Viable Renewable Energy Sources and Storage for the Retired Power Plant in Morro Bay, CA

A Senior Project

By

Teresa Netro

Advisor: Dr. Robert Echols

Department of Physics, California Polytechnic State University — San Luis Obispo

29 May 2020

Contents

Introduction

The site to be examined for potential renewable energy production retrofit is the decommissioned Power Plant in Morro Bay, CA. The plant is located in central California, 14 miles North-West of San Luis Obispo. It was originally opened in 1955 with just one smokestack, and two were later added to create the “three stacks and a rock” unofficial catchphrase that describes the city today. [1] In terms of power, the plant was capable of producing 300 megawatts (MW). Since one megawatt can power about 1,000 homes [1], this plant could power about 300,000 homes. According to PG&E’s newsletter, PG&E operated the plant from 1955 to 1998. Duke energy then ran it until 2006, when LS Energy bought it. Duke energy then acquired LS energy and the plant in 2007 [2]. The plant was then decommissioned in 2014. Nearby is the Diablo Canyon Nuclear Power Plant which produces “18,000 gigawatt-hours of power each year, powering 1.7 million homes.” [3] Diablo is currently in the process of decommissioning both of their reactors. They plan to have Reactor 1 out of operation by 2024 and Reactor 2 out of operation by 2025. This will leave the central coast with a deficit in power production, but a pre-built infrastructure capable of supplying renewable power to the grid.

The closing of these nearby electrical power generating plants is amidst San Luis Obispo and Morro Bay’s switch to Monterey Bay Community Power (MBCP) as their main power supplier. MBCP provides 100% carbon free energy, with 34% coming from solar and wind and 66% coming from large-scale hydroelectric projects. State law does not consider hydroelectricity renewable because of “the limited potential for new dams, and the negative impacts on local river ecosystems and fish populations.” [4] MBCP customers can upgrade their electricity source to MBprime, which uses exclusively wind and solar energy at the added cost of one cent per kilowatt hour.[4] MBCP is currently working on a large scale solar farm in Kern County and plans to extend its service to the rest of SLO and Santa Barbara counties in the coming years. This is a good start for California's transition to renewable energy.

This project will investigate renewable energy production and storage options possible for the Morro Bay Power Plant and provide a recommendation for the energy portfolio of the renovated site. These suggestions can be tested at the Morro Bay facility before being extended to the nearby Diablo Nuclear Power Plant.

Current Site Proposals

The Power Plant in Morro Bay has been vacant since it closed 6 years ago, and there are no confirmed plans for repurposing the site. The New York Times reported "city officials estimated that taking down the stacks could cost $30 million," [5] so any new facility will likely need to work with the existing stacks. While there are no confirmed proposals for the site itself, there are plans to take advantage of the existing infrastructure that can provide power to the grid, including some plans for an offshore wind farm.

Castle Wind has proposed a farm that would include roughly 100 turbines that, when operating collectively, could produce a maximum of 1,000MW of power, which is enough to power up to one million homes. The turbines would be located roughly 30 miles from shore, farther out than most east coast wind farms [6] *(see appendix figure 1.1 & 1.2)*. The growing interest in offshore power warranted a regulating government sector, and the Bureau of Ocean Energy Management (BOEM) was formed.[7] BOEM has since released a call for offshore wind proposals, where they plan to lease out areas of the ocean to companies which would deploy energy-producing turbines. The potential area on California's central coast is quite restricted due to US Department of Defense and Naval Operations [6] *(see appendix figure 2)*. While this does limit wind energy harvesting potential, offshore wind is still the frontrunner in renewable options currently being considered.

Wind

Wind energy is a product of the pressure and temperature differences caused by electromagnetic radiation from the sun. Typical harvesting of wind energy comes from wind turbines. A turbine's blades are designed to catch the Kinetic Energy of the wind and turn a rotor. The rotor transfers power through a drive shaft and gearbox to the generator which converts the kinetic energy from the turbine into electrical energy [8] (*see appendix figure 3*). The primary source of renewable energy being considered for deployment in Morro Bay is offshore wind. Europe has deployed many wind farms and is planning for even more. They have invested heavily in wind turbine technology. A current turbine produces a maximum power of about 3.6MW. [8] The turbines that have been specked for deployment off the coast of Morro Bay are rated for 10MW each. This large increase in power generation capacity can be attributed to larger turbines, stronger wind further offshore, and more efficient energy conversion. [6] Since turbine technology improves with every generation, it is reasonable to expect 10MW windmill capabilities for the Morro Bay and Diablo Canyon sites.

