Offshore Converter Stations

Technology, Regulation, and Potential Impacts

Gulf of Maine Research Institute

Introduction

When offshore wind arrays are located over 30 miles from shore, they typically require offshore converter stations to efficiently deliver power to shore. As large infrastructure developments, complete with industrial cooling systems that interact with the marine environment, offshore converter stations are a source of concern for many stakeholders. This resource offers a brief overview of offshore converter stations, synthesizing existing research and information on this emerging topic. Note, as research on offshore converter stations progresses, so, too, does our understanding of how they function and the potential impacts they may have on the marine environment.

Background

Offshore converter stations convert energy generated by offshore wind turbines into higher voltages to more efficiently move energy to shore. When a wind array is located about 30 or more miles from shore, a high voltage direct current (HVDC) converter station is used to convert a lower voltage alternating current (AC) to a higher voltage direct current (DC) for transport to shore.[1] This is because the electricity produced by turbines far offshore is too weak to travel long distances without losing power, similar to how a garden hose loses water pressure when it is really long. These converter stations work like electrical boosters, taking a weaker electrical current from the wind turbines and stepping it up to a much stronger current that can travel more efficiently without losing power. Offshore wind projects that are closer to shore are more likely to use high voltage alternating current (HVAC) technology for transmission, which does not require an offshore converter station.

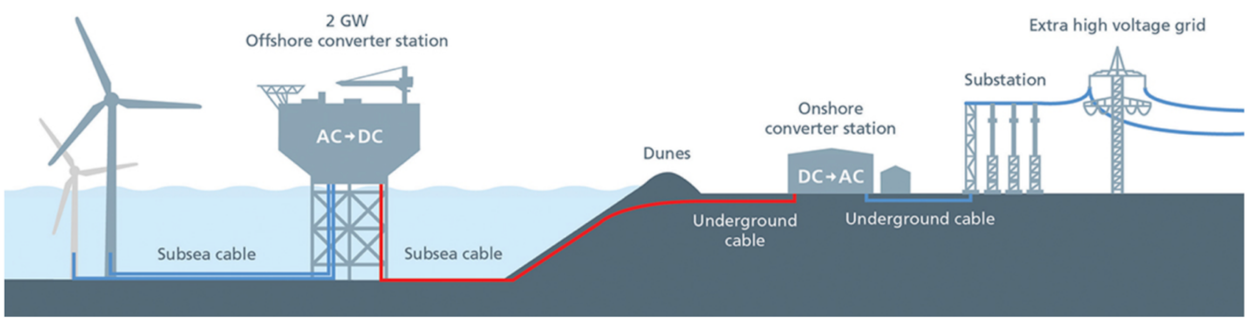

Figure depicting offshore wind energy transmission to shore (Engineer Live 2024).

Offshore converter station platforms typically range from around 200 to 400 feet long, 140 to 350 feet wide, 80 to 300 feet high, and weigh several thousand tons.[1] That's roughly the surface area of an American football field and the height of a high-rise building. Ultimately, however, the size of an offshore converter station is determined by the generating capacity of the wind array.

Image of BorWin Alpha and BorWin Beta Offshore Converter Station in the North Sea (TenneT 2024a, cited in NYSERDA 2025).

The process of converting from AC to DC in an offshore converter station generates heat as a byproduct, necessitating cooling to ensure that systems operate properly.[1] Several cooling methods exist as options for offshore converter stations, including open loop and closed loop systems. Due to cost, operational constraints and other economic, geographic, and technical factors, open loop systems are most commonly used for offshore converter stations.

There are numerous active offshore converter stations around the world, including eight currently operational in the North Sea.[2] In the United States, two projects using offshore converter stations are in the planning and permitting process: Sunrise Wind (OCS-A 0487), HVDC offshore converter station, and SouthCoast Wind (OCS-A 0521), HVDC offshore converter station. Various offshore wind developers in the New York Bight and beyond are also in the early phases of planning/permitting projects that may require offshore converter stations.

