Cooling Water Use at Offshore Converter Stations

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Cooling Water Use at Offshore Converter Stations

Final Report

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Abstract

This report provides an overview of cooling water systems at offshore converter stations, with a particular focus on applications in offshore wind energy development in the New York Bight region. It is designed to serve as an informational resource for stakeholders involved in offshore wind development, including developers, regulators, environmental organizations, and other interested parties who have a baseline understanding of marine infrastructure but may not be familiar with cooling water systems specifically.

While this document references current regulations and permits to provide real-world context, it is not intended to serve as a comprehensive regulatory guide or technical manual. Rather, it aims to:

- Present key concepts and considerations at a level suitable for informed decision-making
- Highlight important technical and environmental aspects of cooling water systems
- Provide examples from existing facilities and permits, where relevant
- Offer a framework for understanding cooling water considerations in offshore applications

The scope intentionally focuses on aspects most relevant to offshore wind development, while acknowledging that additional technical details, regulatory requirements, and environmental considerations exist beyond what is presented here. Readers seeking more detailed information on specific topics are encouraged to consult the referenced materials and regulatory documents.

This document reflects current industry knowledge and practices as of early 2025, but it should not be considered exhaustive or definitive given the evolving nature of offshore wind technology.

Keywords

offshore wind, offshore converter station, cooling water, once-through cooling, closed-cycle (closed-loop) cooling, entrainment, thermal discharge, best technology available, National Pollutant Discharge Elimination System (NPDES), Clean Water Act §316(a) and §316(b)

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Acronyms and Abbreviations

ΔT	incremental temperature differential (or “delta-T”) between the intake and discharge water
µg/L	micrograms per liter
ADCP	acoustic doppler current profiler
AC	alternating current
AIF	actual intake flow
AMMM	Avoidance, Minimization, Mitigation, and Monitoring
BCT	best conventional pollutant control technology
BOEM	Bureau of Ocean Energy Management
BPJ	Best Professional Judgement
BPT	best practicable control technology currently available
BTA	best technology available
ºC	degrees Celsius
CFR	Code of Federal Regulations
CORMIX	Cornell mixing zone expert system model
CWA	Clean Water Act
CWIS	cooling water intake structure
CZMA	Coastal Zone Management Act
DC	direct current
DEC	New York State Department of Environmental Conservation
DEEP	Connecticut Department of Energy and Environmental Protection
DIF	design intake flow
DOS	New York State Department of State
EcoMon	Ecosystem Monitoring Project
EFH	Essential Fish Habitat
EPA	U.S. Environmental Protection Agency
ºF	degrees Fahrenheit
FEIS	Final Environmental Impact Statement
FLNGV	floating liquefied natural gas vessel
FSRU	floating storage regasification unit
ft	feet or foot
ft/s	feet per second
gpm	gallons per minute

GLOBEC	Georges Bank Global Ocean Ecosystems Dynamics
GW	gigawatt
HIOS	High Island Offshore System
HRS	heat recovery system
HVAC	high-voltage alternating-current
HVDC	high-voltage direct-current
HYCOM	Hybrid Coordinate Ocean Model
HZI	hydraulic zone of influence
in.	inch
kg/day	kilograms per day
kg/yr	kilograms per year
km	kilometer
kV	kilovolt
kW	kilowatt
LNG	liquefied natural gas
m	meter
m^3	cubic meter
MA DMF	Massachusetts Division of Marine Fisheries
MARAD	U.S. Dept. of Transportation Maritime Administration
MARMAP	Marine Resources Monitoring, Assessment, and Prediction program
mg/L	milligrams per liter
MGD	million gallons per day
mi	mile
mmscfd	million standard cubic feet per day
MW	megawatt
MPS	Millstone Power Station
NaOCl	sodium hypochlorite
NCEI	National Centers for Environmental Information
NEAMAP	Northeast Area Monitoring and Assessment Program
NEFSC	Northeast Fisheries Science Center
NEG Port	Northeast Gateway LNG Port
NEPA	National Environmental Policy Act
NJ DEP	New Jersey Department of Environmental Protection
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration

NPDES	National Pollutant Discharge Elimination System
PEIS	Programmatic Environmental Impact Statement
RI DEM	Rhode Island Department of Environmental Management
RIS	Representative Important Species
SPDES	State Pollutant Discharge Elimination System
STL	Submerged Turret Loading®
TBEL	technology-based effluent limitation
TRO	total residual oxidant
TWS	traveling water screen
VFD	variable frequency drive
WQS	water quality standards

Executive Summary

This report provides a broad overview of the use of raw seawater as cooling water, and its associated impacts to the marine environment (including entrainment, impingement, and thermal effects), as well as other forms of heat exchange at offshore converter stations that may be used to support offshore wind development for New York State and the surrounding region. Raw seawater cooling has been used for many years by the oil and gas industry, offshore liquefied natural gas (LNG) terminals, commercial vessels of all types, onshore power generating facilities, and, more recently, the offshore wind industry. The rapid growth of offshore wind energy development necessitates a larger context and comprehensive understanding of cooling water usage across industries and ocean users to inform future permitting decisions and environmental assessments. This report is intended to serve as a technical reference document for regulatory agencies, offshore wind developers, environmental consultants, and other stakeholders involved in the planning, permitting, and environmental review of offshore wind projects.

Each of the wind turbine generators in a wind farm generates alternating current (AC), which is collected at an offshore substation, then transmitted via export cable to an onshore interconnection point. Offshore converter stations convert the AC generated by wind turbines to direct current (DC) for more efficient long-distance transmission. While AC transmission is efficient for shorter distances, losses become significant beyond approximately 62 miles (mi), or 100 kilometers (km), due to the capacitive effects in the cables (Elliot et al. 2016; Middleton and Barnhart 2022). High-voltage direct-current (HVDC) transmission reduces these losses by up to 30% to 50% by maintaining higher transmission efficiency over long distances, making it an attractive option for projects with export cables exceeding approximately 31–93 mi (50–150 km).

These stations require efficient cooling systems to manage the heat generated during the AC to DC conversion process. Cooling systems for offshore converter stations can be broadly categorized into two types: once-through (open-loop) systems and closed-cycle (closed-loop) systems. Once-through cooling systems draw in seawater directly from the ocean, use it to absorb heat from the AC to DC conversion equipment, and then discharge the heated water back to the ocean. Closed loop systems, in contrast, use a contained volume of fluid (typically water or a coolant) that is continuously recirculated

through the system, transferring heat to the atmosphere through air coolers or to the ocean through subsea heat exchangers. While once-through (open-loop) cooling systems using seawater are common in various offshore industries due to their lower operational complexity and higher overall energy efficiency compared to closed-loop systems, offshore wind energy projects are a new use of this technology and may require new studies or assessments as part of the permitting process or operational conditions.

The regulatory framework governing these systems primarily falls under several sections of the Clean Water Act (CWA). Section (§) 402(a) establishes the National Pollutant Discharge Elimination System (NPDES), which regulates the discharge of pollutants into federal waters. Additionally, CWA §316(a) and 316(b) specifically address thermal impacts, impingement, and entrainment. The U.S. Environmental Protection Agency (EPA) administers these programs for facilities in federal waters. The U.S. currently has one offshore wind project (Sunrise Wind) with a Final NPDES Permit for once-through cooling water intake and discharge, with a maximum daily design intake flow (DIF) of 7.8 million gallons per day (MGD) (EPA 2024a). Another offshore wind project (SouthCoast Wind) has a Draft NPDES Permit, with a maximum daily DIF of 9.9 MGD (EPA 2024b). Several additional projects in the U.S. are expected to seek NPDES permits for the same purpose. Regulations for similar facilities (e.g., conventional power generating facilities, oil and gas platforms, offshore LNG facilities) are also implemented through the NPDES Program administered by the EPA or by certain states with delegated authority from the EPA. The EPA has implemented several phases of rulemaking related to §316(b); however, because offshore wind energy facilities were not explicitly considered in previous rulemakings, the EPA currently applies these regulations on a case-by-case basis using best professional judgment (BPJ), such as with the Sunrise Wind Final NPDES Permit (EPA 2024a) and the SouthCoast Wind Draft NPDES Permit (EPA 2024b). This BPJ-based approach is reevaluated during each 5-year NPDES permit renewal cycle to ensure that determinations reflect the current best practices and incorporate monitoring data, operational performance metrics, and observed environmental effects from existing facilities.

Once-through cooling uses noncontact water to remove waste heat by passing it through the main condenser (or heat exchanger) within a network of pipes or tubes; the once-through cooling water (also referred to as raw water) does not make direct contact with facility components, similar in principle to how the heat exchanger of a marine engine works. This method of heat exchange is used to cool many types of vessels, oil and gas platforms, offshore LNG ports, and coastal power generating facilities. Maximum permitted once-through cooling water volumes vary depending on the cooling demands of the facility, but generally range between 2 and 3,000 MGD. The once-through cooling water, after exchanging heat, is discharged back into the source water at a temperature higher than the ambient temperature of the source water (the ocean). The incremental temperature difference between the intake and discharge is referred to as the delta-T or ΔT.

The various risks of once-through cooling to fish populations in the marine environment include the following:

- **Hydraulic zone of influence (HZI):** Refers to the portion of a source waterbody that is hydraulically influenced by the withdrawal of source water by the cooling water intake structure (CWIS) (EPA 1977); as such, this is the portion of the water column from which organisms would be entrained if they are unable to escape the intake flow. While HZI itself is not a risk, it is a determining factor in what becomes entrained through the intake.
- **Entrainment:** Describes fish eggs and larvae (or other organisms) small enough to flow through intake bar racks and screens, passing through a facility's cooling water intake system (e.g., pumps, condenser) and eventually being returned to the source water with the heated cooling water discharge, which often results in mortality (EPA 2006).
- **Impingement:** Describes the temporary or permanent contact, or entrapment, of all life stages of fish and shellfish on the outer part of an intake structure or against a screen device during the period of water intake (Martinez-Andrade and Baltz 2003; EPA 2006). In many cases, individual fishes may interact with an intake screen but will be only temporarily impinged without injury or stress; in some cases, impingement may result in the mortality of individual fishes. The EPA considers through-screen intake velocities of 0.5 feet per second (ft/s) or less a suitable compliance option to minimize impingement impacts.
- **Chlorination:** Typically used in combination with once-through cooling to minimize biofouling of internal components (e.g., pump caissons and the seawater system) for both onshore and offshore applications. An offshore converter station is typically equipped with an electrochlorination generator system that produces sodium hypochlorite (NaOCl) by seawater electrolysis. The continuous injection of NaOCl generated from seawater, at low dosage via electrochlorination, results in concentrations of total residual oxidant (TRO) below detection limits at the discharge (EPA 2024a).
- **Thermal discharge:** Following circulation of seawater through a cooling system, the water is discharged and transfers the heat exchanged from the facility or vessel into the discharge (receiving) body of water. A permitted thermal discharge typically has a regulatory mixing zone, which requires the thermal and spatial extent of discharged cooling water to be maintained within 1.8 degrees Fahrenheit (°F), or 1 degree Celsius (°C) from the weekly average temperature of ambient source water within a 330 foot (ft), or 100 meter (m), radius of the discharge during all seasons of the year (EPA 1986).
- **Secondary effects:** Refers to the indirect or cascading impacts that occur as a result of a primary environmental change. For offshore converter stations, secondary effects can include impacts to prey availability for larger marine organisms or changes in local environmental conditions.

A variety of technologies exist for onshore facilities to minimize entrainment and impingement impacts (e.g., variable frequency drives [VFDs], closed-cycle cooling, air cooling, passive cooling). However, some of those technologies may or may not be feasible or available for uncrewed, offshore facilities. The CWA, specifically §316(b), directs EPA to ensure that the location, design, construction, and capacity of cooling water intakes reflect the best technology available (BTA) for minimizing adverse environmental impacts. Some of the BTA options function as mitigation measures, but offshore converter station facilities will also need to demonstrate performance with modeled thermal and entrainment estimates, including monitoring during operations to ensure compliance with §316(a) and §316(b) and other regulations. Regulators will adopt monitoring requirements as a compliance measure when issuing each facility's initial NPDES permit and during every renewal period within an anticipated 5-year cycle.

The Bureau of Ocean Energy Management (BOEM) considers cumulative impacts in its Final Programmatic Environmental Impact Statement (PEIS) for the New York Bight (BOEM 2024), and the EPA considers them as part of their individual-permit NPDES review process (EPA 2024a, 2024b). These agencies will also evaluate the cumulative effects of siting multiple cooling water intake structures when evaluating future permits.

1 Introduction

An offshore converter station converts high-voltage alternating current (HVAC), specifically for offshore wind projects that use high-voltage direct current (HVDC) export cables. Offshore wind projects often utilize offshore HVDC converter stations to more efficiently transmit the electricity generated in the wind farm to shore. Generally, HVDC export transmission is used for effective transmission of electricity over longer distances; therefore, offshore wind projects closer to shore may use HVAC for transmission without the need for a converter station, as the transmission losses in an HVAC system are significantly lower over short distances (Negra et al. 2006; Reed et al. 2013). At the same time, earlier studies suggested that offshore wind projects with a subsea export cable distance of more than approximately 31 miles (mi), or 50 kilometers (km), would use HVDC export cables (Middleton and Barnhart 2022). However, recent technological advances in HVAC and HVDC transmission systems have extended this "break-even" distance, with developers now typically considering HVDC for projects with transmission distances exceeding 31–93 mi (50–150 km) (Zhichu et al. 2024). Predicting the number of offshore wind projects that will require this technology is difficult due to the evolving nature of offshore wind development in the U.S.; however, the need for offshore converter stations is expected to grow accordingly. Although the Bureau of Ocean Energy Management (BOEM) anticipates up to 22 offshore substations will be needed across the 6 New York Bight lease areas, the specific number that will function as HVDC converter stations requiring cooling water has not yet been determined at this stage of project development (BOEM 2024).

The conversion of the alternating current (AC) generated by wind turbines to direct current (DC) produces heat, which necessitates the use of heat-exchange technologies to dissipate it (e.g., once-through noncontact cooling, air cooling, passive cooling). The most common method of heat exchange for such a system in the offshore environment is the use of noncontact once-through cooling water, with typical flows ranging from approximately 2–15 million gallons per day (MGD), or 1,389–10,417 gallons per minute (gpm). Section 4 provides a detailed comparison of cooling water volumes across various marine industries, facilities, and vessels.

The impact-producing factors of an offshore converter station that uses a cooling system primarily include: (1) withdrawal of cooling water resulting in entrainment of planktonic life stages of marine organisms (discussed in Section 5.2), and (2) discharge of heated cooling water resulting in a thermal plume and associated mixing zone. Such impacts to the marine environment in other industries (e.g., conventional power generating facilities, oil and gas platforms, offshore liquified natural gas [LNG] facilities) are regulated and permitted through the National Pollutant Discharge Elimination System (NPDES) Program administered by the U.S. Environmental Protection Agency (EPA) and certain states with delegated authority from EPA.[1] Clean Water Act (CWA) Sections (§§) 316(a) and 316(b) are also applicable to specifically address thermal and entrainment impacts, respectively.

Because offshore wind was not an industry covered by previous or existing rulemaking (see Section 2), offshore wind converter stations are expected to be permitted using site-specific best professional judgement (BPJ) criteria (EPA 2024a, 2024b) to ensure the best technology available (BTA) is used to minimize impacts to marine organisms. The BPJ approach allows EPA to determine appropriate BTA requirements on a case-by-case basis, similar to how the EPA has handled other offshore facilities not explicitly covered by existing regulations. This approach recognizes that while certain technologies might exist for onshore facilities, they may not be technically feasible or commercially viable for offshore converter stations. The BPJ process allows EPA to evaluate available technologies, operational constraints, and site-specific conditions, while ensuring CWA requirements minimize environmental impacts.

This report is intended as a broad overview of the use of, and impacts associated with, cooling water and other forms of heat exchange at offshore converter stations that may be used to support offshore wind development in New York State and the region. While cooling water from the open ocean has been used for many years by the oil and gas industry, offshore LNG terminals, and marine engines and vessels of all types, its application in the offshore wind industry presents new considerations. This report synthesizes existing information about cooling water systems across marine industries to provide context for understanding and evaluating their use in offshore wind development.