The biggest challenge for installing a wind farm on the California coast will be the depth of the water. There is a steep drop-off along the coastline that prevents the turbines from being anchored into the ocean floor. Traditional methods of offshore turbine deployment, such as monopiles, tension-leg, or catenary mooring techniques can only be deployed in shallow to transitional depths (*see appendix figure 4*) and will not work for this location. According to Castle Wind, "a number of floating support structures are expected to be available for commercial use at the time of the project construction, estimated to be in the 2025 to 2027 timeframe.” [6]

This potential for offshore wind is a game-changer for California. Currently, the main deterrents from installing wind power are the high up-front manufacturing and installation costs, the intermittent nature of wind, and possible noise and unpleasant aesthetics. With the farm 30 miles offshore, the aesthetics and noise become less of an issue. Additionally, offshore winds are typically stronger and more predictable than onshore winds. The largest issue remaining will be the upfront cost of developing the floating rig technology. Once this system is developed, it will be cheaper to manufacture and deploy, making it a worthwhile initial investment. [6]

Wave

Waves are generated when kinetic energy from wind is transferred to the ocean as wind hits the ocean’s surface. Since wind is created from high and low pressure zones caused by solar radiation, both wind and wave energy are considered renewable.

There are a number of strategies for harvesting power from ocean waves. The Oscillating Water Column (OWC) is currently the most deployed wave energy collection technology. [9] The OWC works by creating an air chamber on land where incoming waves enter and exit. As water infiltrates the chamber, air is forced out. This air passes through a turbine and turns a generator. As the wave recedes, air is drawn back into the chamber, spinning the turbine and generating power for a second time. (*see appendix figure 5*). Since this system collects energy twice per cycle it is very efficient for energy collection. This technology is currently deployed at the LIMPET facility in Scotland and the harbor of Mutriku, Spain. The LIMPET power plant generates 500 kW with a single 2.6-meter diameter Wells turbine, enough to power about 500 homes. [1,10] This turbine is connected to a collecting chamber consisting of 3 tubes and measuring 6x6 meters. The facility produces an "average annual output of up to 1,800MWhrs in a year with an average wave resource of 20kW [per meter of shoreline]." [10] The Mutriku plant consists of a front opening that is 3.2 meters by 4 meters, and contains 16 air chambers, each with its own Wells turbine. This facility produces roughly one third the power of LIMPET. The 296kW plant generates roughly 600MWhr annually. [11]

Another wave power system is the Surface-following attenuator or "line absorber". It is made from many connected units that sit on the ocean's surface. The units are moved in both horizontal and vertical directions relative to each other. This movement is harnessed and converted into electricity within the point absorber [12] (*see appendix figure 6*). The only full-scale attenuator that has been deployed was in Portugal. It was deployed for only one month before it was disconnected and towed back to land. [12] They have no estimate about whether or not it will be re-deployed. A failed first deployment does not rule-out this technology, but it does make it less appealing compared to other, more successful wave energy collection systems.

The Buoyancy Unit, sometimes called a Point Absorber is another wave power collector. It consists of a buoy that sits on or below the surface, connected to a pump that is anchored in the ground. The vertical movements of the buoy drive the pump and generate electricity (*see appendix figure 7*). There are deployments in Ghana and Sweden, and research is being conducted in the US and Greece. The Swedish deployment consists of 36 units and produces about 3MW. They are in the process of expanding the wave farm to 9MW. The Azura US facility in Hawaii is testing a point absorber that is expected to generate about 1MW. [13] There is still room for growth in this technology. The Department of Energy has begun to invest, and it will continue to improve. [13]

