumer personal computers and has enough storage for about 5 million movies. Temporary data centers with few servers and low power requirements (hundreds of kilowatts) are currently either grid connected with some battery backup, and/or powered by diesel generators.

Figure 10.12. Microsoft Project Natick Phase 2–modular submersed server with renewable ocean energy and ocean cooling, Scotland. *Photo by Scott Eklund/Red Box Pictures*

Path Forward

Customers for marine energy power specific to data centers would be any of the large technology firms that build and operate data centers, such as Amazon, Microsoft, Google, Apple, and Cisco. Although these companies are likely to develop larger data centers that have megawatt-scale needs, smaller data center developers may also be potential customers as their energy overhead is often higher than that of the larger facilities. The military, telecommunications firms, and some disaster response groups may also have interest in pop-up data centers that could be powered by marine energy. The Federal Emergency Management Agency utilizes and sponsors activities in disaster preparedness and response and could be a potential partner for temporary data center development and deployment. Local renewable power enables replacing or supplementing diesel-supplied power. Simple and fast setup paired with very high reliability is essential for these markets. Groups that have invested in cryptocurrency mining operations would be potential customers as well since their computing needs, and thus energy needs, are only expected to increase as adoption of these electronic currencies continues. Lastly, offshore oil and gas service providers are also potential partners worth investigating if pursuing offshore data center developments.

References

Browne, M. A., A. Dissanayake, T. S. Galloway, D. M. Lowe, and R. C. Thompson. 2008. "Ingested microscopic plastic translocates to the circulatory system of the mussel, Mytilus edulis (L)." *Environ. Sci. Technol.* 42, 5026–5031. https://www.ncbi.nlm.nih.gov/pubmed/18678044.

Cisco. 2016. Cisco Global Cloud Index: Forecast and Methodology, 2015–2020. http://www.cisco.com/c/dam/en/us/.

Cutler, Ben, Spencer Fowers, Jeffrey Kramer, and Eric Peterson. 2017. "Want an Energy-Efficient Data Center? Build It Underwater." *IEEE Spectrum*. https://spectrum.ieee.org/computing/hardware/want-an-energyefficient-data-center-build-it-underwater.

DNV GL. 2017a. "Low Carbon Shipping Towards 2050." Accessed April 8, 2018. https://www.dnvgl.com/publications/low-carbon-shipping-towards-2050-93579.

DNV GL. 2017b. "Energy Transition Outlook 2017: Maritime Forecast to 2050." Accessed April 8, 2018. https://eto.dnvgl.com/2017/maritime.

European Marine Energy Centre. 2017. "World's first tidal-powered hydrogen generated at EMEC." Accessed April 8, 2018. http://www.emec.org.uk/press-release-worlds-first-tidal-powered-hydrogen-generated-at-emec/.

Gartner. 2016. Top 10 Technology Trends Impacting Infrastructure & Operations. http://www.gartner.com/smarterwithgartner/.

Genesis Market Insights. 2017. Portable Solar Charger Market By Type (Amorphous solar charger, Mono-crystalline solar charger, Hybrid solar charger, Poly-crystalline solar charger) By Application (Backpack portable solar charger, Small portable solar charger, Fold out portable solar charger) - Global Outlook Analysis and Industry Forecast, 2018–2023. https://www.genesismarketinsights.com/viewreport/80/30/Portable-Solar-Charger-Market-.

GOV.UK. 2018. Future of the Sea: A Report from the Government Chief Scientific Adviser. Government Office for Science, United Kingdom. Accessed April 8, 2018. https://www.gov.uk/government/collections/future-of-the-sea.

Guarnieri, M. 2018. Electrifying Water Buses: A Case Study on Diesel-to-Electric Conversion in Venice. Institute of Electrical and Electronics Engineers. Industry Applications Magazine, Vol. 24, Issue 1, Page 42. January 2018.

Holter, M., and J. Hodges. 2018. "The Next Ferry You Board Might Run on Batteries." *Bloomberg*, March 12, 2018. https://www.bloomberg.com/news/features/2018-03-13/the-next-ship-you-board-might-run-on-batteries.