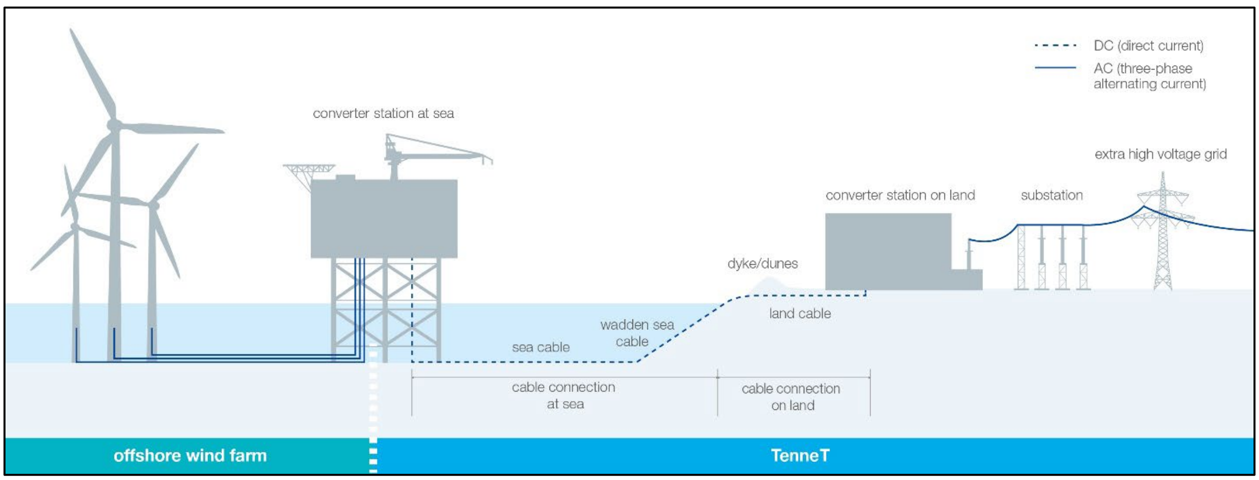
1.1 Offshore Converter Stations

Figure 1 illustrates the process by which each wind turbine generator in a wind farm generates AC, which is collected at an offshore substation. From there, the electricity is transmitted via export cables to an onshore interconnection point. As previously mentioned, for projects with export cables longer than approximately 31–93 mi (50–150 km), HVDC transmission is typically used rather than HVAC. Offshore substations generate heat during the AC to DC conversion process and, therefore, require cooling systems to maintain equipment functionality (Middleton and Barnhart 2022). Once-through (or open-loop) cooling uses noncontact seawater as a heat-exchange medium and is commonly used for this purpose at similar facilities worldwide. Alternative technologies for offshore HVDC converter stations that use little or no seawater, such as closed-cycle (or closed loop) cooling or air cooling, are in development but are not widely available from suppliers at this time because these technologies present technical challenges for offshore uncrewed converter stations (Middleton and Barnhart 2022). Challenges include the need to dissipate large heat loads, vulnerability to greater temperature fluctuations in air compared to seawater, accelerated equipment degradation in marine environments, and space constraints that conflict with industry goals for size reduction of converter stations.

Figure 1. Representative Offshore Converter Station from the 900 megawatt DolWin Epsilon Project

The offshore converter station converts the AC generated by the wind farm into DC for transmission back to land.

Source: TenneT (2024).



Although the detailed specifications of offshore converter stations are project design-specific and addressed in NPDES permit applications, as required under 40 Code of Federal Regulations (CFR) §122.21(r)(3), offshore converter stations typically include the following components (Middleton and Barnhart 2022; EPA 2024a, 2024b):

- **HVDC system:** Converts AC generated by the wind turbines to DC for long-distance transmission using switchgear, transformers, thyristor valves or insulated-gate bipolar transistors, protection and control systems, reactive power equipment, and filters.
- **Thyristor:** Emits heat as a component of the HVDC system and therefore requires cooling.
- **Deionized water system:** Interfaces directly with the HVDC equipment as the closed-loop heat-exchange medium.
- **Cooling Water Intake System (CWIS):** Typically controls the flow of noncontact seawater using a once-through (open-loop) design as the cooling medium for the closed-loop deionized water system and includes the intake and discharge structures.

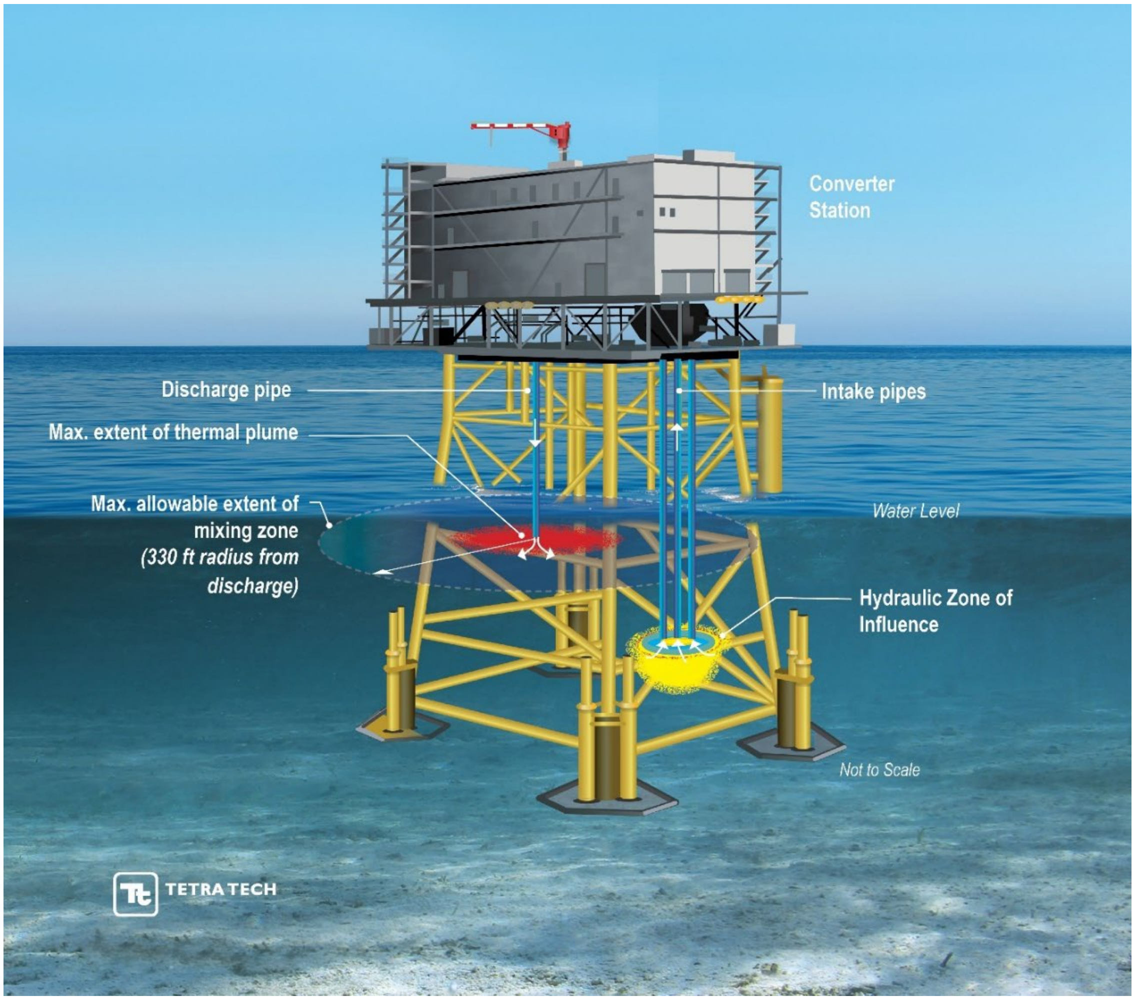
- **Intake structures:** Include up to three independent seawater lift pump caissons, each operating as a separate structure with no common entrance. They are set perpendicular to the seafloor and can be equipped with screens, bar racks, and variable frequency drives to regulate the flow of water, debris, or organisms entering the intake.
- **Discharge structures:** Consist of a single seawater dump caisson set perpendicular to the seafloor through which the system returns the cooling water to the marine environment after heat exchange.
- **Heat exchanger:** Transfers heat carried from the HVDC system components by the deionized water system to the noncontact seawater on the topside.
- **Filtration system:** Filters the seawater (typically down to about 500 microns) downstream of the lift pumps to protect topside components from small particles, sand, and other elements.
- **Electrochlorination system:** Generates sodium hypochlorite (NaOCl) from seawater via electrolysis and circulates it through the noncontact seawater to prevent biofouling of the heat-exchange components, and then dissipates to concentrations below compliance thresholds at the point of discharge.
- **Monitoring equipment:** Includes instruments and systems that ensure compliance with regulations and permit requirements. Based on recent NPDES permits (EPA 2024a, 2024b), typical monitoring parameters include effluent flow rate, ambient and effluent pH, total residual oxidants (TRO), intake and discharge temperatures, and through-screen velocity.

Offshore converter station platforms typically span approximately 200–400 feet (ft), or 61–122 meters (m), in length, 140–350 ft (43–107 m) in width, 80–300 ft (24–91 m) in height, and weigh several thousand tons (Middleton and Barnhart 2022). Wind farm generating capacity (in megawatts [MW]) generally determines the required size of its offshore converter.

Figure 2 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 (ºF), or 1 degree Celsius (1ºC), 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, as detailed in their respective permit Fact Sheets (EPA 2024a, 2024b).

Figure 2. Indicative Offshore Converter Station with Approximations of Hydraulic Zone of Influence and Thermal Plume Extents

Source: Tetra Tech (n.d.a).



1.2 Once-through Cooling

Once-through cooling uses seawater drawn through an intake caisson (vertical pipe) to remove waste heat by passing it through the main heat exchanger and the associated pipes or tubes; the noncontact once-through cooling water (also referred to as raw water) does not make direct contact with facility components, similar in principle to how the heat exchanger of a marine engine works. This method of heat exchange is used to cool many types of vessels, oil and gas platforms, offshore LNG ports, and coastal power generating facilities (see Section 4 for example facilities). The once-through cooling water, after exchanging heat, is discharged back into the source water at a temperature higher than the ambient temperature of the source water. The temperature difference between the intake and discharge is referred to as the delta-T (or ΔT). This thermal differential, combined with rapid mixing in the marine environment, results in the thermal plume returning to within 1.8ºF (1ºC) of ambient temperature within the designated mixing zone. The source of once-through cooling water is typically a large body of water, such as a lake/reservoir, river, or ocean.

The discharge pipe location and depth for offshore converter stations in offshore wind development can vary, with placement influenced by environmental considerations, engineering requirements, and regulatory compliance. Discharge can occur near the surface or at greater depths, depending on factors like environmental impact, regulatory compliance, and the goal of minimizing thermal plumes. Discharging at greater depths, where water is colder and denser, can enhance heat dispersion and reduce the ecological impact by promoting better mixing (Middleton and Barnhart 2022). Discharging at greater depths can also maintain sufficient distance between the intake and discharge point to prevent recirculation of heated water, as demonstrated in recent NPDES permit applications (EPA 2024a, 2024b), as well as ensuring pipes remain submerged during large storm events. Ultimately, optimization of thermal dispersion and compliance with environmental standards, specifically cooling the return to within 1.8ºF (1ºC) of ambient temperature, often determined the permissible depth of discharge (Zhao et al. 2024). The EPA then issues a site-specific BPJ decision, informed by engineering constraints during the permitting process for an individual project.

To minimize biofouling within components of the offshore converter station, an electrochlorination system uses seawater electrolysis to generate the minimum concentration of sodium hypochlorite needed (from the seawater itself) while the seawater lift pumps are operating. This system addresses internal biofouling but does not prevent biofouling on external components, such as intake screens, which require separate maintenance considerations. The sodium hypochlorite is "used up" (broken down as it eliminates organic matter) within the system and reduced to concentrations less than compliance thresholds at the point of discharge. For projects in federal waters, the discharged seawater must meet EPA water quality-based TRO limits of 7.5 micrograms per liter (µg/L) or 0.0075 milligrams per liter (mg/L) as an average monthly value and 13 µg/L (0.013 mg/L) as a daily maximum value at the outfall, or a compliance level of 30 µg/L, the minimum level of detection (EPA 2024a). Section 5.3 details the electrochlorination systems.

Once-through cooling causes impacts to aquatic organisms at intake (impingement and entrainment) and at discharge (thermal), which regulators and developers have evaluated through various site-specific and national assessments as well as federal and state rulemaking, using BTA to minimize those impacts to aquatic organisms, as discussed in Sections 5 and 6.

2 Regulatory Setting

In offshore environments, noncontact once-through cooling is the predominant method of heat exchange. The EPA regulates[2] this process in federal waters under the CWA, primarily focusing on volumes exceeding 2 MGD (1,389 gpm). Regulations for offshore facilities are outlined in 40 CFR Parts 122 and 125 (Subparts I, J, and N) and implemented through the NPDES Program, established under CWA §402(a). CWA §316(a) and §316(b) are also applicable to thermal impacts, impingement, and entrainment. Section 2.0 of the Sunrise Wind Final NPDES Permit Fact Sheet (EPA 2024a) and the SouthCoast Wind Draft NPDES Permit Fact Sheet (EPA 2024b) provide a comprehensive description of the statutory and regulatory authority for setting NPDES permit requirements for offshore converter stations.

Once-through cooling at conventional power generating facilities has been the focus of stakeholder concern, permitting challenges, and litigation historically, at many onshore or coastal power generating facilities (e.g., Indian Point, Brayton Point, Millstone, Bowline, Roseton), as evidenced by U.S. Supreme Court cases such as *Entergy Corp. v. Riverkeeper, Inc.* (2009). In response, the EPA developed rulemaking for the intake and discharge of cooling water. However, none of this rulemaking considered offshore wind as an industry subject to specific components of those rules. Therefore, for offshore wind converter stations, the EPA implements §316(b) on a site-specific, BPJ basis. In *Entergy Corp. v. Riverkeeper, Inc.,* the U.S. Supreme Court determined that when considering the BTA[3] for minimizing environmental impact, the EPA may consider compliance costs. This approach acknowledges that offshore wind energy facilities require unique regulatory consideration, as previous rulemaking efforts did not account for them.

While most states, including New York State, have delegated authority from EPA to administer NPDES permits, offshore wind converter stations will be located in federal waters, placing them under EPA jurisdiction. However, 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 it 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. In this process, the EPA uses the same NEPA document and associated consultations as part of its NPDES permitting process. Additionally, while converter stations are expected to be located in federal waters, NPDES permits also cover activities listed in the New York State Coastal Management Program, which implements the Coastal Zone Management Act of 1972 (CZMA) for actions affecting the State's coastal uses and resources. In federal waters, certain renewable energy activities (including offshore wind) are subject to federal consistency review by the New York State Department of State (DOS).

While the EPA focuses primarily on technical aspects of cooling water systems, including piping specifications, pump designs, and operational flow rates, consultation with the National Marine Fisheries Service (NMFS) regarding Essential Fish Habitat (EFH) and Endangered Species Act compliance involves detailed evaluation of potential environmental impacts, particularly species composition and entrainment risks. Recent offshore wind projects demonstrate the depth of this review. For example, NMFS required additional entrainment analysis beyond the EPA's initial requirements for Sunrise Wind (EPA 2024a) and established specific monitoring protocols for certain species, such as seasonal monitoring of various cod life stages in EFH-designated areas. BOEM coordinates these complementary but distinct agency reviews on behalf of all federal a gencies involved in permitting offshore wind projects.

The CZMA federal consistency review process adds another layer of regulatory oversight for offshore wind converter stations. While these facilities are located in federal waters, their potential effects on New York's coastal resources trigger federal consistency requirements under 15 CFR §930.57. The DOS evaluates whether the proposed cooling water systems align with the State's enforceable coastal policies, particularly focusing on marine habitat protection and water quality standards (DOS 2025). This review considers both direct and indirect effects on State coastal resources, including potential impacts on fish populations that migrate between federal and state waters. DOS must complete its consistency review before EPA can issue an NPDES permit, even if the facility is located in federal waters, under Section 307 of the CZMA (NOAA 2024).

To streamline the complex multiagency permitting process, many offshore wind projects use the Federal Permitting Improvement Steering Council's FAST-41 program. Established under Title 41 of the Fixing America's Surface Transportation Act of 2015 and managed by the council, FAST-41 provides enhanced coordination and oversight for large infrastructure projects (DOE 2025). For eligible offshore wind projects, FAST-41 designation establishes project-specific timelines for all federal environmental reviews and authorizations. Projects must meet one of three criteria: (1) the project is subject to NEPA; (2) the project is likely to require a total investment greater than $200 million; or (3) the project does not qualify for abbreviated authorization or environmental review processes under any applicable law (DOE 2025). This designation also applies specifically to the NPDES permitting process. The program has proven valuable for coordinating the interconnected NEPA, CZMA, and CWA reviews.

2.1 Application of Clean Water Act §316(b)

While the CWA primarily focuses on controlling pollutant discharges to federal waters, §316(b) specifically addresses environmental impacts caused by water withdrawals for cooling purposes. CWA §316(b) requires that the ". . . location, design, construction, and capacity of cooling water intake structures reflect the . . . BTA for minimizing adverse environmental impact." The EPA has implemented this requirement through a series of rules, including the Phase I and Phase II Rules (described below).

In its implementing regulations (40 CFR Part 125, Subparts I and J), the EPA typically applies §316(b) requirements to facilities with a CWIS that has a design intake flow (DIF) greater than 2 MGD (1,389 gpm) and withdraws from federal waters, using at least 25% of the total water withdrawn exclusively for cooling purposes. However, §316(b) itself does not specify these flow requirements, and states may impose more restrictive requirements for compliance.

The EPA established three rulemaking phases for implementing §316(b):

1. **Phase I:** New Facilities Rule (40 CFR Part 125, Subpart I)
2. **Phase II** (later remanded and reissued as the 2014 Rule): Existing Facilities Rule (40 CFR Part 125, Subpart J)
3. **Phase III:** New Offshore Oil and Gas Extraction Facilities Rule (40 CFR Part 125, Subpart N)

Under the New Facilities Rule, the EPA established a two-track approach for compliance. A "new facility" is defined as a new discharger that is a greenfield facility, construction occurring on previously undeveloped land or vacant coastal areas (Energy Link 2022), with a newly constructed CWIS. This includes facilities that begin construction after the rule's effective date, where no prior industrial operations existed at the site.

Because offshore wind was not an industry addressed in previous or existing rulemakings, the two-track approach under the New Facilities Rule does not directly apply to offshore wind converter stations. However, both tracks are described below because elements of either track may influence the EPA's permitting rationale using site-specific BPJ criteria (EPA 2024a, 2024b) to ensure the use of BTA to minimize impacts to marine organisms.