Solar

There are two types of Solar energy collection, photovoltaic solar panels (PV) and concentrated solar power (CSP). PV panels work by using an interface to create an electric field. As electromagnetic radiation from the sun hits the panel, some electrons move to the conduction band due to the photoelectric effect, inducing a current.[14] On a sunny day, about 1,000 W/m^2 fall on the Earth's surface when the sun's angle is approximately 48 degrees. Today's solar panels are about 20% efficient, meaning that a square-meter panel can collect up to 200 Watts. This means that it would take about 5,000 square meters, or about 1.2 acres of panels working at maximum efficiency to produce 1MW of power. There are some advancements in creating multijunction solar cells that can make use of more of the incident solar radiation, but these technologies are slow-developing and very expensive. The added energy produced is not currently worth the added cost. [14]

The concentrated solar power system uses mirrors to concentrate the sun's heat to collect thermal energy. There are a few variations of the system that are currently in use. The Trough System (*see figure 8)* uses parabolic mirrors to reflect sunlight onto an oil-filled core. This hot oil is then used to boil water, and the resulting steam turns a generator.[15] The Power Tower or Central Receiver System uses many mirrors to reflect light onto a central heat-receiving tower. The tower is filled with a liquid that gets very hot, such as molten salt. Again, the hot fluid is used to make steam or can be stored for later use. [15] The last is the Dish Engine system. It uses large dish shaped mirrors to reflect light onto a receiver and engine mounted at the focal point of the disk. The engine has thin tubes containing hydrogen or helium gas that run along the outside of the engine's piston cylinders and open into the cylinders. As concentrated sunlight falls on the receiver, it heats the gas in the tubes to very high temperatures, which causes hot gas to expand inside the cylinders. The expanding gas drives the pistons. The pistons turn a crankshaft, which drives an electric generator. [15] A number of these systems have been deployed since the 1980's. The most recent ones, deployed between 2013-2015, are located in the Mojave Desert in California as well as Arizona.[16] One of these projects, Genesis, uses the parabolic trough system to produce 250MW.[16] Another, called Ivanpah, uses the power tower to produce 377MW.[16] These systems are very powerful but can be slightly dangerous. It makes sense for these systems to be in a less populated area since there is so much exposed, concentrated heat involved.

Hydrogen Fuel Cells

The potential for energy storage is an important consideration in the switch to renewable energy. It is not sunny or windy 24 hours per day, and waves are sometimes minimal, having a way to store any excess energy is crucial to the efficacy of renewable power. Hydrogen fuel cells are an option that combine hydrogen and oxygen to produce electricity, heat, and water [17] (*see appendix figure 9*). They are comparable to batteries, but don't need to "recharge" as long as hydrogen fuel is being supplied. [17] There are a few ways to obtain hydrogen to run these cells. Currently, most hydrogen is collected through the process of reforming, in which a natural gas is heated and releases hydrogen. [17] Another, greener way to produce hydrogen is by farming certain algae and bacteria which naturally release hydrogen. [17] In this project though, it would make the most sense to run hydrogen fuel cells like batteries using a process called electrolysis. In this process an electrical current separates water into its components of oxygen and hydrogen. The Morro Bay site would use excess energy to perform electrolysis and store the resultant hydrogen fuel until energy is needed again. Then, the fuel cell “battery” will run forwards, producing energy. [18]

Buoyancy Storage

Another energy storage option uses buoyancy to store excess energy. When there is unused energy, a floating volume will be pulled a certain distance underwater and stored there until energy is needed. Then, upon release it will turn a generator to produce electricity. This method of energy storage is still under testing and development. Current designs include a large raft that could be placed under or near the floating offshore windmills to store the energy that they produce. The Turbulence and Energy lab at the University of Windsor has designed a rig (*see appendix figure 10*) that is 55 meters by 65 meters and can store 1 MWhr when moved a distance of 100m underwater. [19] If a buoyant array could be set up with each windmill, there is a potential to store 100MWhr, or even more if more floats are added.

Gravitational Potential Energy Storage

There are a few systems being tested that store energy by elevating mass to store energy as potential energy, before releasing the mass to the original elevation and harnessing the stored energy. One system called the Advanced Rail Energy Storage (ARES), uses large masses on tracks to pull the masses uphill when there is excess energy and store them in a “storage zone” until energy is required. Then the masses are released back down-hill and energy is produced due to generator’s regenerative breaking. [20] According to ARES, its “facilities are highly scalable in power and energy ranging from a small installation of 100MW with 200MWh of storage capacity up to large 2-3GW regional energy storage system with 16-24GWh energy storage capacity.” [20] Other gravity storage systems utilize underground facilities such as old mineshafts and repurpose them into “gravity batteries”. In these systems, masses are lifted and lowered according to energy supply or demand. These systems make more sense economically when re-using an existing site. The possibility of using the Morro Bay stacks themselves as the structure for an above-ground gravity battery in which a large mass within the stack could be lifted and lowered to store energy was intriguing. While this could be a possible energy storage solution, it would require a substantial structural retrofit of the stacks themselves, and in the end the amount of energy stored would not be enough to power the whole town of Morro Bay.