Types of Cooling Systems

Open Loop Systems (a.k.a. once-through cooling systems), draw cooler water from a source, use it to absorb heat, and discharge the heated water back to the environment. Open loop systems are used for cooling many sources of energy production including coal, natural gas, thermoelectric, and nuclear.[3] They are also the most common cooling system in offshore converter stations for wind arrays. In these systems, deionized water is enclosed within the system and cooled by cold sea water pumped through a heat exchanger.[1] Sea water absorbs heat from the deionized water, ensuring that the internal system remains cool.[1] In some systems, sea water is treated with sodium hypochlorite to prevent biological growth within the system. The sea water is then filtered to remove small particles. This filtered, heated water is discharged back into the ocean, where it quickly returns to ambient temperature. Note, Environmental Protection Agency (EPA) standards are in place to ensure the discharged water from offshore converter stations meets existing water quality standards. For more information on these standards or the potential impacts of this heated water in the ocean, see the “Potential Impacts” section.

Closed Loop Systems typically require little to no water and appear in many different forms:

- Air cooling is a type of closed loop system where air, instead of water, is used to cool the water in the system, typically by a system of electric powered fans. Other closed loop air cooling systems use refrigerant gasses to pull heat from water and dissipate it with fans into the air.[1] Refrigerant systems require power for operation and the refrigerant gasses must be replenished over time. As such, these systems are currently not used for cooling offshore converter stations due to capacity limitations and the need for a crew to manage the operation. The risks of corrosion for offshore converter stations also requires that equipment is sealed from the elements, which limits air cooling capabilities.[1] However, air cooling is being explored for larger offshore converter stations such as the TenneT 2GW Program, where these stations can be partially crewed.[2]
- Subsea cooling systems are mounted to the sea floor and dissipate heat by circulating heated water through pipes exposed to cooler seawater.[2] Their location on the seabed, however, makes them difficult to service and maintain, presenting challenges at facilities without crews.
- Semi-closed loop systems are another cooling method where fan systems and evaporating water are leveraged to increase cooling capacity. These systems require a supply of freshwater on site that must be replenished regularly to ensure proper function.[1]

As cooling technology evolves, closed loop systems may become more feasible for use in offshore converter stations, which could limit potential impacts to ocean ecosystems.

How are Offshore Converter Stations Regulated?

The report, *Cooling Water Use at Offshore Converter Stations*, offers a detailed overview of how once-through cooling methods in offshore converter stations are regulated. Multiple agencies are responsible for ensuring that offshore cooling systems are safe for the environment and align with existing state and federal regulations:

- EPA regulates this process in federal waters under the Clean Water Act and implements it through the National Pollutant Discharge Elimination System (NPDES) Program. The Clean Water Act has provisions applicable to thermal impacts, impingement, and entrainment.
- BOEM serves as the lead federal agency for the environmental review of offshore wind projects. This review process fulfills National Environmental Policy Act (NEPA) requirements, and includes consultations on behalf of all the federal agencies issuing licenses or permits for each offshore wind project, including the EPA, about potential impacts from a project’s offshore converter station.

    - These reviews include consultation with the National Marine Fisheries Service (NMFS) regarding Essential Fish Habitat and Endangered Species Act compliance to assess potential environmental impacts to fish species.
- State departments, such as New York's Department of State (DOS) may also evaluate projects for compliance with local coastal management policies to ensure the protection of state coastal resources.

Potential Impacts

While offshore converter stations are subject to regulation from several state and federal agencies, there are concerns about the potential impacts they may have on the marine environment. Few studies explicitly evaluating the environmental effects of these systems for offshore wind arrays have been conducted. However, the Sunrise Wind Farm offshore converter station permitted for construction near Long Island, NY, offers a valuable point of comparison to understand how these systems work and their potential impacts. The three main concerns we are currently aware of regarding offshore converter stations include the impacts of heated effluent on the environment, the presence of chemicals (e.g. sodium hypochlorite) in effluent, and entrainment risks to marine organisms. This section explores these potential impacts at the Sunrise Wind Farm offshore converter station. For greater detail on potential risks and impacts beyond this case study, see Section 5 of *Cooling Water Use at Offshore Converter Stations*. Note, research on this topic is evolving. The information below is a snapshot of potential impacts that we are currently aware of. As research continues, knowledge of these potential impacts may shift.