- **Track I:** This option requires all new facilities to construct each CWIS with a maximum through-screen design intake velocity of 0.5 ft per second (ft/s). It also sets capacity requirements based on size and location, with specific flow proportion reductions for river and stream sources. By this regulation, new facilities must also incorporate technologies and/or operational measures to reduce impingement and entrainment, as approved by the NPDES permitting authority.
- **Track II:** This option allows facilities to demonstrate, through site-specific studies, that alternative compliance strategies mitigate adverse environmental impacts commensurate with Track I requirements. These studies typically include biological characterization of the waterbody (species present, life stages, seasonal variations); source water baseline biological characterization; analysis of proposed technological and operational measures; verification of monitoring to demonstrate effectiveness; and a quantitative and/or qualitative demonstration that impacts are comparable to Track I. Alternative technologies or operational measures may include, but are not limited to, flow reduction, wedgewire screens, or other technologies capable of achieving equivalent performance. As outlined in the EPA's Phase I Technical Development Document (EPA 2001), the criteria for evaluating Track II compliance are determined on a case-by-case basis through the individual NPDES permit application process. Facilities must demonstrate that the alternative approach achieves reductions in impingement mortality and entrainment equivalent to Track I requirements for the specific site conditions

Guidance for new facility permit applications under §316(b) is provided in §§122.2(r) and 125.86.

The EPA determined that a new offshore converter station, such as those proposed for the Sunrise Wind and SouthCoast Wind projects, meets the fundamental definition of a new facility under the New Facilities Rule (as a new discharger at a greenfield site with a newly constructed CWIS). The EPA has established a precedent for permitting offshore wind projects with converter stations (e.g., Sunrise Wind and SouthCoast Wind), within the NPDES framework, including how it addressed timing, BTA, monitoring, and other permit components, as illustrated in the examples below.

Table 1. Current Offshore Wind NPDES Permitting Examples

<table>
<tr><th>Category</th><th>Sunrise Wind
Final (MA0004940)</th><th>SouthCoast Win
Draft (MA0006018)</th></tr>
<tr><td>Project Specifics</td><td>• Located offshore New York
• Approved for up to 84 wind turbine generators and 1 offshore converter station
• Designed for 924-MW generating capacity</td><td>• Located offshore Massachusetts
• Approved for up to 141 wind turbine generators and 5 offshore substation platforms
• Designed for 2,400-MW generating capacity</td></tr>
<tr><td>Timeframe</td><td>• Submitted application in December 2021 (deemed complete January 2022)
• Issued Draft NPDES Permit in May 2023 (EPA 2023)
• Issued Final NPDES Permit in June 2024 (EPA 2024a)</td><td>• Submitted application in August 2023 (deemed complete September 2023)
• Issued Draft NPDES Permit in October 2024 (EPA 2024b)</td></tr>
<tr><td>Regulatory Applicability</td><td colspan="2">• Determined that the offshore converter station is not subject to the New Facilities Rule (Phase I) because offshore wind was not considered in the rule’s development
• Applied §125.90(b) to develop §316(b) requirements on a case-by-case, BPJ basis
• Maintained consistency with previous determinations made for other offshore facilities; as such, referenced requirements from the Phase I and Phase III Rules to inform the §316(b) BTA determination for the Sunrise Wind (Final) and SouthCoast Wind (Draft) NPDES Permits</td></tr>
<tr><td>BTA Determination</td><td>• Design, construct, and operate the CWIS at a through-screen velocity no greater than 0.5 ft/s
• Operate VFDs, maintaining a maximum daily intake flow of 7.8 MGD and a maximum average monthly flow of 5.3 MGD
• Locate intake at a depth of 30–50 ft above preconstruction seafloor grade</td><td>• Design, construct, and operate the CWIS at a through-screen velocity of 0.5 ft/s
• Operate VFDs, maintaining a maximum daily intake flow of 9.9 MGD and a maximum average monthly flow of 4.8 MGD
• Locate intake at a depth of 10–20 ft above preconstruction seafloor grade</td></tr>
</table>

The EPA maintains flexibility to adjust requirements for future projects based on operational experience and monitoring data. Through the 5-year NPDES permit renewal process, the agency can modify permit conditions if monitoring reveals unexpected or unintended consequences. This adaptive approach allows the EPA to revise BTA determinations and adjust permit requirements based on real-world performance data, ensuring that environmental protection measures remain effective and appropriate. While these initial projects help establish a regulatory framework, the EPA will evaluate subsequent projects individually, incorporating lessons learned and applying updated criteria as needed.

As previously stated, the primary adverse environmental impacts associated with cooling water withdrawal are: (1) mortality of organisms resulting from impingement against intake screens or other physical barriers; and (2) entrainment of small organisms, particularly early life stages of fish and shellfish (both described in Section 5). Facilities can minimize impingement, and entrainment can be minimized through the reduction of flow and/or installation of impingement and entrainment mortality reduction technologies. Recognized impingement and entrainment reduction technology and operation options to meet BTA are discussed in Section 6 of this report.

2.2 Ensuring Balanced Indigenous Populations under the Clean Water Act §316(a)

§316(a) of the CWA requires facilities to ". . . assure the projection and propagation of a balanced, indigenous population of shellfish, fish and wildlife in and on the body of water into which the discharge is to be made . . . ." Regulations implementing §316(a) defined under 40 CFR Part 125, Subpart H, focus on the thermal component of any NPDES-permitted point source discharge.

Most facilities comply with EPA's current national recommendations for temperature-based water quality criteria, limiting the maximum acceptable increase in the weekly average temperature caused by artificial sources to 1.8ºF (1ºC) year-round (EPA 1986). Facilities demonstrate the thermal and spatial extent of the mixing zone using hydraulic modeling tools such as the Cornell Mixing Zone Expert System (CORMIX). These models predict the zone of initial dilution consistent with the <100 m (330 ft) radius requirement for the 1.8ºF (1ºC) temperature increase limitation, as described in the Ocean Discharge Criteria at §125.121(c).

Thermal plumes from the relatively low cooling water discharge volumes of most offshore converter stations (2–15 MGD, compared to >50 MGD for shipping vessels and 125–950 MGD for conventional power plants; see Section 4 for detailed comparisons) are expected to comply with the temperature-based criteria within the mixing zone. Modelling worst-case thermal conditions demonstrates that thermal plumes will not extend beyond the maximum allowable discharge pipe extent (Figure 2). Sunrise Wind and SouthCoast Wind included CORMIX modelling data in their NPDES permit applications to show that the proposed offshore converter stations will not exceed any marine water quality criteria under §125.22 (TRC 2021; Tetra Tech and Normandeau 2023). They did not request a thermal variance under §316(a), with the applicable mixing zone compliance requirements included in their NPDES permits (EPA 2024a, 2024b).

Alternatively, if a thermal discharge is expected to exceed these criteria, the NPDES permitting authority may authorize alternative thermal effluent limitations, or a thermal variance, if requested by an applicant. To obtain a thermal variance, applicants must demonstrate that the proposed alternative thermal effluent limits are more stringent than the otherwise applicable limitations to mitigate impacts to a balanced indigenous population, defined as ". . . a biotic community typically characterized by diversity, the capacity to sustain itself through cyclic seasonal changes, presence of necessary food chain species and by lack of domination by pollution tolerant species. . . .” A §316(a) thermal demonstration study typically accompanies a request for alternative effluent limitations. It must consider the cumulative impact of the thermal discharge on balanced indigenous populations along with other environmental impacts. Existing facilities may demonstrate the absence of historical impacts during normal discharge operations or show that proposed alternative effluent limits or other modifications will mitigate impacts, considering the discharge’s operational history and nature.

2.3 NPDES Permits

The NPDES permit program allows facilities to discharge pollutants or combinations of pollutants under the conditions that comply with standards specified in the CWA (§§301, 306, and 403). Under the program, NPDES permits stipulate pollutant discharge limitations and establish related monitoring and reporting requirements. NPDES permits also establish specific requirements for CWIS under CWA §316(b), as discussed in Section 2. In addition to established federal requirements, NPDES permits must include any more stringent permit conditions for CWIS to satisfy applicable state requirements. For example, New York State’s policy (CP-#52) requires facilities withdrawing more than 20 MGD from state waters to implement closed-cycle cooling or its equivalent as the BTA performance goal to minimize adverse environmental impacts (DEC 2011). California’s Once-through Cooling Policy, adopted by the State Water Resources Control Board, requires existing power generating facilities to reduce intake flow rates to levels comparable to closed-cycle cooling, which is more stringent than federal §316(b) requirements (CA SWRCB 2023).

In some states, like New York State, water quality standards are derived from separate regulations referenced in the coastal policies but are not explicitly part of the water quality standards. While state policies and regulations may inform the NPDES permitting process, offshore converter stations located in federal waters are subject to federal jurisdiction (with appropriate CZMA consistency review).

NPDES permit limits must, at a minimum, satisfy applicable federal technology standards[4] specified through several narrative technology standards that apply to different pollutant types. Where applicable, technology-based effluent limitations (TBELs) reflect the pollution achievable by technology meeting the applicable standard. According to 40 CFR 125.3(a)(2)(i), effluent limitations based on the “best practicable control technology currently available” standard apply to “conventional pollutants” (i.e., biochemical oxygen demand, total suspended solids, pH, fecal coliform, and oil and grease) for facilities that began discharging prior to July 1, 1977. For facilities commencing discharge after this date, effluent limitations for conventional pollutants follow the “best conventional pollutant control technology” (BCT) standard. EPA determines technology-based CWIS requirements for many types of new facilities under 40 CFR Part 125, Subpart I (the Phase I Rule), but certain new facilities are evaluated on a case-by-case, BPJ basis. For many existing facilities, EPA develops CWIS technology-based requirements under 40 CFR Part 125, Subpart J (the Phase II Rule). Conversely, for other existing facilities, such as offshore wind converter stations, requirements are developed on a BPJ basis.

The CWA, as part of NPDES permitting, requires states to develop water quality standards (WQS) for each waterbody classification, associating designated uses and numeric and narrative water quality criteria (CWA §303 and 40 CFR §§131.10-131.12). These criteria ensure water bodies attain their designated uses assigned to a particular waterbody classification. Regulations require NPDES permits to include quantity-based limits when TBELs are insufficient to meet state WQS. However, facilities located in federal waters, such as offshore wind converter stations, follow federal water quality criteria and Ocean Discharge Criteria for the receiving water. For facilities in federal waters well outside state waters, pollutant discharges and cooling water withdrawals fall solely under federal jurisdiction (with appropriate CZMA consistency review). Point source pollutant discharges to the waters of the territorial seas, the contiguous zone, and the ocean—CWA §§502(8), (9) and (10), respectively—are subject to the federal Ocean Discharge Criteria under Section 403(a) of the CWA. The EPA may issue NPDES permits authorizing pollutant discharge to ocean waters, assessing that no reasonable alternatives exist and the discharge will not cause "unreasonable degradation of the marine environment."

Facility operators must submit individual NPDES permit applications at least 180 days before discharge commencement (i.e., offshore converter station), as described in Part 122 Subpart B. However, a more realistic timeframe is 2–3 years (as shown in the Sunrise Wind and SouthCoast Wind examples in Section 2.1). The NPDES permit application process includes the following steps:

1. Submit the permit application with required technical information
2. Review the application for completeness (EPA)
3. Develop draft permit conditions (EPA)
4. Issue public notice and conduct a comment period (typically 30 days)
5. Hold a public hearing if requested
6. Respond to public comments (EPA)
7. Issue final permit decision

During the public comment period, interested parties, including state agencies, environmental organizations, and other stakeholders, can review the draft permit and submit written comments or concerns. The EPA must consider all significant comments received and may modify the permit based on these comments before issuing the final decision.

The CWA limits NPDES permits to 5 years. Facilities may renew permits for an additional 5-year period after applying. The renewal process is not merely administrative but serves as an important opportunity for regulatory review and potential permit modification based on operational experience and monitoring data. If monitoring reveals unexpected impacts during the initial permit term, the EPA may require additional mitigation measures, modify monitoring requirements, or adjust operational conditions to better protect water quality and aquatic life. This adaptive management approach ensures permit requirements remain protective and reflect current best practices. In addition, NPDES permits can be administratively extended if the facility reapplies more than 180 days before the permit expires and the EPA or state regulatory agency does not renew the permit before its expiration date through no fault of the permittee.

NPDES permits for oil and gas facilities divide jurisdiction between EPA Region 6 (South Central Gulf of Mexico) and Region 4 (Southeast Gulf of Mexico). This programmatic approach established NPDES permitting by establishing NPDES General Permits for New and Existing Sources in the Oil and Gas Extraction Point Source Category. Each Gulf region is covered by a specific General Permit (Central to Western, GMG290000; Eastern, GEG460000). Like other commercial facilities, CWA §402, 33 U.S.C. §1342, authorizes the EPA to issue NPDES permits allowing discharges if they meet requirements under CWA §301, §304, §306, §401, and §403. Both General Permits include comprehensive standards and regulations covering monitoring, sample testing procedures, and best management practices. The General Permit includes effluent prohibitions, including no discharge within 3,281 ft (1,000 m) of an area of biological concern, sanitary requirements for crewed facilities, deck stormwater management, biocides, and compliance with Phase-III §316(b) requirements.

3 Data Sources

Instead of site-specific data from a proposed offshore converter station location (none exist in the U.S. to date), developers and agencies expect to use both publicly available data and project-specific data and project-specific data collected by developers to characterize the composition of species, their life stages, and their relative abundance in the vicinity of a proposed offshore converter station. The focus centers on plankton and fish species, driven by their particular vulnerability to cooling water intake systems: planktonic organisms (including both ichthyoplankton and zooplankton) are susceptible to entrainment due to their small size and limited mobility, while fish at various life stages may experience impingement. Zooplankton also serve as an important forage base for federally managed fish species and are, therefore, an important component of EFH. This data supports §122.21(r)(4)(ii)–(vi) as the basis of potential impingement and entrainment estimates. The following sections describe the data sources.

3.1 Marine Resources Monitoring, Assessment, and Prediction Program

The long-term Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program (NMFS NEFSC 2019) zooplankton and ichthyoplankton dataset typically establishes the baseline and existing densities and subsequent entrainment estimates. The MARMAP program collected zooplankton and ichthyoplankton abundance data on the U.S. Northeast Continental Shelf extending from North Carolina to Nova Scotia from 1977 through 1987 using 505-micron mesh bongo nets following standardized protocols. The Ecosystem Monitoring (EcoMon) project continues the core part of MARMAP from 1992 to the present using 333-micron mesh bongo nets. The herring-sand lance survey, 1988–1994, and Georges Bank Global Ocean Ecosystems Dynamics survey (GLOBEC), 1995–1999, also provided ichthyoplankton data. Ichthyoplankton density data compiled from these four surveys from 1997 through 2019 were obtained from the publicly available EcoMon plankton data that are (NMFS NEFSC).

3.2 EcoMon

The EcoMon plankton dataset is a publicly available, standardized collection maintained by the National Oceanic and Atmospheric Administration's (NOAA) Northeast Fisheries Science Center (NEFSC) and archived at NOAA's National Centers for Environmental Information (NCEI). It includes only zooplankton and larval-stage ichthyoplankton from common taxa collected on the Northeast U.S. Continental Shelf (NMFS NEFSC 2019). The dataset includes taxa based on a time series mean abundance greater than 100 individuals per 100 cubic meters (m^3) and occurrence in greater than 5% of samples (NMFS NEFSC 2019). To estimate potential ichthyoplankton impacts at a proposed offshore converter station, researchers may use the long-term MARMAP/EcoMon ichthyoplankton dataset from designated stations near the proposed location to characterize the most commonly occurring species. Researchers can then conduct species-specific impact assessments by calculating baseline density estimates for each species and life stage, evaluating species' life history strategies that influence entrainment susceptibility (e.g., species with buoyant eggs or adhesive eggs show less susceptibility entrainment in an intake withdrawing from the middle or lower portion of the water column), and combining density estimates with proposed intake flow rates to project potential entrainment number by species and life stage. However, because sampling stations per strata vary randomly each year, the dataset has limitations for representing the complete species and life stage composition immediately in the vicinity of an offshore converter station. To address this limitation and verify impact projections, developers expect to include a site-specific biological monitoring program, similar to that required for Sunrise Wind and SouthCoast Wind (see Section 7), as a compliance measure to inform potential entrainment impacts, implemented for subsequent NPDES-permitted offshore converter station facilities.

3.3 State and Regional Trawl Surveys

State trawl surveys, such as the New Jersey Department of Environmental Protection (NJ DEP), which operates in both state and federal waters, New York State Department of Environmental Conservation (DEC), Rhode Island Department of Environmental Management (RI DEM), Connecticut Department of Energy and Protection (DEEP), and Massachusetts Division of Marine Fisheries (MA DMF), conduct annual trawl surveys to characterize fish abundance and inform stock assessments for state-managed species. While these surveys provide valuable data on fish populations, their spatial coverage may not overlap with proposed offshore converter station locations, limiting their utility for project-specific impact assessments. NMFS and the Northeast Area Monitoring and Assessment Program (NEAMAP) conduct regional trawl surveys that provide data for assessing long-term stock assessments, gear performance, and ecosystem health on a broader spatial scale. Additionally, some project-specific monitoring plans implement parallel sampling efforts that mirror or expand on state survey methodologies to better characterize conditions at proposed converter station locations.