Chosen Energy Sources and Storage for Project

For the adaptive re-use of the Morro Bay powerplant as a renewable energy facility, it makes the most sense to proceed with a diverse portfolio. Since most renewable energy sources are intermittent, it would be best to rely on a variety of energy collection methods for a steady energy supply. For wind energy collection and storage would like to continue with Castle Wind’s offshore turbine concept and integrate a buoyancy energy storage solution onto each windmill’s rig. For wave energy collection, the plant’s old water exchange tunnel leading into the ocean would be an excellent place to set up an Oscillating Water Column. Lastly, I would like to deploy solar on as much of the existing site as possible. Any excess energy produced by these systems would power electrolysis and be stored as hydrogen for later use in hydrogen fuel cells stored on site. Switching to renewable energy will not be an easy task, but it is essential for the future of our planet. The Morro Bay power plant site is an excellent opportunity to test a diverse renewable energy production portfolio. If the deployment goes well, the systems in place can be expanded for the post-retirement of nearby Diablo Nuclear Power Plant. Taking advantage of the existing infrastructure to transfer power to the grid makes retired power plants a good place to continue humanity’s switch to renewable energy.

Appendix

Figure 1.1: Rendered view of offshore wind farm from San Simeon, CA. See enlarged Fig. 1.2 [A]

Figure 1.2: Enlarged view of Figure 1.1 [A]

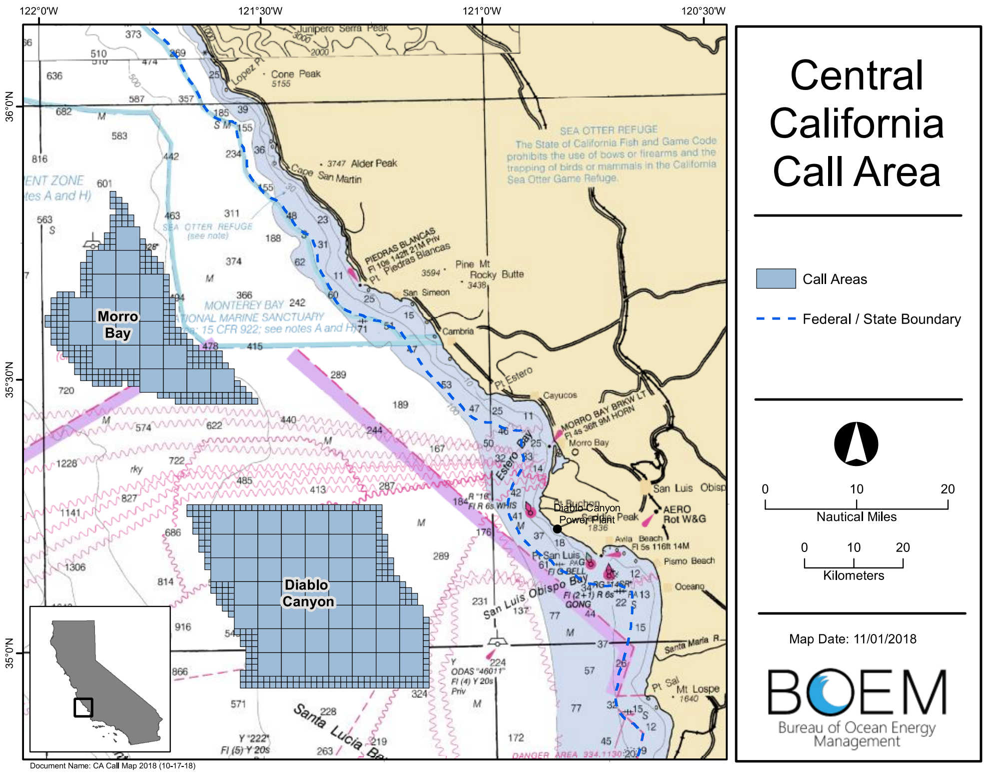

Figure 2: BOEM map of potential offshore wind farm deployment area. [B]