International Data Corporation. 2017. Worldwide Semiannual Public Cloud Services Spending Guide. https://www.idc.com/getdoc.jsp?containerId=prUS42321417.

International Maritime Organization. 2014. Reduction of GHG Emissions from Ships. Third IMO GHG Study - Final Report. Marine Environment Protection Committee 67th Sessions. Accessed November 30, 2018. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/MEPC%2067-INF.3%20-%20Third%20IMO%20GHG%20Study%202014%20-%20Final%20Report%20(Secretariat).pdf.

Jones Lang LaSalle IP, Inc. 2017. Data Center Outlook: A Wave of Global Momentum. North America. http://www.us.jll.com/united-states/en-us/Research/.

Kitty Hawk. 2018. "Meet Cora." YouTube video, 2:45. Posted by Kitty Hawk, March 12, 2018. https://www.youtube.com/watch?v=LeFxjRMv5U8.

Klebanoff, Leonard E., Joseph W. Pratt, Robert T. Madsen, Sean A. M. Caughlan, Timothy S. Leach, et al. 2018. Feasibility of the Zero-V: A Zero-Emission, Hydrogen Fuel-Cell, Coastal Research Vessel. Sandia National Laboratory Report, SAND2018-4664. Accessed November 26, 2018. https://energy.sandia.gov/transportation-energy/hydrogen/market-transformation/maritime-fuel-cells/.

Lentz, S. and B. Howe. 2018. SMART Cable Systems: Integration of Sensors into Telecommunications Repeaters, IEEE/MTS Oceans Kobe. Accessed November 1, 2018. https://www.itu.int/en/ITU-T/climatechange/task-force-sc/Documents/Lentz-Howe-OceansKobe-SMART-cables-sensor-integration.pdf.

Lithner, D., A. Larsson, and G. Dave. 2011. "Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition." *Sci. Total. Environ*. 409, 3309–3324. https://www.ncbi.nlm.nih.gov/pubmed/21663944.

The Maritime Executive. 2017. Wave Energy Concept Ready for Ship Propulsion. Accessed November 1, 2018. https://www.maritime-executive.com/article/wave-energy-concept-ready-for-ship-propulsion.

The Maritime Executive. 2018. Norway's Experience Helps Washington Ferries Go Electric. Accessed November 26, 2018. https://www.maritime-executive.com/article/norway-s-experience-helps-seattle-ferries-go-electric.

MarketsandMarkets. 2018. "Underwater Acoustic Communication Market by Interface Platform, Communication Range, Application (Environmental Monitoring, Pollution Monitoring, Climate Recording, Hydrography, Oceanography), End User, and Geography—Global Forecast to 2023." Accessed November 1, 2018. https://www.marketsandmarkets.com/PressReleases/underwater-acoustic-communication.asp.

Microsoft. 2018. "Project Natick." Accessed October 29, 2018. http://natick.research.microsoft.com/.

National Atmospheric and Space Administration. 2017. NASA Armstrong Fact Sheet: NASA X-57 Maxwell. https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-109.html.

National Oceanic and Atmospheric Administration (NOAA). 2017. *Tsunami Messages for the Pacific Ocean (Past 30 days)*. http://ptwc.weather.gov/?region=1.

NOAA. 2018a. Looking for information about oil spills? Accessed November 1, 2018. https://response.restoration.noaa.gov/about/media/looking-information-about-oil-spills.html.

NOAA. 2018b. How does climate change affect coral reefs? Accessed November 26, 2018. https://oceanservice.noaa.gov/facts/coralreef-climate.html.

New Scientist. 2018. Divers are attempting to regrow Great Barrier Reef with electricity. Accessed November 26, 2018. https://www.newscientist.com/article/2180369-divers-are-attempting-to-regrow-great-barrier-reef-with-electricity/.

Pratt, Joseph W. and Leonard E. Klebanoff. 2016. Feasibility of the SF-BREEZE: a Zero-Emission, Hydrogen Fuel Cell, High-Speed Passenger Ferry. Sandia National Laboratory Report, SAND2016-9719. Accessed November 26, 2018. https://energy.sandia.gov/transportation-energy/hydrogen/market-transformation/maritime-fuel-cells/sf-breeze/.