3.4 Metocean and Water Quality Data

Data from NOAA buoys located near proposed offshore converter station locations characterize the hydrological and oceanographic conditions in the project area. The metocean data from the Hybrid Coordinate Ocean Model (HYCOM) provide water temperature and current data to feed into the CORMIX thermal modelling and HZI calculations (see Section 5.2.1). Additionally, site-specific data from a developer's metocean buoy (if available) further refine the modelling/calculations. The EPA's National Coastal Condition Assessment (NCCA) program provides regional estimates of coastal water quality conditions for the U.S. East Coast. The NCCA sampling occurs on a 5-year cycle and evaluates four indices of condition—water quality, sediment quality, benthic community condition, and fish tissue contaminants—and several other indicators to evaluate the ecological condition and recreational potential of coastal waters (EPA 2024c). At the regional and state level, each state also collects and reports on water quality data. In the New York Bight, for example, water quality monitoring programs by the NJ DEP and DEC provide such data. While these data sources provide useful information, they have limited applicability beyond a state's coastal waters. Depending on what surveys developers have conducted for a particular project, ancillary site-specific water quality data may also be available if collected as part of other preconstruction survey activities (e.g., geophysical, benthic).

3.5 Other Data Sources

Other data sources used to characterize baseline conditions for an offshore converter station include the NMFS EFH Mapper, which identifies managed species and life stages with designated EFH that overlap with a proposed offshore converter station intake location. The temporal distribution of these species and life stages throughout the year identifies periods of increased vulnerability (e.g., spawning seasons, larval periods, migration windows) when impacts may be more significant. Site-specific geophysical, benthic, and fisheries survey data also enter the analysis, where appropriate, with consideration given to seasonal patterns in species abundance and distribution. This temporal understanding informs potential mitigation measures, such as adjusting operations during critical life stage periods or peak abundance times for sensitive species.

Data and design specifications from a developer's engineering team (e.g., depth of withdrawal, bar rack, pipe/caisson diameter, intake velocity, flow volume, electrochlorination system, depth of discharge, discharge temperature) inform the NPDES permitting process so that project component impacts can be assessed. Researchers can assess the timing and duration of various operational activities against known temporal patterns in species occurrence to identify opportunities for impact reduction through seasonal operational adjustments, where feasible.

4 Example Facilities in Operation

Example facilities and applications of once-through (or open-loop) cooling using noncontact seawater as a heat exchange medium appear in various industries. These broadly fall into two types: fixed facilities and mobile vessels. Fixed facilities include offshore wind converter stations, offshore oil and gas platforms, offshore LNG ports, onshore power generation, onshore industrial facilities, and other sources in both offshore and onshore settings. These stationary installations use sustained, localized cooling water withdrawals at fixed locations, although their environmental settings vary significantly. Onshore and nearshore facilities operate in relatively shallow, coastal environments, while offshore facilities operate in deeper waters that may overlap with different ecological zones and species assemblages. The cooling water requirements among these fixed facilities vary substantially, from relatively modest needs for offshore wind converter stations (5–10 MGD) to much larger volumes for coastal power generating facilities (>1,000 MGD).

Mobile vessels, as discussed in Section 4.5, form a distinct category, with cooling water withdrawal occurring across varying locations rather than at a fixed point. These range from small recreational vessels to large commercial ships, and they follow different regulatory requirements and operational patterns. The following sections present examples of various facility types that use once-through cooling.

4.1 Offshore Wind Converter Stations

Several offshore converter station facilities currently operate in the North Sea as part of Germany's offshore wind development, including the BorWin, DolWin, HelWin, and SylWin projects (TenneT 2024a). These projects use HVDC technology because it delivers electricity more efficiently across long distances, for example, from North Sea facilities located 28 to 188 mi, or 45 to 190 km, offshore (similar to certain U.S.-based offshore wind projects), to onshore connection points in Germany.

The technical specifications and operational models for offshore converter stations vary significantly between European and U.S. markets. European projects, particularly under the TenneT 2GW (gigawatt) Program, an innovative offshore grid connection concept TenneT developed for future offshore wind projects, use 525-kilovolt (kV) HVDC systems with larger capacity (2,000 MW) at crewed platforms. This configuration allows operators to maintain on-site monitoring and operational flexibility among cooling technologies.

In contrast, projects in the New York Bight region typically employ 320-kV systems at uncrewed platforms. Regulatory frameworks and economic considerations, partly shaped by procurement models, drive this difference. European grid operators like TenneT procure converter stations with guaranteed returns on capital expenditure, while U.S. offshore wind developers incorporate converter station costs into their power purchase agreements.

In each of these projects, the wind farm generates AC, which the substation(s) or offshore converter station collects and converts to HVDC using once-through cooling (or air cooling, in limited cases). Export cable(s) then transmit the HVDC electricity to the landfall and onshore interconnection, where the system converts it back into AC for the local electrical transmission grid. Some older North Sea HVDC projects use separate platforms for the substation and converter station. However, recent and future North Sea projects, as well as U.S. projects, are expected to combine the converter station and the substation into a single offshore facility.

Project planners increasingly consider air cooling and other closed-loop systems for offshore converter stations. For example, the TenneT 2GW Program anticipates using air cooling to build up to 13 such systems in the Dutch and German North Sea between 2029 and 2031 (TenneT 2024b). The program uses a series of large offshore converter stations, each with a 2,000 MW capacity, more than double that of any current offshore converter station platform, and with a significantly larger footprint.

Recent technological advances have also expanded the feasibility of closed-loop systems for some offshore applications. These systems offer several potential advantages over once-through cooling, including eliminating seawater intake and associated entrainment impacts, avoiding biocide or heated effluent discharge into marine waters, reduced internal space requirements for seawater/deionized water heat exchangers, and enabling remote operation, as demonstrated in recent developments in subsea cooling technology.

Air cooling and closed-loop systems may offer a feasible alternative to once-through cooling for U.S. offshore converter stations, but various constraints often limit their adoption. These include platform size and design requirements, operational strategy (crewed versus uncrewed platforms), supplier limitations, and engineering challenges associated with typical platform size. These findings align with Middleton and Barnhart (2022), the New York Bight Final Programmatic Environmental Impact Statement (PEIS) (BOEM 2024), and are further described in Section 6.2.3.

Table 2 shows the status and parameters associated with various projects that use offshore converter stations, including those currently in permitting in the U.S. Figures 3 through 11 present representative examples of offshore converter stations currently in operation. These facilities range from 19 mi (30 km; Sunrise Wind) to 100 mi (160 km; SylWin alpha) offshore. Designers configure all of these platforms to operate primarily uncrewed during normal operations, with periodic maintenance visits by personnel. These stations use automated systems and allow remote monitoring and control. However, they include living quarters and facilities (such as helidecks) to support maintenance crews during periodic or extended on-site work.

Table 2. Representative Offshore Converter Station Facilities in Operation or Development

Source: BOEM (2024); EPA (2024a); TenneT (2024a).

Facility (Operational or In-Development)	Developer	Water Body	Location	Type of Cooling	Design Intake Flow (MGD)	Generating Capacity Supported (MW)	Status
SylWin alpha	TenneT	North Sea	Germany	Once-through	Unknown	924	Operational since 2015.
BorWin alpha BorWin beta	TenneT	North Sea	Germany	Once-through	Unknown	400 + 800	Operational since 2015. Both facilities are connected to the same export cable.
HelWin alpha HelWin beta	TenneT	North Sea	Germany	Once-through	Unknown	575 + 690	Operational since 2015. Both offshore converter station facilities are connected to the same export cable.
DolWin beta	TenneT	North Sea	Germany	Once-through	Unknown	800	Operational since 2016. Gravity-based structure.
BorWin gamma	TenneT	North Sea	Germany	Once-through	Unknown	900	Operational since 2019.
BorWin Kappa	TenneT	North Sea	Germany	Once-through	Unknown	900	Operational since 2019.
DolWin alpha DolWin gamma	TenneT	North Sea	Germany	Once-through	Unknown	800 + 900	Operational since 2015. Operational since 2018.
DolWin kappa	TenneT	North Sea	Germany	Once-through	Unknown	900	Operational since 2023. Utilizes a combined offshore converter station/substation on the same offshore platform structure.
DolWin epsilon	TenneT	North Sea	Germany	Air-cooling	N/A	900	Expected operational date in 2025. Uses a combined offshore converter station/substation on the same offshore platform structure.

Table 2. (continued)

Facility (operational or in-development)	Developer	Water Body	Location	Type of Cooling	Design Intake Flow (MGD)	Generating Capacity Supported (MW)	Status
Multiple HVDC projects as part of the TenneT 2GW Program (Nederwiek 1, 2, 3; Doordewind 1, 2; Ijmuiden Ver alpha, beta, gamma)	TenneT	North Sea	Netherlands, Germany, Denmark	Air-cooling	N/A	2,000 each	In development; expected operations between 2028 and 2030. Significantly larger footprint compared to the uncrewed platforms included in this table.
Sunrise Wind (OCS-A 0487), HVDC offshore converter station	Orsted	Atlantic Ocean	RI/MA-WEA	Once-Through	7.8 MGD	880	Final NPDES Permit issued in 2024 (MA0004940). Expected operational date in 2026.
SouthCoast Wind (OCS-A 0521), HVDC offshore converter station	Ocean Winds	Atlantic Ocean	RI/MA-WEA	Once-Through	9.9 MGD	Up to 2,400 (split between two projects)	Draft NPDES Permit issued in 2024 (MA0006018).
Other New York Bight Projects, TBD	Various developers	Atlantic Ocean	New York Bight	Unknown	Unknown	Unknown	Pending construction and operations plan submittals and NPDES Applications.

Figure 3. BorWin Alpha and BorWin Beta Offshore Converter Station

Source: TenneT (2024a).

Figure 4. BorWin Gamma Offshore Converter Station under Construction

Photographed during a storm in the North Sea.

Source: TenneT (2024a).

Figure 5. DolWin Gamma and DolWin Alpha Offshore Converter Stations

DolWin Gamma shown at left; DolWin Alpha at right.

Source: TenneT (2024a).

Figure 6. DolWin Beta Offshore Converter Station

Source: TenneT (2024a).

Figure 7. DolWin Epsilon Offshore Converter Station

Proposed design includes air cooling and accommodations for up to 50 workers aboard the platform.

Source: TenneT (2024a).

Figure 8. HelWin Alpha and HelWin Gamma Offshore Converter Stations

HelWin Alpha shown at left; HelWin Gamma at right.

Source: TenneT (2024a).

Figure 9. SylWin Alpha Offshore Converter Station

Source: TenneT (2024a).

Figure 10. TenneT 2-gigawatt Program Offshore Converter Station

Planned for wind areas Nederwiek 1, 2, and 3; Doordewind 1 and 2; and Ijmuiden Ver Alpha, Beta, and Gamma.

Source: TenneT (2024a).

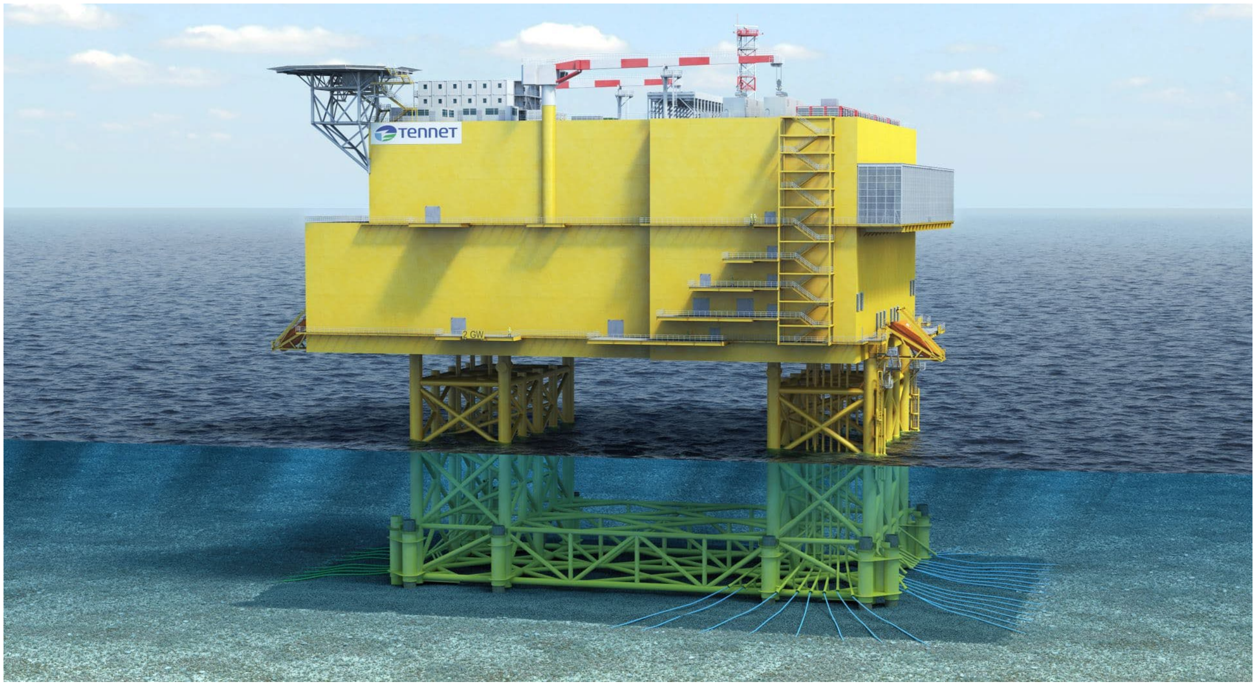


Figure 11. Sunrise Wind Project Offshore Converter Station

Source: Sunrise Wind (2021).

4.2 Offshore Oil and Gas Platforms

Currently, approximately 3,500 offshore oil and gas platforms exist in the Gulf of Mexico, each using once-through cooling in some capacity, typically ranging from 2 to 50 MGD (1,389 to 34,722 gpm) (EPA 2006); of these, more than 3,200 remain active (Gulf of Mexico Data Atlas 2024).

Table 3 shows the scale of operations and spatial context for the top 10 companies, ranked by acres held (BOEM 2023a).

Table 3. Footprint of Oil and Gas Leases in the Gulf of Mexico

Source: EPA (2006); BOEM (2023a).

Rank	Company	Acres Held	Number of Leases Held	Once-Through Cooling Water
1	Shell	1,489,845	386	< 50 MGD (for each platform authorized under the NPDES General Permit Western: GMG290000; Eastern: GEG460000)
2	BP	1,072,020	250	
3	Chevron	957,168	273	
4	Occidental	949,872	221	
5	ExxonMobil	596,883	122	
6	Talos	562,944	191	
7	Cox	560,398	142	
8	Equinor	507,133	169	
9	Woodside	365,247	111	
10	Fieldwood	347,119	108	

As discussed in Section 2.1, the Phase III §316(b) Rule applies to individual offshore oil and gas facilities that withdraw more than 2 MGD (1,389 gpm). However, most offshore oil and gas extraction facilities are under general permits issued by EPA, which incorporate requirements based on the Phase III Rule.

A key distinction in rulemaking for offshore oil and gas facilities is the difference in technology *availability* between Phase III offshore oil and gas extraction facilities and onshore facilities subject to the Phase I Rule. When the EPA established the Phase III Rule in 2006, it did not base impingement and entrainment requirements for new offshore oil and gas facilities on closed-cycle recirculating cooling. The EPA cited several factors at the time, including space constraints, weight limitations, safety concerns with electric equipment, and economic considerations (EPA 2006).

However, technological advances over the past two decades, particularly in closed-loop cooling systems and emerging platform design capabilities, have reduced some of these historical constraints. The continued use of once-through cooling in current offshore oil and gas operations appears to result from a combination of established industry practices, operational requirements, and cost considerations, rather than from purely technical feasibility limitations. These considerations still influence cooling system selection for new offshore facilities, though technological options have expanded since the EPA developed the original Phase III Rule.

Oil and gas platform structures range from single, near-shore well caissons to large complex facilities in offshore waters approximately 10,000 ft (3,038 m) deep. Figures 12 through 15 show examples of typical large platforms, including floating, semi-submersible, spar, and tension leg types.

Figure 12. Mad Dog Spar Platform with Offshore Service Vessel

Operated by BP and Chevron.

Source: Marine Insight (2023).

Figure 13. Thunder Horse Semisubmersible Platform

Operated by BP and ExxonMobil.

Source: Marine Insight (2023).

Figure 14. Magnolia Extended Tension Leg Platform

Operated by W&T Offshore.

Source: NOAA Ocean Explorer (2010).

Figure 15. Mars Tension Leg Platform

Operated by Shell.

Source: Offshore Technology (2021).

4.3 Offshore Liquefied Natural Gas Ports

Offshore LNG ports undergo a comprehensive federal review and permitting process, which follows steps similar to those described in Section 2 for offshore converter stations. This process begins with a Deepwater Port License application review by the U.S. Dept. of Transportation Maritime Administration (MARAD) and the U.S. Coast Guard. As part of this review, agencies require a full environmental analysis under NEPA, typically in the form of an Environmental Impact Statement. Beyond the Deepwater Port License and NEPA review, facilities must obtain numerous other permits and authorizations before construction and operation can begin. These include a NPDES Permit from the EPA, a CWA §404 Permit from the U.S. Army Corps of Engineers, a CZMA Consistency Determination, and consultations under the Marine Mammal Protection Act, Endangered Species Act, and EFH provisions.