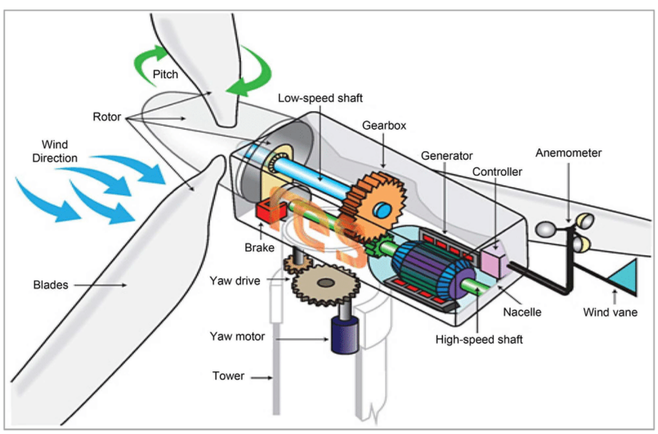

Figure 3: Diagram of a wind turbine’s power generation process. [C]

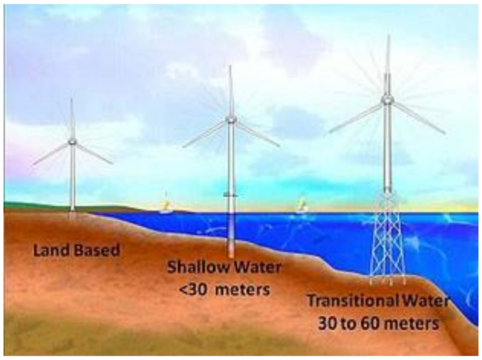

Figure 4: Traditional offshore anchoring techniques at less than 60m ocean depth. [D]

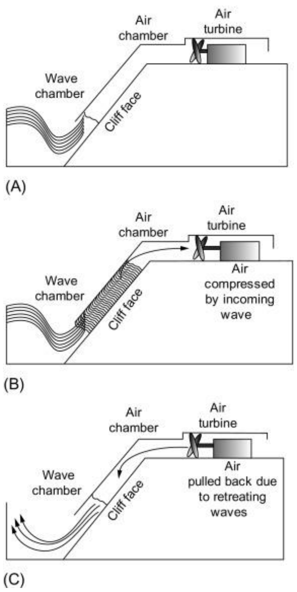

Figure 5: Oscillating Water Column [E]

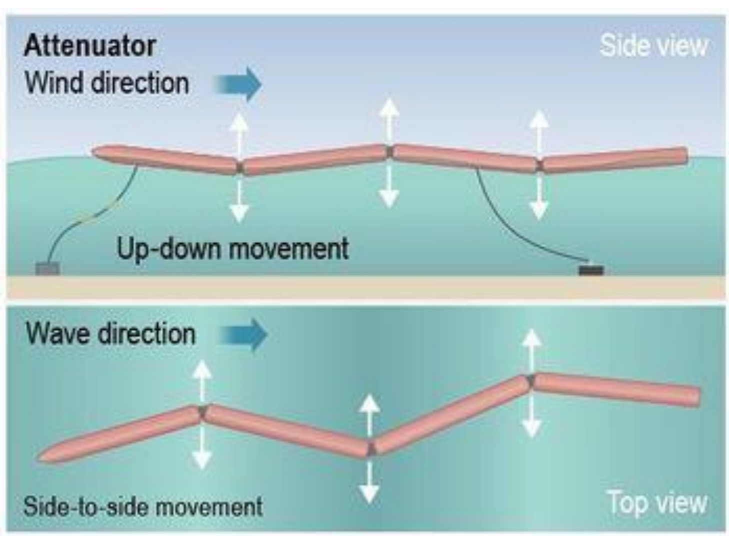

Figure 6: Surface Following Attenuator [F]