Effluent Temperature: Open loop systems discharge heated water back into the ocean, creating a warm plume of water above ambient temperatures (see figure below). Since several marine organisms can be sensitive to changes in water temperature, it is critical that cooling system discharge is safe to marine life. The NPDES permitting process, which requires that discharges meet the Water Quality Standards of a given state, helps ensure that thermal discharges do not cause unacceptable changes to the local aquatic community and habitat.[4] EPA also typically requires continuous monitoring for effluent temperature for large cooling systems, including those used for offshore converter stations

At the Sunrise Wind Farm offshore converter station, for instance, the average monthly temperature limit for effluent is 86°F and the maximum daily temperature is 90°F.[5] These limits were established from a modeling process, which indicates the maximum daily temperature will result in a relatively small thermal plume that, under worst-case conditions during spring slack tide, will be within 1.8°F of the ambient temperature within 25 meters (~82 feet) of the outfall location.[5] These thermal discharge limits are expected to protect the marine community from adverse thermal effects, according to the response to comments in the Sunrise Wind Farm Final NPDES Permit.[5] The impacts of a thermal plume at the scale proposed for Sunrise Wind are also expected to be similar to, but proportionally smaller than, those observed at large ocean discharge sources such as offshore LNG ports or coastal power plants.[2] EPA requires continuous monitoring for temperature throughout the life of the Sunrise Wind facility to ensure compliance with these standards. As offshore converter stations are developed for wind arrays, consistent ecological monitoring over several years and adaptive management will be critical in helping understand and manage potential impacts to marine life.

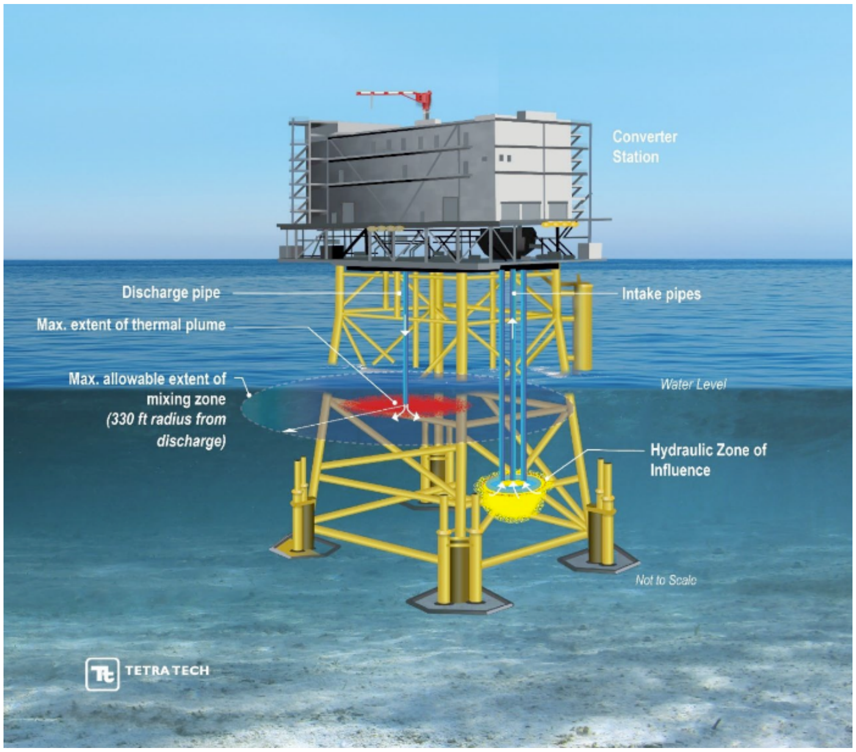

Figure showing an offshore converter station with approximations of hydraulic zone of influence and thermal plume extents (Tetra Tech (n.d.a), cited in NYSERDA 2025). As outlined in *Cooling Water Use at Offshore Converter Stations*: "This figure depicts the process by which an offshore converter station uses cooling water, which also shows approximations of the hydraulic zone of influence (HZI) at the intake, and the extent of the thermal plume at the discharge. The extent of the thermal plume must be within the maximum allowable extent of the regulatory mixing zone, where the heated discharge water temperature must fall back to within 1.8 degrees Fahrenheit (^{0} F) of ambient water temperatures. The maximum radial extent of the thermal plume is depicted well within the mixing zone (shown in red for illustrative purposes, but not to scale), based on thermal modeling from Sunrise Wind's Final and SouthCoast Wind's Draft NPDES permits." Note, HZI refers to the portion of the water column from which organisms would be entrained if they are unable to escape the intake flow.