To date, applicants have filed 30 Deepwater Port License applications for offshore LNG ports (DOT MARAD 2024). Of those, seven licenses have been issued. Two of these facilities have been constructed on the East Coast (Neptune LNG and Northeast Gateway), one has been constructed and decommissioned in the Gulf of Mexico (Gulf Gateway LNG), one has received approval and is pending licensing (Delfin LNG), and three ports have received approval but had their licenses surrendered (Gulf Landing, Port Dolphin, and Port Pelican). Each of these deepwater offshore LNG ports consists of an LNG delivery vessel that moors to a submerged buoy or a fixed structure, where it connects and offloads product to an existing pipeline. While at port, the LNG vessel uses once-through cooling water to maintain vessel operating conditions, with typical cooling water intake flows of more than 50 MGD (34,722 gpm) (EPA 2006).

Table 4 summarizes these projects, along with proposed LNG ports that still have pending Deepwater Port applications.

Table 4. Operational and Proposed Liquefied Natural Gas Deepwater Port Projects

Source: MARAD (2024).

Facility (Proposed or In-Development)	Developer	Water Body	Location	Design Intake Flow (MGD)	Status[a]
Northeast Gateway Deepwater Port (NPDES Permit #MA0040266)	Excelerate Energy	Atlantic Ocean	Offshore Massachusetts	56 MGD	Operational
Neptune Deepwater Port (NPDES Permit #MA0040258)	Neptune LNG LLC	Atlantic Ocean	Offshore Massachusetts	2.55 MGD	Operations suspended in 2022, due to market conditions
Gulf Gateway Deepwater Port (NPDES Permit #GM0000003)	Excelerate Energy	Gulf of Mexico	Offshore Louisiana	8.81 MGD	Decommissioned in 2013
Delfin LNG	Delfin LNG LLC	Gulf of Mexico	Offshore Louisiana	12.98 MGD	Approved; pending license
Gulf Landing	Shell U.S. Gas & Oil LLC	Gulf of Mexico	Offshore Louisiana	136 MGD	Approved; license surrendered
Port Dolphin	Port Dolphin Energy LLC	Gulf of Mexico	Offshore Florida	9.51 MGD	
Port Pelican	ChevronTexaco Corporation	Gulf of Mexico	Offshore Louisiana	176.4 MGD	
West Delta LNG	West Delta LNG LLC	Gulf of Mexico	Offshore Louisiana	Unknown	Application pending
New Fortress Energy Louisiana	New Fortress Energy Louisiana FLNG LLC	Gulf of Mexico	Offshore Louisiana	Unknown	
Aguirre Offshore Gas Port	Excelerate	Caribbean Sea	Offshore Puerto Rico	56 MGD	Application withdrawn
Beacon Port	ConocoPhillips	Gulf of Mexico	Offshore Texas	167.5 MGD	
Calypso LNG	Suez LNG N.A.	Gulf of Mexico	Offshore Florida	43.6 MGD	
Clearwater Port	NorthernStar Natural Gas Inc., Formerly Crystal Energy	Pacific Ocean	Offshore Southern California	Unknown	
Compass Port.	ConocoPhillips	Gulf of Mexico	Offshore Alabama and Mississippi	Unknown	
Oceanway Secure Energy	Woodside Natural Gas, Inc.	Pacific Ocean	Offshore Southern California	Unknown	
Pearl Crossing	ExxonMobil	Gulf of Mexico	Offshore Louisiana	Unknown	
Safe Harbor Energy	Atlantic Sea Island Group LLC	Atlantic Ocean	Offshore New York and New Jersey	Unknown	
Bienville Offshore Energy Terminal	TORP Terminal L.P.	Gulf of Mexico	Offshore Alabama	127 MGD	Withdrawn after record of decision
Main Pass Energy Hub	Freeport McMoRan	Gulf of Mexico	Offshore Louisiana	0 MGD	
Cabrillo Port	BHP Billiton LNG International	Pacific Ocean	Offshore Southern California	8.2 MGD	Not approved
Port Ambrose	Liberty Natural Gas LLC	Atlantic Ocean	Offshore New York State and New Jersey	8.2 MGD	

[a] Operational status based on publicly available information (MARAD 2024).

The Northeast Gateway LNG Port (NEG Port), located in Massachusetts Bay, is an example of a similar use of once-through cooling water at much larger volumes than expected for offshore converter stations and is a representative example of the offshore LNG projects in Table 4, providing context and comparison to cooling water intake and discharge parameters for offshore converter stations. The NEG Port is located in federal waters approximately 13 mi (21 km) off the coast of Massachusetts in approximately 270 to 290 ft (82 to 88 m) of water, within BOEM Lease Blocks NK 19-04 6625 and 6657.

Commissioned in 2008, the NEG Port has operated since then. The currently issued NPDES Permit (MA0040266) authorizes up to 56 MGD (39,000 gpm) of once-through cooling water. The permit approves continuous LNG delivery operations from December 1 through February 28, assuming the continuous presence of a floating storage regasification unit (FSRU) moored at the port. Two FSRUs may moor simultaneously up to 10% of the time, totaling 2,160 hours of discharge from the main condenser and auxiliary seawater service cooling. From March 1 through November 30, the NPDES Permit authorizes an additional 528 hours for these outfalls, allowing FSRU presence outside the winter operating condition.

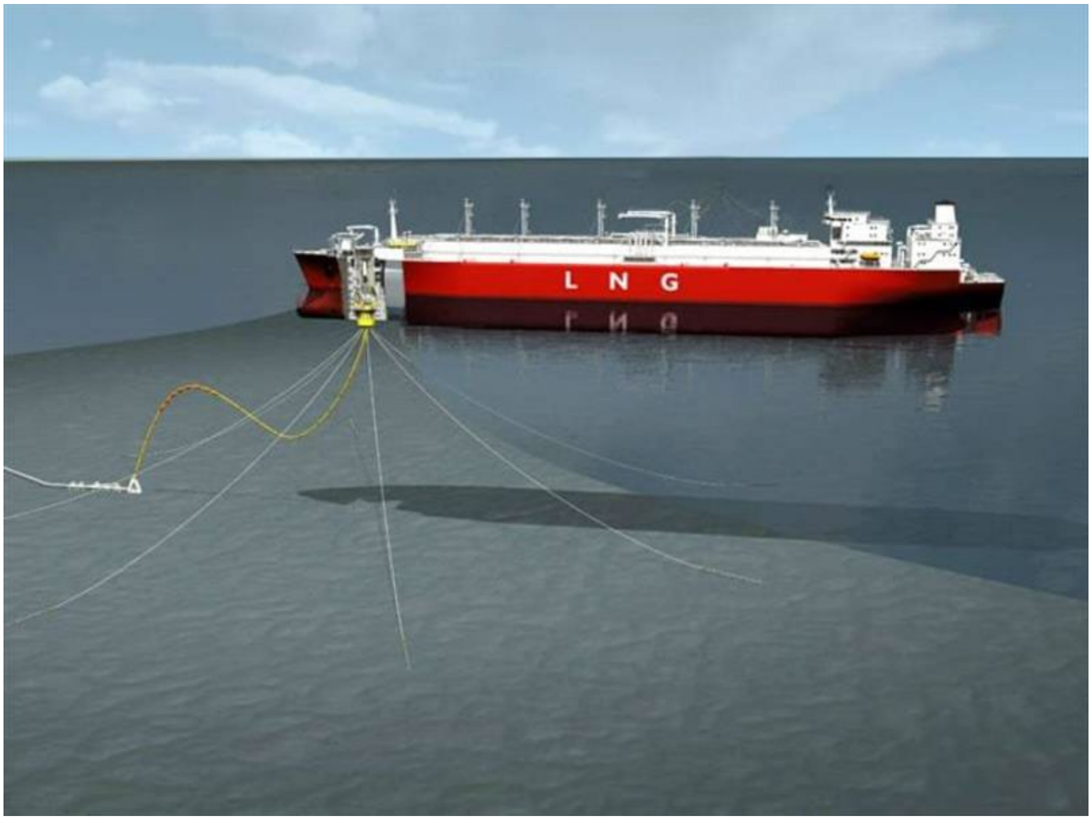
The permit also authorizes continuous year-round operational discharge from the Water Curtain and freshwater generator outfalls, totaling 8,496 hours. The Water Curtain, a safety deluge system, cascades seawater across the FSRU deck to mitigate hull fracture risk during an LNG spill. The Water Curtain operates continuously during LNG delivery, with a permitted outfall rate of 0.6 MGD. The freshwater generator intermittently converts seawater into freshwater for FSRU crew sanitary and potable use, with authorized brine discharge at a rate of 0.3 MGD.

The NEG Port delivers gas via a fleet of 138,000 and 151,000 m^3 capacity FSRU vessels. Engineers designed and installed the port to deliver regasified LNG as natural gas to onshore markets via a 16.1 mi long (25.9 km long), 24-inch (in.) diameter (0.6 m diameter) natural gas pipeline, referred to as the pipeline lateral. This pipeline interconnects the NEG Port to the offshore natural gas pipeline known as the HubLine. The NEG Port facility includes two subsea Submerged Turret Loading (STL) Buoys (Buoy A and Buoy B), each attached to the pipeline lateral by a flexible riser assembly, connecting manifold, and an 18 in. diameter (0.5 m diameter) subsea flowline. Each STL Buoy is secured to the seafloor using a series of suction anchors and a combination of chain and cable anchor lines, as shown in Figure 16.

Figure 16. Northeast Gateway Floating Storage Regasification Unit Vessel

Rendering shown with STL buoy connected to pipeline lateral.

Source: Northeast Gateway (2006).



During port operations, the FSRU requires up to 56 MGD (39,000 gpm) of seawater (with a maximum intake velocity of no more than 0.45 ft/s) to support standard vessel operating requirements, including engine cooling, ballast water, safety water curtain, fire systems, and crew sanitary and potable water needs. Of this total volume, the vessel discharges approximately 54 MGD (37,500 gpm) back into the surrounding environment as primarily heated discharge. The discharge water may not exceed 21.6ºF (12ºC) above the ambient ocean water temperature, referred to as deltaT, or ΔT = 21.6ºF (12ºC). FSRUs draw all water through four interconnected sea chests, each fitted with metal grates with 0.83 in. (0.02 m) slots between the grate bars. Sea chests commonly serve as cooling water intake systems on large vessels (see Section 4.5). The FSRU positions its sea chests approximately 23 to 38 ft (7 to 12 m) below the surface of the water.

FSRUs have the unique capability to substantially reduce water use below their DIF by operating in heat recovery mode, also referred to as the heat recovery system (HRS), during LNG offloading. As heated freshwater circulates through the FSRU vaporizers to warm the LNG during regassification, the temperature drops, allowing the system to reuse that water in the ship's main condenser and auxiliary engine cooling systems. When FSRUs operate in regasification mode and natural gas delivery reaches a minimum natural send-out rate of 200 million standard cubic feet per day (mmscfd), they reduce water use by switching to HRS. At this send-out rate, water flows through the LNG vaporizers at a rate and temperature sufficient to support the cooling needs of the ship's main condenser and auxiliary cooling. While in HRS, the process of transferring heat in the closed-loop shell-and-tube system to warm LNG provides all of the cooling water for the vessel's needs. Under optimal conditions of LNG pressure, water flow, and other parameters, the cooling water cycle can safely transition into the HRS mode, during which daily cooling water use can drop from its maximum DIF of 56 MGD (39,000 gpm) to a minimum intake rate of approximately 2.77 MGD (1,924 gpm).

The NPDES Permit conditions for the NEG Port include shipboard monitoring of all outfall volumes, flow rates, and discharge temperatures during operations. The NEG Port must also conduct quarterly in situ thermal plume and water quality monitoring of the discharges. This monitoring includes measurements of temperature gradients, dissolved oxygen levels, and other water quality parameters to evaluate the extent and intensity of thermal impacts from cooling water discharge. Additionally, a 5-year ichthyoplankton monitoring program quantifies potential impacts on early life stages of fish species. The program includes collecting and analyzing samples to determine species composition, abundance, and seasonal patterns of ichthyoplankton in the vicinity of the port, enabling assessment of entrainment losses during FSRU operations. These monitoring requirements, specified in the facility's NPDES Permit, ensure compliance with water quality standards and support evaluation of potential ecological effects from port operations.

4.4 Onshore Power Generation and Industrial Facilities

Onshore conventional power generation and industrial facilities account for a substantial number of facilities subject to NPDES requirements. More than 900 existing power generation or industrial facilities in the U.S. each hold permits to withdraw more than 2 MGD of cooling water, for a cumulative total of approximately 372 billion gallons per day (EPA 2010). Of these, 155 coastal or estuarine power generation and industrial facilities account for approximately one-third of that total water volume, approximately 112 billion gallons per day. These existing facilities are subject to the 2014 §316(b) Final Rule (EPA 2010; 2014).

Most onshore cooling water intakes withdraw water from shoreline locations, in contrast to offshore converter stations that use vertical caisson intakes in the open ocean. Only a few onshore facilities in the northeast, such as Seabrook Station in New Hampshire (with an intake located approximately 1 mi offshore), use an offshore intake. Source water bodies for onshore intakes are much shallower than for those proposed offshore converter stations, which typically overlap with nearshore and estuarine habitats. Onshore facilities face different engineering and configuration constraints and generally offer more flexibility for implementing protective technologies to support BTA requirements compared to uncrewed offshore facilities. Shoreline intakes also support structural features for screening technologies such as bar racks, traveling water screens, fish-return troughs, and similar equipment, as shown in Figures 17 through 21.

Figure 17. Typical Shoreline Cooling Water Intake Structure

Profile view of CWIS. Cooling water enters through the bar rack from below the curtain wall and passes through screens before entering the seawater pumps

Source: Taft et al. (1986).

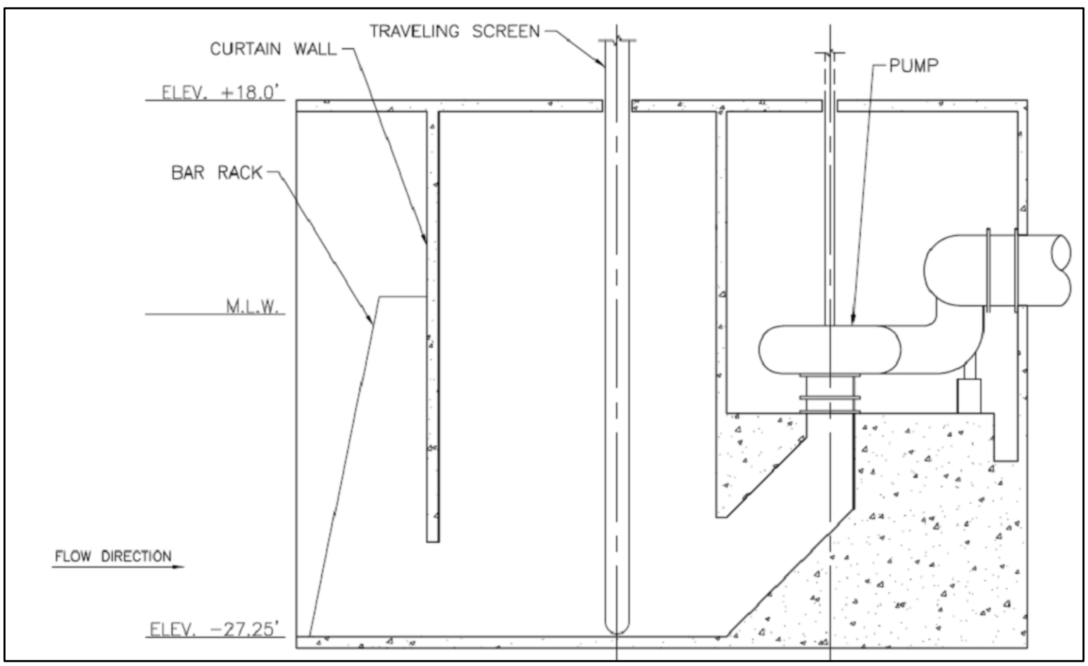


Figure 18. Representative Onshore Cooling Water Intake Structure Components

Source: Steinbeck et al. (2007).

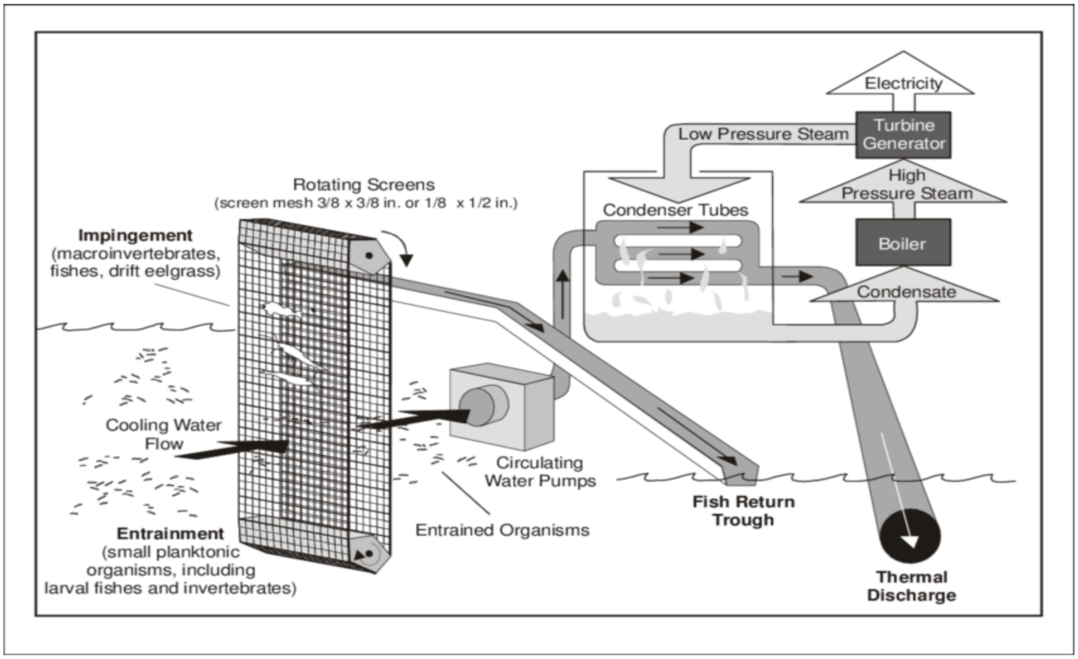


Figure 19. Typical Steel Bar Rack System at Onshore Cooling Water Intake Structure

A typical steel bar rack system with 4-inch spacing prevents large debris and organisms from entering the CWIS

Source: Tetra Tech (n.d.b).