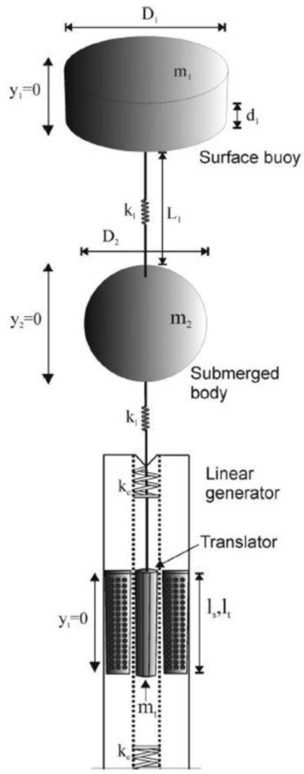

Figure 7: Buoyance Unit (Point Absorber) [G]

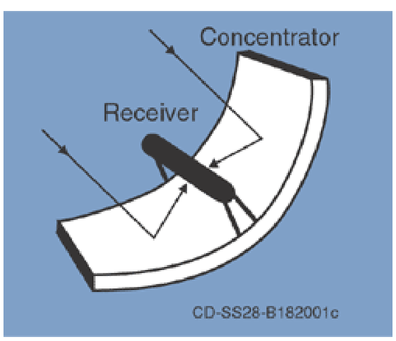

Figure 8.1 & 8.2: Parabolic Trough System

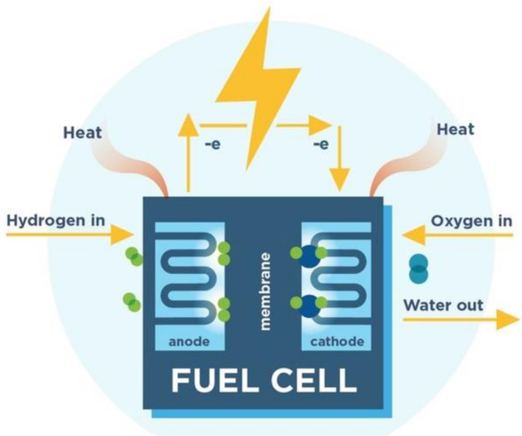

Figure 9: Hydrogen Fuel Cell [I]

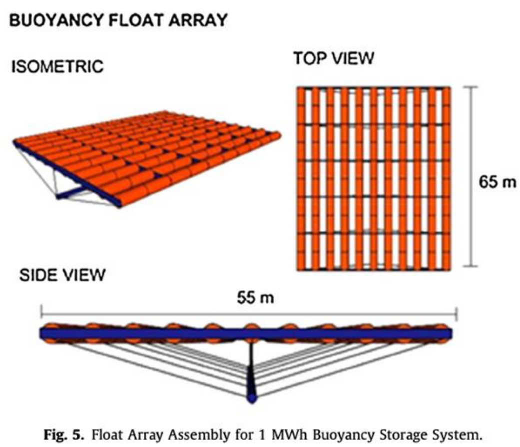

Figure 10: Buoyant Energy Storage Rig [J]

Image Citations

[A] "California Visual Simulation." *Bureau of Ocean Energy Management*, www.boem.gov/renewable-energy/state-activities/california-visual-simulation.

[B] "Central California Call Area." *NOAA Chart*, BOEM, www.boem.gov/sites/default/files/renewable-energy-program/State-Activities/CA/Central-California-Call-Areas-Map-NOAA.pdf.

[C] "Wind Turbine Facts." *Loeriesfontein Wind Farm*, loeriesfonteinwind.co.za/wind-energy-library/wind-turbine-facts/.

[D] Umaine, J. "Offshore Wind: What Lies Beneath?" *The Bard CEP Eco Reader*, 3 May 2017, www.bard.edu/cep/blog/?p=9240.

[E] “Oscillating Water Column.” *Oscillating Water Column - an Overview | ScienceDirect Topics*, www.sciencedirect.com/topics/engineering/oscillating-water-column.

[F] “Wave Energy.” *Wave Energy*, 9 Feb. 2016, envirogroupmohawk.wordpress.com/2016/02/09/wave-energy/.

[G] Engström, J.; Kurupath, V.; Isberg, J.; Leijon, M. A resonant two body system for a point absorbing wave energy converter with direct-driven linear generator. J. Appl. Phys. 2011, 110.

[H] “Concentrating Solar Power (CSP) Technology.” Solar Energy Development Programmatic EIS, Solar PEIS, www.solareis.anl.gov/guide/solar/csp/.