Entrainment: Open loop systems require continuous intake of seawater to function. At the Sunrise Wind Farm offshore converter station, the total permitted maximum daily flow rate (the amount of water moving through a system in a given day) is 7.8 million gallons per day (MGD).[5] To put that into perspective, the Pilgrim Nuclear Power Station in Plymouth, MA had a cooling water intake system that drew 500 MGD, which is over 60 times more daily water intake than the Sunrise Wind facility.[6] With these levels of intake, and what we know from a history of research on entrainment in power plant cooling systems, some larval fish are expected to become entrained within the cooling system or impinged against a barrier structure like a filter, potentially resulting in mortality.[1]

To mitigate this, EPA requires in the Sunrise Wind Farm NPDES permit that the design, location, construction, and capacity of the cooling water intake structure (CWIS) uses the best technology available (BTA) for minimizing adverse environmental impacts from the impingement and entrainment of all life stages of fish (e.g., eggs, larvae, juveniles, and adults) by the CWIS.[5] At the Sunrise Wind Farm offshore converter station, the BTA for minimizing impingement and entrainment includes, but is not limited to, using a through-screen intake velocity no greater than 0.5 feet per second, ensuring the opening of the intake includes a screen or other device with a maximum spacing of 7.1-inches to exclude large aquatic organisms, and installing the CWIS at a depth between 30 to 50 feet above pre-construction seafloor grade.[5] In addition to these preventative measures, EPA requires quarterly bongo net sampling at the offshore converter station, including at intake depth to track larval density of marine organisms before and after the operation of the system.[5] While implementing BTA standards and practices plays a significant role in reducing the potential for entrainment or impingement of marine organisms, risks remain a concern not only at the Sunrise Wind Farm offshore converter station, but in any array that may use such cooling systems. On-site research and ecological monitoring are necessary to inform a more comprehensive understanding of the implications of entrainment or impingement of marine organisms in offshore converter stations for wind arrays.

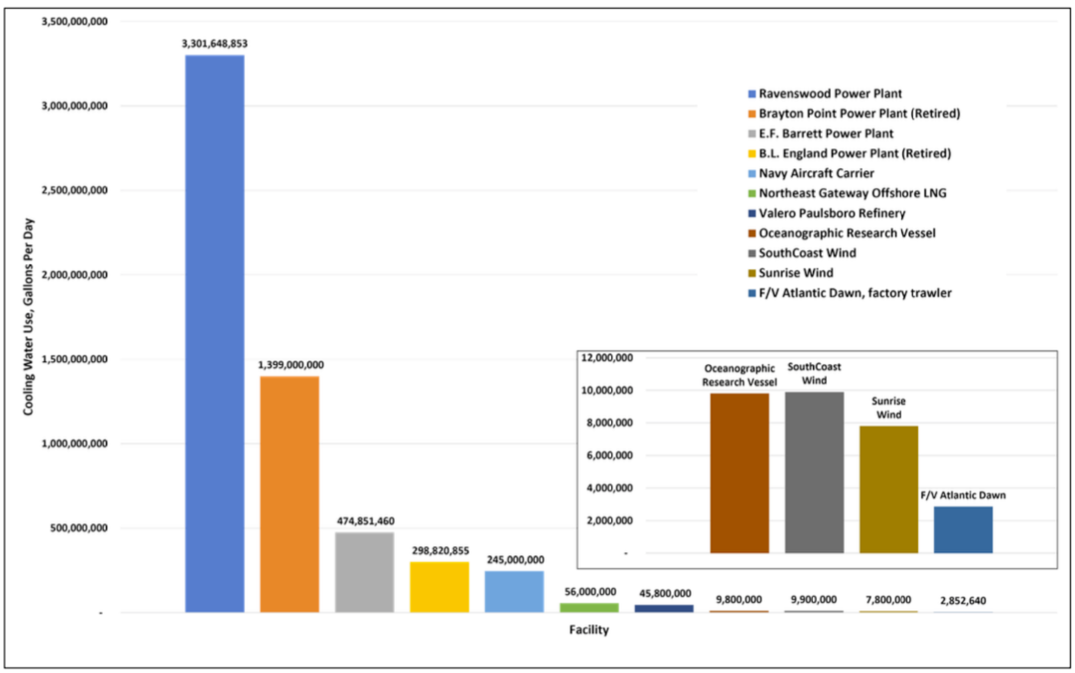

Figure summarizing cooling water sources within the New York Bight, Southern New England, and Surrounding waters (NYSERDA 2025).