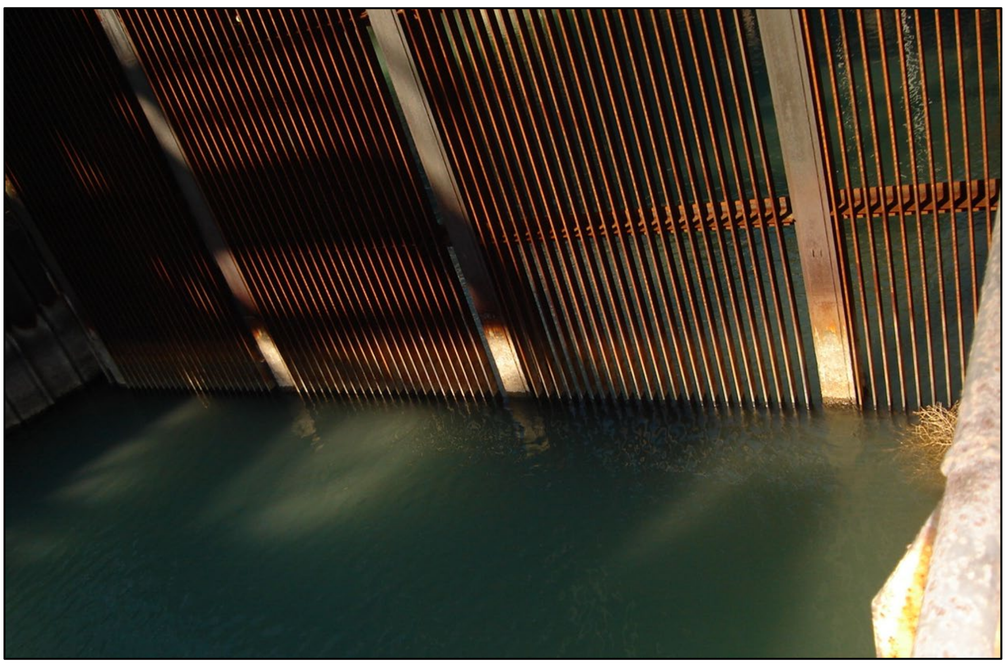


Figure 20. Traveling Screen Housing at Onshore Cooling Water Intake Structure

A typical housing for traveling screens prevents debris and organisms from entering the pumps and condenser at an onshore CWIS.

Source: Tetra Tech (n.d.c).

Figure 21. Traveling Screen Panel with 3/8-inch Mesh

Fish, organisms, and debris may become impinged on or entrained through a typical traveling screen panel with 3/8-in. mesh.

Source: Tetra Tech (n.d.d).

Although the screen and bar or trash rack configurations may differ between onshore intakes and the proposed offshore converter station offshore intakes, a review of NPDES requirements for onshore facilities provides useful context for regulatory decision making. The example facilities listed in Table 5 are located in coastal and estuarine environments and are subject to NPDES and §§316(b) and 316(a) requirements. These facilities have generated decades of permitting compliance and monitoring data f or their once-through cooling systems. Although the requirements differ across onshore facilities, this historical data is expected to inform impact assessment, permitting, and monitoring requirements for offshore converter stations.

Table 5. Representative Range of Onshore Coastal Facilities within the U.S. Environmental Protection Agency's Regions 1 and 2

Source: EPA (2010).

Facility	Industry	Owning Company	Water Body	Location	Maximum Design Intake Flow[a] (MGD)	Status
Ravenswood Generating Station	Power generation	Rise Light & Power	East River	Queens, NY	3,301.6	Operational; proposed offshore wind interconnection
Salem Generating Station	Power generation	PSEG	Delaware Bay	Salem, NJ	3,024.0	Operational
Millstone Power Station	Power generation	Dominion Energy	Niantic Bay	Waterford, CT	2,914.4	Operational; proposed offshore wind interconnection
Northport	Power generation	National Grid	Long Island Sound	Fort Salonga, NY	1,867.5	Operational
Astoria Generating Station	Power generation	NRG	East River	Queens, NY	1,769.2	Planned retirement (2025); proposed offshore wind interconnection
Bridgeport Harbor	Power generation	PSEG	Long Island Sound	Bridgeport, CT	1,657.8	Retired
Brayton Point Station	Power generation	Dominion Energy	Mount Hope Bay	Somerset, MA	1,399.0	Retired (2017); proposed offshore wind interconnection
Arthur Kill	Power generation	Alpha Generation	Arthur Kill	Staten Island, NY	712.8	Planned retirement (2025)
E.F. Barrett Power Station	Power generation	National Grid	Hempstead Bay	Island Park, NY	474.9	Operational; proposed offshore wind interconnection
Bayway Refinery	Power generation	Phillips 66	Newark Bay	Linden, NJ	302.4	Operational
B.L. England Generating Station	Power generation	RC Cape May Holdings	Egg Harbor	Beesleys Point, NJ	298.8	Retired; proposed offshore wind interconnection
Hope Creek	Power generation	PSEG	Delaware Bay	Hancocks Bridge, NJ	115.2	Operational
Brooklyn Navy Yard Cogeneration	Power generation	Brooklyn Navy Yard Cogeneration Partners	New York Bay	Brooklyn, NY	94.0	Operational
Valero Paulsboro	Industrial	PBF Energy	Delaware Bay	Paulsboro, NJ	45.8	Operational

[a] Actual (or average) intake flow (AIF) is typically lower than the as-built maximum DIF. Under §125.92(a), AIF refers to the average volume of water withdrawn annually by the cooling water intake structures over the past 3 years. After October 14, 2019, AIF refers to the average annual withdrawal over the previous 5 years. Some facilities may negotiate lower permitted intake flows (lower than DIF) for compliance or other operational reasons. For example, Ravenswood currently holds a permit allowing withdrawal of up to 1,527.8 MGD, according to its water withdrawal permit (DEC #2-6304-0002400056), which reflects its AIF.

Several of the facilities listed in Table 5 have been retired or are scheduled to retire by 2025 (DEC 2023). While these retirements are unrelated to offshore wind development, factors such as economic conditions, environmental regulations, and state energy policies drive the closures. Some of these locations are now being considered for transformation into offshore wind interconnections. This transition is important for evaluating cumulative cooling water uses as a tradeoff, as well as reducing water withdrawal needs proximate to sensitive estuarine habitats. For example, the maximum DIF of the oil- and gas-fired Ravenswood Generating Station is 3,301.6 MGD,[5] one of the largest once-through cooling water intake flows in the U.S. (EPA 2010). With plans to convert this facility into an offshore wind interconnection point for multiple projects (Rise Light & Power 2024), the combined cooling water need of each offshore wind converter station (5–10 MGD) would represent a small fraction of that single facility's use. Ravenswood's DIF is equivalent to the cooling water flow needs of more than 300 hypothetical offshore wind converter stations, based solely on water use. However, environmental or biological impacts are not necessarily equivalent or proportional because they depend on site-specific and temporal factors, such as seasonal variations in species presence and abundance, life stage timing of marine organism movements, and interannual variability in marine communities (discussed in Section 5.2.2). Additionally, while conventional power generating facilities typically operate year-round, offshore converter stations may follow different operational patterns, affecting cooling water timing and duration. These spatial, environmental, and temporal factors must be evaluated case by case during facility permitting.

Brayton Point Station, also listed in Table 5, was a coal-fired power generating facility on Mount Hope Bay Estuary in Somerset, MA. Under a 2007 EPA Administrative Order, Brayton Point constructed natural draft cooling towers at the facility to meet the flow reduction and temperature standards required by its NPDES permit. However, in 2013, shortly after completing the towers, the facility announced its closure and retired in 2017. As with Ravenswood, Brayton Point's closure reduced overall cooling water use and transitioned the site toward renewable energy interconnection (Mass CEC 2017).

The Millstone Power Station (MPS) in Waterford, CT, provides another example of large-scale NPDES implementation. MPS, a nuclear facility located on Niantic Bay, operates two units (Units 2 and 3) with a combined DIF of 2,914.4 MGD of once-through cooling water. Each unit includes a curtain wall, 2-in. bar racks, and 3/8-in.–coarse mesh traveling screens. Impinged organisms are washed from the screens using a spray wash system and returned to the source waterbody via a fish return sluice. Originally permitted in December 1992, MPS currently operates under a September 2010 reissued NPDES permit (CT0003263). Between permit issuances, ecological monitoring showed deteriorating fisheries in Niantic Bay, most notably the winter flounder (*Pseudopleuronectes americanus*) stock.

Entrainment of eggs and larvae at MPS contributed to this decline. The 2010 NPDES permit required updated entrainment and impingement monitoring and a full BTA evaluation. MPS submitted its renewal application in February 2015, but the permit remains administratively continued. This case shows how monitoring data informs evolving NPDES requirements and BTA evaluations for minimizing ecological impacts, even during administrative continuance.

Onshore CWIS associated with conventional power plants withdraw significantly larger volumes of once-through cooling water, often several orders of magnitude more, than proposed offshore converter stations. As a result, these facilities have faced substantial regulatory and stakeholder scrutiny regarding entrainment, impingement, and thermal discharge impacts (*Entergy Corp. v. Riverkeeper, Inc.* 2009; Riverkeeper 2014). When assessing offshore converter station impacts, considering the scope and scale of onshore facilities compared to offshore facilities is critical. Scaling potential impacts on a site-specific basis supports a more accurate and relevant environmental assessment.

4.5 Other Sources of Cooling Water in the Ocean Environment

Most powered marine vessels use some form of once-through cooling water, ranging from small outboard motors to large commercial vessels with "sea-chest" intake structures used for engine cooling, ballast, and other water uses. Nonpowered vessels, such as sailing vessels without auxiliary engines, barges under tow, and unpowered platforms, do not require cooling water systems. Vessels commonly use sea chests to withdraw cooling water, typically located either near the surface or at the bottom of the hull. Seawater pumps withdraw water through an opening in the hull, which is covered by steel grating or a bar rack to prevent most organisms from entering the intake. A strainer, located further upstream, protects internal components of the seawater system. Figure 22 shows a schematic of a sea chest and seawater system, with examples shown in Figure 23.

Figure 22. Typical Sea Chest Configuration on the Hull of a Large Vessel

Source: Ultrasonic Antifouling (2025).

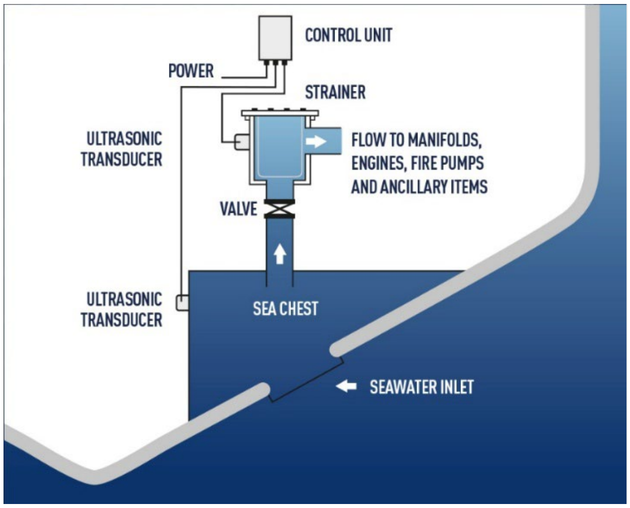


Figure 23. Sea Chest Openings

Typical rectangular and round sea chest openings with visible barnacle growth on the grating and bar racks.

Source: Virtue Marine (2024).

Certain vessel types, such as offshore LNG tankers while at port, require an individual NPDES Permit, as described in Section 4.3. Most other large commercial vessels fall under the Vessel Incidental Discharge Act of 2018 (EPA 2024d), subject to the Vessel General Permit (EPA 2013). In 2024, the EPA published the Vessel Incidental Discharge National Standards of Performance (40 CFR 139), which include updated performance standards for vessels 79 ft (24 m) or greater (excluding fishing vessels without ballast tanks, recreational vessels, and U.S. Department of Defense vessels), with a focus on ballast water (EPA 2024d). For large vessels (>79 ft or 24 m), operators typically use water withdrawn through the sea chests for cooling, fire protection, sanitary and graywater systems, ballast, and so forth, which makes separating the various uses within the Vessel General Permit challenging.

However, in preparation for the §316(b) Phase I Rule, the EPA quantified the cooling water use of various U.S. Department of Defense vessels (EPA 1999). These data provide a relevant comparison to specific cooling water uses[6] by other vessel types common in ocean waters. Table 6 summarizes once-through cooling water usage by select vessel classes, which Figure 24 further summarizes and compares to other examples discussed in Section 4 (e.g., offshore wind converter stations, oil and gas platforms, offshore LNG, onshore power generation, and vessels).

Table 6. Example of Once-through Cooling Water Usage: Selected Vessel Class

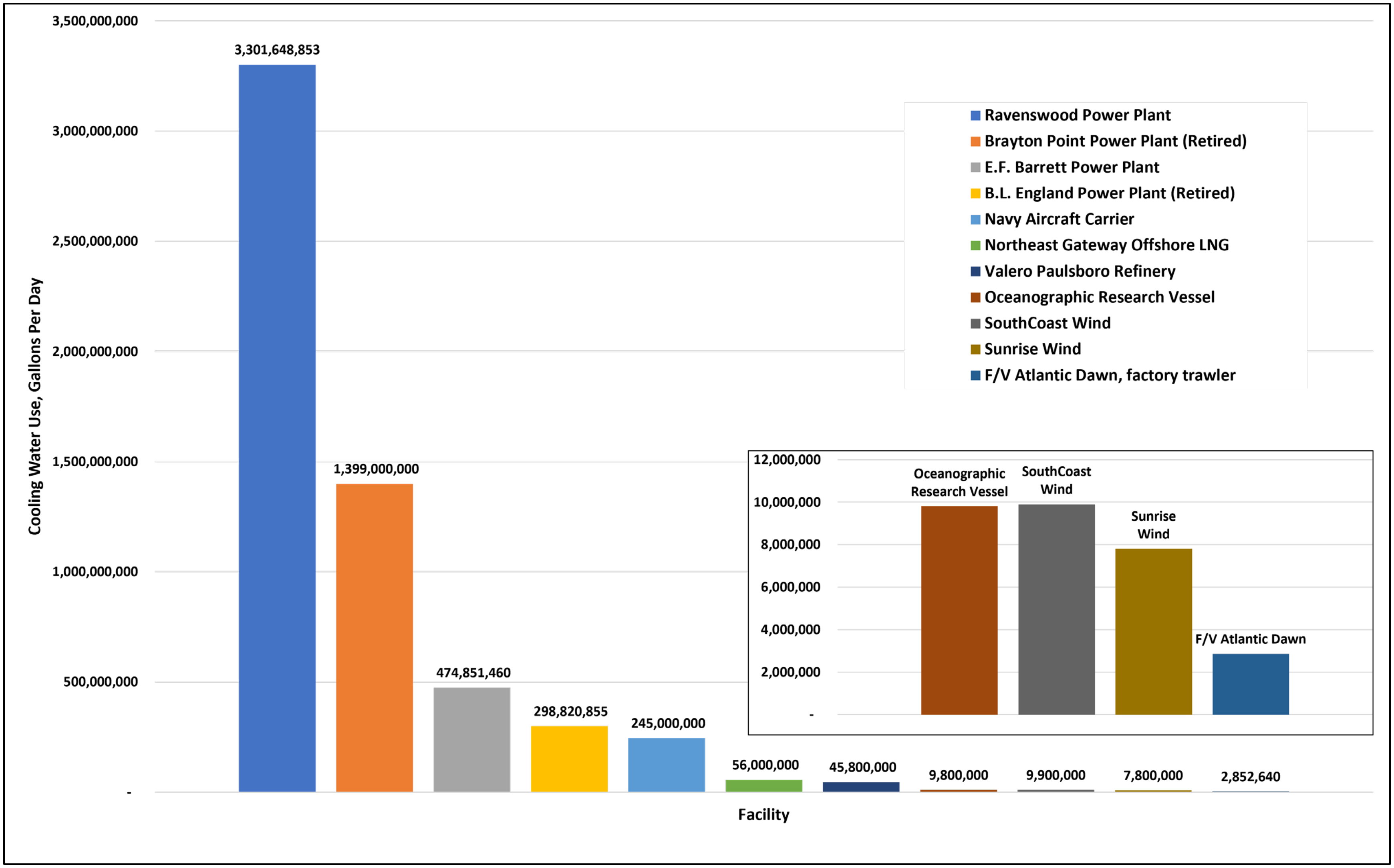
Vessel Example[a]	Vessel Class	Length (ft)	Gross Tonnage (GT)	Cooling Flow Rates	
				Pierside (MGD)	In Transit (MGD)
U.S. Navy Vessel[b]					
CVN 68	Aircraft carrier	n/a	n/a	5.9	>244.8
CG 47	Cruiser	n/a	n/a	2.4	10.1
DDG 51	Destroyer	n/a	n/a	2.2	9.8
FFG 71	Frigate	n/a	n/a	2.5	4.3
LHD 1	Amphibious assault ship	n/a	n/a	4.3	up to 58.3
Submarine	n/a	n/a	n/a	2.9	14.4–17.3
Large Commercial Fishing Vessels					
F/V Atlantic Dawn	Mega/factory trawler	472	14,055	0.8	2.9
F/V Kirkella	Large freezer trawler	266	3,500	0.6	2.2
F/V Annelies Ilena	Mega/factory trawler	472	14,055	1.0	3.8
F/V Cornelis Vrolijk	Large freezer trawler	377	5,444	0.7	2.7
F/V Pacific Dawn	Purse seiner	243	1,750	0.5	2.0
Other Marine Vessels					
Gulf Commander	Tugboat	78	98	0.3	1.0
San Francisco Pilot Boat	Pilot boat	65	50	0.1	0.5
M/V Harbor Queen	Passenger Ferry	72	140	0.3	0.8
R/V Rachel Carson	Research Vessel	72	100	0.2	0.6

[a] Information presented is based on publicly available data. Not all vessels listed operate in U.S. waters or are permitted to fish in the Atlantic Exclusive Economic Zone. Actual cooling water usage may vary based on vessel operations and configurations

[b] Certain U.S. Navy vessel specifications are unavailable for security purposes.