[I] “Hydrogen & Fuel Cells.” Renewable Energy World, www.renewableenergyworld.com/types-of-renewable-energy/hydrogen/#gref.

[J] Bassett, K.p., et al. “Integration of Buoyancy-Based Energy Storage with Utility Scale Wind Energy Generation.” Journal of Energy Storage, vol. 14, 2017, pp. 256–263., doi:10.1016/j.est.2017.04.013.

References

[1] “What Is a Megawatt?” *Bellamare*, NRC, 2012.

[2] Kmetz, Ben. “Morro Bay: Iconic Central Coast Power Plant, Once Owned by PG&E, Shutting Down.” *Currents*, PG&E, 18 Feb. 2014, www.pgecurrents.com/2014/02/18/morro-bay-iconic-central-coast-power-plant-once-owned-by-pge-shutting-down/.

[3] Nikolewski, Rob. “Regulators Vote to Shut down Diablo Canyon, California's Last Nuclear Power Plant.” *Los Angeles Times*, Los Angeles Times, 11 Jan. 2018, www.latimes.com/business/la-fi-diablo-canyon-nuclear-20180111-story.html.

[4] “Understanding Clean Energy.” *MBCP*, 2020, www.mbcommunitypower.org/understanding-clean-energy/.

[5] Nagourney, Adam. “A Power Plant in California Goes Quiet, but the Stacks Still Tower.” *The New York Times*, The New York Times, 24 Nov. 2014, www.nytimes.com/2014/11/24/us/a-power-plant-in-california-goes-quiet-but-the-stacks-still-tower.html.

[6] “Project Overview.” *Morro Bay Offshore Project*, Castle Wind, 2019, www.castlewind.com/morro-bay-project/.

[7] “The Reorganization Of The Former MMS.” *Bureau of Ocean Energy Management*, BOEM, https://www.boem.gov/about-boem/reorganization/reorganization-former-mms.

[8] “Wind Energy.” *EWEA RSS*, www.ewea.org/wind-energy-basics/faq/.

[9] “How Does Ocean Wave Power Work?” *Energy Informative*, www.energyinformative.org/wave-energy/.

[10] *Islay LIMPET Wave Power Plant*. The Queen’s University of Belfast, 2002.

[11] “Mutriku Wave Energy Plant” *Energy News and Market Analysis*, Power Technology, www.power-technology.com/projects/mutriku-wave/.

[12] Blum, Patrick. “A Setback for Wave Power Technology.” *The New York Times*, The New York Times, 16 Mar. 2009, www.nytimes.com/2009/03/16/business/global/16iht-renport.html.

[13] “Innovative Wave Power Device Starts Producing Clean Power in Hawaii.” *Energy.gov*, 2015, www.energy.gov/eere/articles/innovative-wave-power-device-starts-producing-clean-power-hawaii.

[14] Knier, Gil. “How Do Photovoltaics Work?” How Do Photovoltaics Work?, NASA, www.science.nasa.gov/science-news/science-at-nasa/2002/solarcells.

[15] “Concentrating Solar Power (CSP) Technology.” Solar Energy Development Programmatic EIS, Solar PEIS, www.solareis.anl.gov/guide/solar/csp/.

[16] “CSP Project Development.” *Solar PACES*, Energy Technology Network, https://www.solarpaces.org/csp-technologies/csp-potential-solar-thermal-energy-by-member-nation/usa

[17] “Hydrogen & Fuel Cells.” Renewable Energy World, www.renewableenergyworld.com/types-of-renewable-energy/hydrogen/#gref.

[18] Dolan, Connor. “Unlocking the Potential of Hydrogen Energy Storage.” Fuel Cell & Hydrogen Energy Association, Fuel Cell & Hydrogen Energy Association, 22 July 2019, www.fchea.org/in-transition/2019/7/22/unlocking-the-potential-of-hydrogen-energy-storage.

[19] Bassett, K.p., et al. “Integration of Buoyancy-Based Energy Storage with Utility Scale Wind Energy Generation.” Journal of Energy Storage, vol. 14, 2017, pp. 256–263., doi:10.1016/j.est.2017.04.013.

[20] “Frequently Asked Questions.” Ares North America, www.aresnorthamerica.com/frequently-asked-questions.