RECAP. 2017. "Global Data Center Market: Market Briefing." Irish Center for Cloud Computing. Accessed April 7, 2018. https://recap-project.eu/media/market-briefings/.

RECAP. 2018. What Makes a Data Center "Hyperscale?" Accessed November 1, 2018. https://recap-project.eu/news/hyperscale-data-center/.

Research Nester Pvt. Ltd. 2018. Global Portable Solar Charger Market Size, Demand, Opportunity & Growth Outlook 2023. https://www.researchnester.com/reports/portable-solar-charger-market-global-demand-analysis-opportunity-outlook-2023/247.

Rochman, C. M., E. Hoh, B. T. Hentschel, and S. Kaye. 2013a. "Long-Term Field Measurement of Sorption of Organic Contaminants to Five Types of Plastic Pellets: Implications for Plastic Marine Debris." *Environ. Sci. Technol.* 47 (3), 646–1654. http://dx.doi.org/10.1021/es303700s.

Rochman, C. M., M. A. Browne, B. S. Halpern, B. T. Hentschel, E. Hoh, H. K. Karapanagioti, L. M. Rios-Mendoza, H. Takada, S. Teh, and R. C. Thompson. 2013b. "Policy: Classify plastic waste as hazardous." *Nature* 14: 169-71. https://www.nature.com/articles/494169a.

Shehabi, Arman, Sarah Josephine Smith, Dale A. Sartor, Richard E. Brown, Magnus Herrlin, Jonathan G. Koomey, Eric R. Masanet, Nathaniel Horner, Inês Lima Azevedo, and William Lintner. 2016. *United States Data Center Energy Usage Report*. LBNL-1005775. Berkeley, California (US): Lawrence Berkeley National Laboratory.

Smithsonian. 2016. This Coral Restoration Technique Is 'Electrifying' a Balinese Village. Accessed November 26, 2018. https://www.smithsonianmag.com/science-nature/coral-restoration-technique-electrifying-balinese-village-180959206/.

Starosielski, N. 2015. *The Undersea Network*. Durham, NC: Duke University Press.

TeleGeography. 2018. Submarine cable 101 - Submarine Cable Frequently Asked Questions. Accessed November 1, 2018. https://www2.telegeography.com/submarine-cable-faqs-frequently-asked-questions.

Teuten, E. L., J. M. Saquing, D. R. U. Knappe, M. A. Barlaz, S. Jonsson, A. Björn, S. J. Rowland, R. C. Thompson, T. S. Galloway, R. Yamashita, et al. 2009. *Philos Trans R Soc Lond B Biol Sci.* 364: 2027–2045. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2873017/.

Tullis, P. 2018. "How Hydrogen Could Help Clean Up the Global Shipping Industry." *Oceans Deeply*, January 10. https://www.newsdeeply.com/oceans/articles/2018/01/10/how-hydrogen-could-help-clean-up-the-global-shipping-industry.

U.S. Department of Energy. 2018. WindExchange Small Wind Guidebook. Accessed November 1, 2018. https://windexchange.energy.gov/small-wind-guidebook.

Vance, A., and B. Stone. 2018. "Air-Taxi Startup Has a Working Prototype and a Fresh $100 Million." *Bloomberg*, February 1, 2018. https://www.bloomberg.com/news/articles/2018-02-01/air-taxi-startup-joby-has-a-working-prototype-and-a-fresh-100m.

World Bank. 2018. The 2018 Global Off-Grid Solar Market Trends Report. Accessed April 8, 2018. https://www.lightingglobal.org/2018-global-off-grid-solar-market-trends-report/.

Wu, C., T. W. Kim, T. Guo, and F. Li. 2017. "Wearable ultra-lightweight solar textiles based on transparent electronic fabrics." *Nano Energy* 32 (February): 367–373. https://doi.org/10.1016/j.nanoen.2016.12.040.