Figure 24. Cooling Water Sources within the New York Bight, Southern New England, and Surrounding Waters

Source: EPA (1999).



5 Risks and Impacts

The cooling system is a critical component of offshore converter stations, but it interacts with the surrounding marine environment in ways that require careful consideration. Insights on risks to fish populations in the marine environment are based on several decades of evaluating impacts at coastal and offshore facilities, including impingement, entrainment, thermal discharge, and secondary effects—as summarized in this section. These impacts can affect different components of the marine ecosystem, including fish populations and other marine organisms. Figure 2 includes a schematic representation of impacts. As examples, both the Sunrise Wind Final and SouthCoast Wind Draft NPDES Permits address such impacts associated with their offshore converter stations

5.1 Impingement

Impingement refers to the temporary or permanent contact, or entrapment of all life stages of fish and shellfish on the outer part of an intake structure or against a screen device during intake water withdrawal (Martinez-Andrade and Baltz 2003; EPA 2006). Individual fishes may interact with an intake screen, which may result in temporary impingement without injury or stress, or, in some cases, may cause mortality.

CWA §316(b) requires NPDES permits to ensure that the location, design, construction, and capacity of CWIS reflect the BTA to minimize adverse environmental impact from impingement and entrainment of aquatic organisms. Studies evaluating impingement have demonstrated post-impingement latent survival rates ranging between 58% to 100% for nonfragile[7] marine and estuarine species; however, in some cases, impingement may cause individual mortality (as summarized in EPRI 2012). Many ecologically, commercially, and recreationally important species are classified as “fragile species,” defined as those with impingement survival rates of less than 30%. These include key forage fish such as Atlantic herring (*Clupea harengus*), Atlantic menhaden (*Brevoortia tyrannus*), and bay anchovy (*Anchoa mitchilli*), as well as commercially and recreationally valuable species like bluefish (*Pomatomus saltatrix*) and American shad (*Alosa sapidissima*). Despite this classification, fragile species remain important given their ecological roles in the food web and their economic significance to regional fisheries.

The CWIS of an offshore converter station could result in impingement risks to marine organisms (BOEM 2024). Organisms most susceptible to impingement are large enough to avoid passing through intake screens but may lack sufficient swim speeds (or face other physiological constraints) to avoid becoming impinged, such as many of the fragile species mentioned previously. However, the lack of traveling screens at such facilities limits impingement to the bar rack structure at the intake opening. Bar racks not only prevent debris and large organisms (i.e., marine mammals) from entering the intake (and becoming entrapped), but also help maintain appropriate through-screen velocities, as demonstrated in the Sunrise Wind NPDES permitting process (EPA 2024a).

Individual organisms are expected to avoid impingement (and entrapment) at bar racks due to a low intake velocity of 0.5 ft/s or less (compliance threshold) because most juvenile and adult fishes can swim fast enough to prevent impingement. However, operational conditions such as screen clogging may cause velocities to exceed this threshold, potentially increasing impingement (and entrapment) risk. Therefore, a facility must account for a reasonable clogging or biofouling factor when calculating intake velocities to ensure that velocities remain at or below 0.5 ft/s even under such conditions. Furthermore, as specified in the Sunrise Wind NPDES Permit, if the through-screen velocity exceeds 0.5 ft/s, the facility must implement best management practices to limit, diagnose, and resolve the issue as soon as practicable (EPA 2024a). The EPA considers intake velocities of 0.5 ft/s or less to represent the BTA for minimizing impingement impacts, and offshore wind converter stations must maintain compliance with this velocity requirement through operational controls and monitoring.

5.2 Entrainment

Entrainment describes fish eggs and larvae (or other organisms) small enough to flow through intake bar racks and screens, pass through a facility's cooling water intake system (e.g., pumps, condenser), and eventually return to the source water with the heated cooling water discharge, which often causes mortality[8] (EPA 2006). In the absence of site-specific studies, regulators presume 100% mortality of all entrained ichthyoplankton due to pump, mechanical, and thermal stress (EPA 2001, 2014). While this conservative assumption supports regulatory compliance, site-specific studies at various onshore and coastal facilities have demonstrated that actual entrainment mortality may be substantially less than 100% for certain taxonomic groups and under certain operational parameters and/or life history characteristics. For example, studies have shown that some marine planktonic crustaceans, particularly copepods and certain decapod larvae, survive at rates between 20% and 80% under operational parameters similar to those proposed for offshore converter stations, including discharge temperatures below 86ºF (30ºC), minimal chlorination, and reduced physical stress due to pump design (Bamber and Seaby 2004; EPA 2004; ERPI 2009).

The primary entrainment risk for offshore wind projects stems from HVDC converter stations that use once-through (open-loop) cooling water intake and discharge systems. Water intake associated with cable installation (trenching) and intake pumps also has the potential to entrain planktonic organisms, such as larval fish and larval and juvenile benthic organisms. However, because this equipment is not part of the cooling water operations of the offshore converter station and the volume of water it takes in is a discrete, one-time impact during cable installation, it is not subject to NPDES regulation. This report does not further address entrainment under that scenario.

5.2.1 Hydraulic Zone of Influence

One of the key environmental considerations of a cooling water intake structure is the HZI (40 CFR 122.21(r)(2)(ii)), which refers to the portion of a source waterbody that the CWIS hydraulically influences (EPA 1977, 2014). Essentially, the HZI defines the portion of the water column from which organisms would be withdrawn (entrained) if they cannot escape the intake flow. The HZI is dynamic and varies with environmental conditions. Tidal currents can substantially alter the shape and extent of the HZI. During strong tidal flow, the HZI elongates and stretches in the direction of the current, while during slack tides, it appears more symmetrical around the intake (Turnpenny et al. 2010). Seasonal variations in water temperature and stratification also influence the HZI by affecting aquatic organisms' swimming capabilities and the water column's vertical mixing (EPRI 2000). While the HZI itself does not pose a direct risk, it determines what organisms may become entrained through the intake.

The extent of the HZI in the open ocean depends on the ratio of water intake flow to ocean current flow. Contributing factors include the intake velocity, intake opening cross-sectional area, ambient current velocities near intake, local bathymetry and water column characteristics, and physical structure effects (such as jacket foundations) that influence local water flow and stratification (EPRI 2000). Outside the HZI, ambient factors such as ocean currents and winds drive water flow, not the CWIS. The HZI is the initial force acting on the ambient water column, influencing the likelihood of an organism becoming impinged or entrained; therefore, understanding the HZI is important for evaluating impingement and entrainment risks associated with offshore converter stations and other facilities that require water intake for cooling or other purposes.

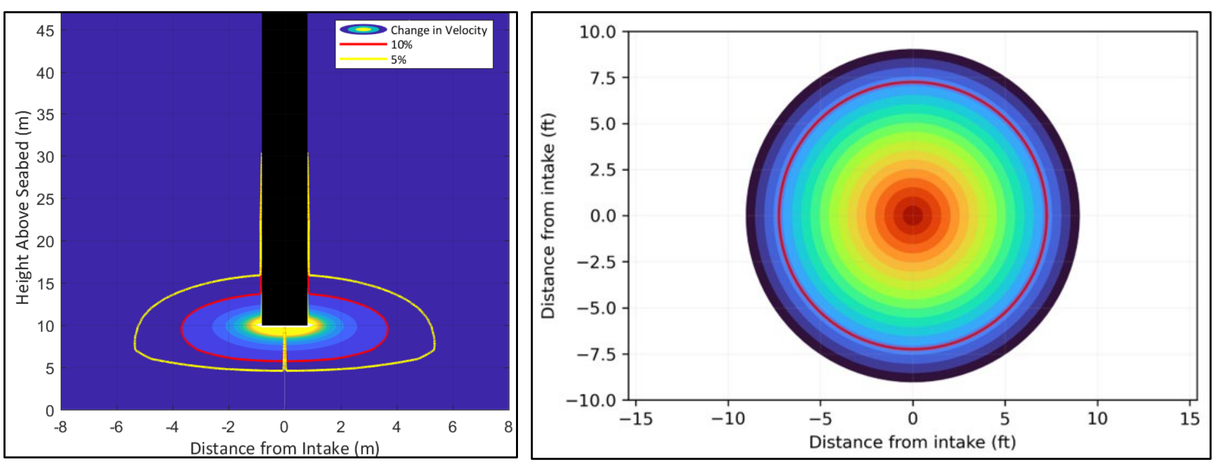
Accurate HZI determination plays an important role in assessing the potential impacts of water intake structures on aquatic life. Understanding the extent of the HZI enables consideration of strategies to minimize entrainment and impingement risks, such as optimizing intake locations, reducing intake velocities, or implementing physical barriers or behavioral deterrents (Taft 2000). Regulatory agencies typically require HZI calculations or modelling as part of the permitting process for facilities with CWIS to ensure compliance with environmental regulations and protect aquatic ecosystems (EPA 2014).

Engineers initially developed HZI calculation methods for coastal and riverine facilities, with early approaches focused on shoreline intakes (Wiegel 1964). One of the first analytical approaches, the cylinder model, approximates the HZI as a cylinder extending from the intake opening to the point where the intake velocity drops below a critical threshold (Huang et al. 2010). This threshold velocity is often set at 0.5 ft/s, or 0.15 meters per second (m/s), which reflects the maximum swimming speed of many juvenile fish and small organisms (EPRI 2000). However, this threshold does not apply to planktonic organisms (including eggs and larvae), which have limited to no swimming ability. For these organisms, the total volume of water withdrawn, not intake velocity, is the more relevant metric for assessing entrainment potential. Figure 25 show an example of output from HZI modelling by Sunrise Wind and SouthCoast Wind.

Figure 25. HZI Modelling Results for Sunrise Wind and SouthCoast Wind

Results show a relative change in current velocity associated with the intake caisson. Profile view shown for Sunrise Wind; plan view shown for SouthCoast Wind. The red line indicates the 10% change in current velocity, based on HZI modelling. Color-ramp is a relative reference only, based on the original figure.

Source: TRC (2021; left image); Tetra Tech and Normandeau (2023; right image).



More advanced methods for determining the HZI have evolved to computational fluid dynamics models that can simulate the three-dimensional flow field around the intake structure, taking into account factors such as the bathymetry, tidal currents, and stratification (Pugh et al. 2005). These models may provide a more accurate representation of the HZI and help identify regions of high entrainment risk, where applicable. For example, Pugh et al. used a computational fluid dynamics model to investigate the HZI of a coastal power generating facility's intake. They demonstrated that the HZI can extend several hundred meters from the intake under certain tidal conditions constrained by the shoreline.

As engineers adapt these calculation methods from coastal to offshore applications, they must incorporate additional considerations, particularly the effects of offshore substation jacket foundations on localized water flow and stratification. Recent offshore wind projects have employed two main calculation approaches: a simplified equation derived from Wiegel (1964) with modifications for oceanic intakes, and stream function theory using maximum DIF, as demonstrated in the Sunrise Wind and SouthCoast Wind permits (EPA 2024a, 2024b). While developers initially propose calculation methods in their NPDES permit applications, EPA may require specific calculation methods or modelling approaches to be included as part of the HZI calculation as permitting advances for offshore converter stations.

Maintaining a low intake velocity (0.5 ft/s or less) and placing bar racks on the caisson opening of the intake structure minimizes or eliminates the potential for entrapment (entrainment of larger organisms behind an intake bar-rack) or entrainment of larger free-swimming life stages (juvenile and adult) of fish and other aquatic organisms within the intake caisson. However, these measures do not prevent entrainment of early life stages of plankton fishes and invertebrates within the HZI of HVDC converter intakes (BOEM 2024).

5.2.2 Species Susceptibility

The species and life stages most susceptible to entrainment are zooplankton and ichthyoplankton (including fish eggs and larvae) from species that inhabit the broader oceanographic strata, spawn near the proposed intake structure, and have buoyant egg or larval stages. In the New York Bight, based on MARMAP/EcoMon ichthyoplankton data (NMFS NFSC 2019), which samples across defined strata bounded by isobaths throughout the continental shelf, expected susceptible species with pelagic early life stages (eggs and larvae) include Atlantic butterfish (*Peprilus triacanthus*), Atlantic cod (*Gadus morhua*), Atlantic mackerel (*Scomber scombrus*), American plaice (*Hippoglossoides platessoides*), black sea bass (*Centropristis striata*), bluefish (*Pomatomus saltatrix*), haddock (*Melanogrammus aeglefinus*), monkfish (*Lophius americanus*), pollock (*Pollachius virens*), red hake (*Urophycis chuss*), scup (*Stenotomus chrysops*), silver hake (*Merluccius bilinearis*), summer flounder (*Paralichthys dentatus*), windowpane flounder (*Scophthalmus aquosus*), witch flounder (*Glyptocephalus cynoglossus*), winter flounder (*Pseudopleuronectes americanus*), and yellowtail flounder (*Pleuronectes ferruginea*). While some species like Atlantic sea scallop (*Placopecten magellanicus*) and Atlantic surfclam (*Spisula solidissima*) have benthic eggs and adult stages and are thus unlikely to experience entrainment, their larvae remain in the water column for days to weeks (4 to 6 weeks for Atlantic sea scallop) before settling to the ocean floor, making them susceptible to entrainment during this planktonic phase (Cargnelli et al. 1999; NOAA Fisheries 2025). Species with both egg and larval stages occurring in benthic environments (e.g., ocean pout [*Zoarces americanus*] eggs) are unlikely to experience entrainment due to their position within the water column from which water is withdrawn.

Species with pelagic early life stages generally follow life history strategies of naturally high-fecundity broadcast spawning and low survival from egg to larval stage and larval to juvenile stages. Many species produce thousands to millions of eggs per fish, and spawning aggregations release tens to hundreds of millions of eggs in areas of dense spawning activity (e.g., Pitt 1971; Kelly and Stevenson 1985; Papaconstantinou and Vassilopoulou 1986; Kjesbu 1989). For example, adult female Atlantic cod can produce several million eggs per spawning cycle, while Atlantic herring produce an estimated 285,000 to nearly 2 million eggs per individual (Morse 1980; Kjesbu). Atlantic sea scallops show even higher fecundity, with mature females producing 10 million to 270 million eggs annually, depending on size and age (Hart and Chute 2004; Thompson et al. 2014).

Additionally, the timing of spawning activities varies significantly among these species, creating temporal patterns in entrainment susceptibility. Species exhibit different spawning strategies and durations, which affect the temporal distribution of vulnerable early life stages. For example, Atlantic cod are broadcast batch spawners that release eggs and sperm in multiple batches over an extended period of 1–2 months (Kjesbu 1989; McBride and Smedbol 2022). Individual female cod may spawn over a 50- to 60-day period, producing between 17 and 19 egg batches during that time (Kjesbu). This prolonged spawning results in a more extended period during which eggs and larvae may be vulnerable to entrainment compared to species that complete spawning in a single event or over a shorter duration. This temporal variation means that the potential for entrainment varies seasonally based on which species have vulnerable life stages present during CWIS operation. The concentration of eggs and larvae during spawning periods influences entrainment susceptibility, with greater potential for recruitment reduction in areas of high spawning activity compared to areas with lower spawning activity (EPRI 2011a; Vasconcelos et al. 2014).

Broadcast spawning species like Atlantic cod exhibit naturally high early life stage mortality, with daily natural mortality rates of eggs estimated at 10% to 20% and larval mortality rates up to approximately 6% per day (Mountain et al. 2008; Stiasny et al. 2016). These mortality rates result from predation, adverse environmental conditions, transport away from nursery habitats, and starvation or developmental stress. These mortality factors, combined with spatial and temporal spawning patterns, influence early life stage distribution and abundance throughout the New York Bight. Furthermore, additional spawning grounds, areas with high concentrations of early life stages, areas with designated EFH, and areas with vulnerable populations or depleted stock status also influence susceptibility.

5.2.3 Entrainment Metrics

Analysts estimate entrainment impacts by using ichthyoplankton and zooplankton density data (number of individuals per gallon) to calculate a flow-based density ratio, based on expected cooling water withdrawal (gallons) on a daily, seasonal, or annual basis. Entrainment rates scale directly with water flow; as such, an effective entrainment reduction strategy includes minimizing and managing water use through flow reduction measures (e.g., implementation of variable speed drives, single-pump operation), as discussed in Section 7.