Presence of Chemicals in Effluent: In some cases, cooling systems will treat intake water with chemicals like sodium hypochlorite to limit biological growth within the system (biofouling). Sodium hypochlorite is a common chemical compound that acts as a disinfectant and is an active ingredient in bleach. Chlorine and chlorine compounds are toxic to marine life. As such, the NPDES Program ensures discharges meet strict water quality standards and chemical thresholds that are safe to marine life before they are released within the marine environment.[5]

For the Sunrise Wind Farm offshore converter station, the NPDES Permit requires the average monthly Total Residual Oxidants (TRO) limit to be 7.5 μg/L (0.0075 mg/L) and the maximum daily TRO limit to be 13 μg/L (0.013 mg/L).[5] TRO, in this case, refers to the concentration of chlorine or chlorine-produced oxidants in the treated seawater being discharged. In other words, the amount of chlorine that is present in the water. Compliance with these TRO limits, according to the Draft NPDES Permit Fact Sheet for the Sunrise Wind farm offshore converter station, is expected to be protective of aquatic life and consistent with the proposed operation of the system to achieve chlorine concentrations near zero.[5] In other words, the TRO limits are set at levels that should not result in acute or chronic toxicity at the outfall prior to mixing with surrounding ocean water.[5] Continuous monitoring for TRO levels throughout the life of the Sunrise Wind facility is also an EPA requirement, helping ensure compliance with operating standards that are safe to marine life. Nevertheless, greater research into how the presence of trace chemicals in effluent, when paired with other stressors (e.g. thermal plumes), is necessary to holistically understand potential impacts to the marine environment.

Relevant Resources

This resource offers a brief overview of offshore converter stations. For more information, particularly on the potential impacts or technical elements of these systems, please refer to the following resources:

- *Cooling Water Use at Offshore Converter Stations*
- *Supporting National Environmental Policy Act Documentation for Offshore Wind Energy Development Related to High Voltage Direct Current Cooling Systems*
- *Wires and Wildlife: Offshore Transmission Development and the Benthos*
- *Guide to a Floating Offshore Wind Farm: Offshore Substation*
- *Offshore wind farms interfacing using HVAC-HVDC schemes: A review*

References

1. Middleton, P., Barnhart, B. 2022. Supporting National Environmental Policy Act Documentation for Offshore Wind Energy Development Related to High Voltage Direct Current Cooling Systems. Washington (DC): U.S. Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2022-023.

2. New York State Energy and Development Authority (NYSERDA). 2025. "Cooling Water Use at Offshore Converter Stations Final Report." NYSERDA Report Number 25-28. Prepared by Tetra Tech, Inc., Boston, MA. nyserda.ny.gov/publications

3. U.S. Energy Information Administration (EIA). 2011. *Today In Energy*. https://www.eia.gov/todayinenergy/detail.php?id=3950

4. U.S. Environmental Protection Agency (EPA). 2023. Thermal Discharges in NPDES Permits Overview of Resources and Tools. https://www.epa.gov/system/files/documents/2023-07/Thermal-Discharges-Report.pdf

5. U.S. Environmental Protection Agency (EPA). 2024. *National Pollutant Discharge Elimination System (NPDES) Permit No. MA0004940. Final Permit Issued to Sunrise Wind LLC for the Sunrise Wind Project, BOEM Renewable Lease Area OCS-A0487*. Washington, DC: EPA Region 1. https://www.epa.gov/system/files/documents/2025-06/finalma0004940permit-2024.pdf

6. U.S. Environmental Protection Agency (EPA). n.d. Pilgrim Nuclear Power Station Final NPDES Permit Overview. https://19january2021snapshot.epa.gov/npdes-permits/pilgrim-nuclear-power-station_.html