Current entrainment analyses face important limitations that affect impact assessment. For example, the MARMAP/EcoMon dataset used in NPDES permit applications does not identify eggs to species level, resulting in entrainment estimates based solely on larval stages. The Sunrise Wind facility's projected monthly average operational flows are expected to result in an estimated annual entrainment of 5.5 to 6.5 million larvae per year (EPA 2024a). However, since eggs typically occur at higher densities than larvae, total annual entrainment could increase by a factor of two or more. By comparison, coastal or deepwater facilities with larger cooling water demands typically have much higher entrainment numbers, proportional to cooling water flow. For example, studies at the Northeast Gateway (with a cooling water flow of 56 MGD) estimated annual entrainment of 67 million larvae and 106 million fish eggs (Northeast Gateway 2012).

Analysts can further contextualize entrainment impacts based on each species' life history characteristics (as discussed in Section 5.2.2) and natural mortality, using a "common currency" approach, typically the age-1 equivalent model, to assess population impact (Goodyear 1977; Horst 1977; Boreman et al. 1981; Saila et al. 1997; EPRI 2004a; Barnthouse 2013). This model accounts for the naturally high mortality rates between egg/larval stages and age-1. For example, bay anchovy eggs experience natural mortality rates exceeding 99% during early life stages, resulting in only a small fraction surviving to age-1 even without entrainment. Thus, entraining 10,000,000 bay anchovy eggs may impact only 627 to 654 age-1 equivalent individuals (EPRI 2004a). Analysts have applied such models across hundreds of power generating facilities throughout the U.S. for NPDES permit applications or §316(b) compliance documentation, including examples described in Section 4.4. Table 7 summarizes the EPRI-developed species-specific baseline models, incorporating forward projections and fecundity hindcasting versions of equivalent adult models for selected species at a hypothetical power generating facility.

Table 7. Baseline Equivalent Adult Model Projections for Selected Species

Source: EPRI (2004a).

Life History Stage	Number Entrained	Adult Equivalents[a]
Gizzard Shad		
Eggs	100,000	0.5–2
Larvae	100,000	5–24
Juveniles	10,000	185–852
Alewife		
Eggs	1,000,000	15–16
Larvae	750,000	74–77
Juveniles	100,000	150–155
Bay Anchovy		
Eggs	10,000,000	627–654
Larvae	1,200,000	1,231–1,285
Juveniles	85,000	25,571–26,684
Striped Bass		
Eggs	100,000	0
Larvae	100,000	6
Juveniles	35,000	1,619–1,640
Pacific Sardine		
Eggs	10,000,000	15–64
Larvae	5,750,000	491–2,077
Juveniles	15,000	1,036–4,374

[a] Ranges based on forward projection and fecundity hindcasting versions of equivalent adult models.

Age-1 equivalents typically serve as the standard for assessing entrainment population impacts because they provide a consistent method for evaluating mortality, particularly of fish larvae and eggs drawn into cooling systems or other water intakes (EPRI 2004a). This method enables consistent comparison and evaluation of potential long-term impacts on population dynamics and fisheries. By focusing on a common age class, analysts can more easily assess the potential long-term impacts on population dynamics and reproductive success. However, the age of equivalence can vary depending on the purpose of assessment, particularly age at sexual maturity or age and entry into a fishery, where fishing mortality becomes an additional source of mortality for a given species.

Equivalent adult estimates are inherently conservative because they do not account for the density-dependence of early life stage mortality (EPRI 2011b). Turnpenny and Taylor (2000) noted that values derived from the equivalent adult methodology should be viewed as overestimates because the model excludes density-dependent factors that could enhance survival, growth, and reproductive rates of individuals remaining in the population when competition decreases. Stige et al. (2019) examined how density- and size-dependent mortality in the early life stages of fish can significantly influence recruitment and population dynamics. Compensatory density-dependence plays a key role in population regulation, allowing populations to recover at low densities by increasing survival rates. Density-dependent mortality often occurs early in life, affecting recruitment more than later stages. The influence of early life stage mortality varies among species depending on life history characteristics and population dynamics. This concept is particularly relevant for depleted populations like Atlantic cod and winter flounder, where increased early life stage mortality may disproportionately affect adult populations.

Analysts may also characterize entrainment impacts as "production forgone," estimating the future biomass lost due to entrainment mortality, and use real-world metrics to contextualize these impacts. Using this approach along with commercial catch data, Saila et al. (1997) calculated that one full year of cooling water intake operations at a coastal power generating station (Seabrook) resulted in losses equivalent to 3 days of typical landings for a single small inshore trawler targeting winter flounder. This analytical approach has become a standard practice in CWA §316(b) assessment under 40 CFR 122.21 (i.e., benefits valuation studies), and aligns with similar studies across species and locations. These studies have generally placed ecological- or population-level entrainment impacts in the context of other stressors on fish populations, such as environmental changes, overfishing, habitat degradation, pollution, and invasive species (Turnpenny 1988; Turnpenny and Taylor 2000; Greenwood 2008; Barnthouse 2013). The magnitude of these impacts can vary based on site-specific factors, including proximity to spawning grounds and seasonal patterns of early life stage occurrence.

The New York Bight Final PEIS indicates no evidence that anticipated discharges or entrainment volumes and extent would impact benthic resources (BOEM 2024). BOEM concluded that entrainment impacts from offshore converter substations would remain mostly confined to the immediate area around the intake and would be localized and negligible, although long-term (BOEM 2024). This assessment aligns with project-specific evaluations; for example, in the Final Environmental Impact Statement (FEIS) for

Sunrise Wind, BOEM determined that impacts to finfish and invertebrate early life stages susceptible to entrainment at the Sunrise Wind offshore converter station are expected to be minor (BOEM 2023b). Project-specific siting, design, and environmental reviews aim to avoid substantial impacts to fish and invertebrate populations; these reviews could lead to mitigation measures that minimize potential adverse impacts.

5.3 Chlorination

Operators typically use a chlorination system with once-through cooling to minimize biofouling of internal components (e.g., pump caissons and the seawater system) in both onshore and offshore applications. Offshore converter stations often include an electrochlorination generator system that produces NaOCl at a concentration sufficient to function as a biocide, using seawater electrolysis generated from the seawater itself. Chlorinated seawater is continuously injected at a minimum concentration to avoid biofouling in the intake caisson and piping system upstream of the seawater lift pumps during operation; during nonoperational periods, a small stream of chlorinated seawater still flows to the pumps to inhibit biofouling. The chlorinated seawater flows through the cooling water system, including the heat exchangers, where it is consumed and reduced to concentrations below compliance thresholds at discharge. Continuous injection of seawater-generated NaOCl into the pump caisson results in negligible TRO, in this case, free chlorine and bromine, due to chlorides and bromides in seawater (EPA 2024a), at the outlet, with "little or no hypochlorite present in the effluent" (EPA 2024a) and no expected negative effect on the surrounding water column.

Operators optimize the electrochlorination system to maintain low TRO concentrations in discharge water. For Sunrise Wind and SouthCoast Wind, the Final and Draft NPDES Permits, respectively, specify average monthly and maximum daily TRO concentrations of 7.5 µg/L and 13 µg/L. These levels fall below the detection limits for TRO under 40 CFR Part 136; therefore, the permits include a "compliance level" for TRO at 30 µg/L to reflect the detection limit of 30 µg/L.

As a biocide, hypochlorite is toxic to fish and other marine organisms. At high concentrations, it may cause mortality in organisms entrained and directly exposed to chlorinated seawater within the CWIS (EPA 1976; Linden et al. 1980; Khalanski and Jenner 2012). From a compliance perspective, entrainment is assumed to cause 100% mortality (EPA 2001, 2014). Chlorination, combined with thermal stress and mechanical stress, contributes to actual entrainment mortality (EPA 2004). Researchers conducted laboratory experiments to determine the effects of chlorine treatment associated with cooling water intakes on entrained fish and found varying degrees of mortality depending on chlorine concentrations and life stages, with eggs being less susceptible to biocides than larvae (Lauer et al. 1974; Morgan and Carpenter 1978). Additional experiments with copepod species found that entrainment-related mortality results not only from biocide exposure, but also thermal stress and exposure duration (Ershath et al. 2019). Melton and Serviss (2000) found that longer exposure durations correlate with higher mortality rates, while shorter exposures result in lower mortality. Once discharged back to the ocean, the maximum allowable TRO of 13 µg/L (0.013 mg/L, or 13 parts per billion) falls far below harmful concentrations for marine organisms (Linden et al. 1980) and would dilute quickly upon mixing with ambient seawater at the discharge point.

5.4 Thermal Discharge

Thermal discharges can produce a broad range of biological and ecological effects, from no impact to behavioral changes, stress, mortality, habitat alteration, or community shifts, as described in Barnthouse and Coutant (2022). This range of impacts is generally limited to marine organisms in the immediate vicinity when water temperatures exceed species-specific acute or chronic thermal tolerance thresholds. Mobile organisms may be less susceptible to thermal effects because they can exhibit avoidance behaviors. Persistent changes in water temperature from the thermal discharges during a facility's operational life may result in highly localized effects.

Once-through cooling systems circulate water through a power generation facility or vessel to provide continuous heat exchange and cooling during operations. After seawater circulates through a cooling system, it is discharged and transfers the heat exchanged from a facility or vessel into the discharge (receiving) waterbody. Typically, the discharge waterbody also serves as the intake source waterbody, although at a different location or depth to prevent recirculation of heated discharge water. This creates a localized water temperature increase.

Permitted discharge temperatures from once-through cooling systems vary by facility type, but typically range from 14.4ºF to 21.6ºF (8ºC to 12ºC) above ambient seawater intake temperatures. Some systems raise temperatures by as much as 37.8ºF (21ºC) (Langford 2001; Madden et al. 2013). This temperature increase is known as the delta-T, or ΔT.

Permitted conditions associated with thermal discharge typically specify the maximum discharge temperature, as identified in the facility's NPDES Permit. The key permitting condition is the mixing zone, which, as described in Section 2.2 and the Ocean Discharge Criteria at §125.121(c), requires the thermal and spatial extent of discharged cooling water to be maintained within 1.8ºF (1ºC) of the weekly average ambient source water temperature within a 330 ft (100 m) radius of the discharge during all seasons (EPA 1986); see also Figure 2. The actual footprint, extent, and behavior of the thermal plume depend heavily on project- and location-specific factors, based on CORMIX modelling that incorporates both facility design parameters and site-specific environmental data collected by developers. Key model inputs include:

- For Sunrise Wind, the Final NPDES Permit sets a maximum allowable daily discharge temperature of 90ºF (32.2ºC) and an average monthly limit of 86ºF (30.0ºC). Modelling indicates that the resulting thermal plume is contained within an 87 ft (26.5 m) radius of the discharge caisson pipe, well within the allowable mixing zone of 330 ft (100 m), as Figure 26 shows (TRC 2021; EPA 2024a).
- For SouthCoast Wind, the Draft NPDES Permit includes a maximum allowable discharge temperature of 83.3ºF (28.5ºC). Modelling indicates that the thermal plume is contained within an 85 ft (25.9 m) radius of the discharge caisson and pipe, also well within the allowable mixing zone of 330 ft (100 m), as Figure 27 shows (Tetra Tech and Normandeau 2023; EPA 2024b).

Section 2.1 provides additional details comparing the Sunrise Wind Final and SouthCoast Wind Draft NPDES permits.

Figure 26. Maximum Thermal Plume Extent in Spring: Sunrise Wind

Profile (top) and plan (bottom) views show the maximum modeled thermal plume extent during spring, when metocean conditions produce the greatest spread. The red and black lines indicate the modelled 1.8ºF (1ºC) and 7.2ºF (4ºC) temperature change from ambient, respectively. The color ramp is for relative reference only, based on the original figure.

Source: TRC (2021).

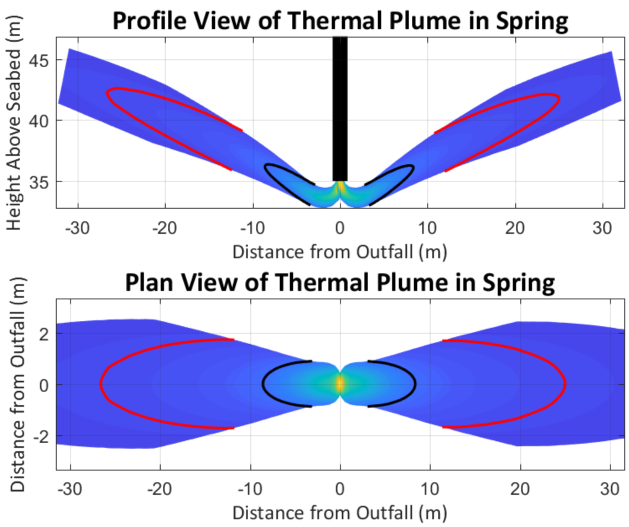
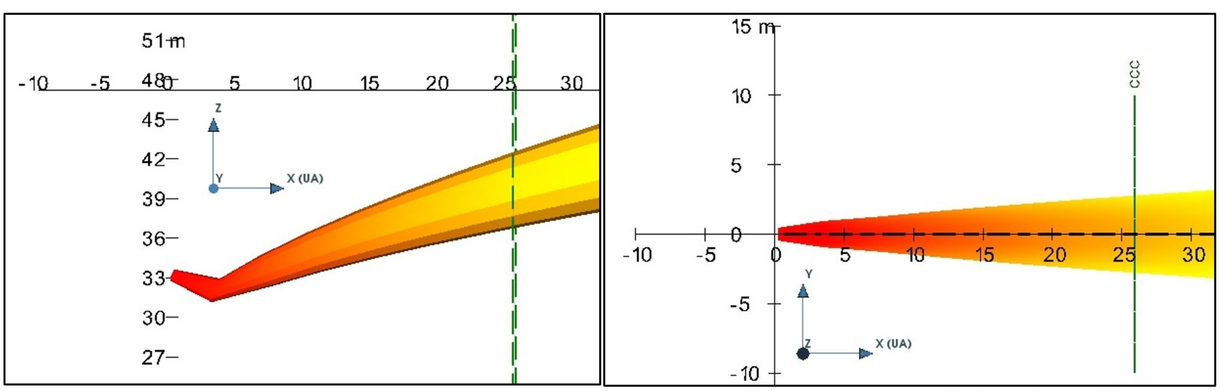


Figure 27. Maximum Thermal Plume Extent in Winter: SouthCoast Wind

Profile (top) and plan (bottom) views show the maximum modeled thermal plume extent (in meters) during winter, when metocean conditions produce the greatest spread. The color ramp is for relative reference only, based on the original figure.

Source: Tetra Tech and Normandeau (2023).



Some aquatic organisms rely heavily on specific environmental conditions and may be sensitive to changes in water temperatures. Thermal effluent can affect individual species, local populations, or aquatic ecosystems in various ways (Langford 2001; Madden et al. 2013). Understanding thermal plume extent and temperature decay is essential for assessing the potential ecological impacts (Langford 1990). Predicting the spatial extent and intensity of thermal plumes allows for impact mitigation through optimized discharge locations and depths, efficient mixing zone designs, or operational controls (Jirka 2004). Discharge structure design, including the outfall depth and configuration, plays a critical role in shaping initial plume characteristics and how they dissipate in the water column. For example, species more tolerant of warmer water temperatures may become dominant, while less tolerant species may shift away from a thermal plume. Thermal discharges can also act as one of multiple stressors that cumulatively affect marine species or local ecosystems.

The modelling analysis of thermal plumes from similar regional offshore wind projects (e.g., Sunrise Wind, SouthCoast Wind) shows that thermal plumes are contained within 87 ft (26.5 m) and 85 ft (25.9 m), respectively, with temperature increases limited to 1.8ºF (1ºC) above ambient ocean temperatures outside of these zones. Therefore, impacts on benthic organisms within the thermal plume are anticipated to be negligible (BOEM 2024). These impacts are 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.

The now-retired Brayton Point Station is a notable example of a large-scale coastal power plant. It discharged cooling water at volumes ranging from 915.8 to 1,452.5 MGD with discharge temperatures approaching 95ºF (35ºC) into shallow coastal waters of Mount Hope Bay, MA. From 1972 to 2000, extensive biological monitoring, including trawl surveys, ichthyoplankton surveys, and water quality monitoring, documented declines in fish populations, specifically winter flounder (Gibson 1996; EPA 2002; Barnthouse and Coutant 2022), as well as in marine organisms and habitats within Mount Hope Bay and Narragansett Bay (Barnthouse and Coutant). Researchers used thermal tolerance data for 17 representative important species (RIS), focusing on the most sensitive life stage of each species, to model critical temperatures. Thermal plume temperatures reached "avoidance" levels for subadult and adult striped bass, but not for other RIS. Some RIS, such as Atlantic menhaden (*Brevoortia tyrannus*), appeared attracted to the thermal discharge, which increased their impingement (Barnthouse and Coutant). Over years of permitting and litigation, the EPA concluded that Brayton Point Station's operations in Mount Hope Bay did not support a balanced indigenous community (see Section 2.2) due to reduced fish abundance and increased thermotolerant species (e.g., ctenophores, smallmouth flounder [*Etropus microstomus*]) (Barnthouse and Coutant).

In contrast, thermal discharges from offshore converter stations are expected to have minimal effects. Discharge water mixes with the ocean water, decreasing to within a 1ºC (1.8ºF) change from ambient temperature well within the permitted 330 ft (100 m) mixing zone, as demonstrated by Sunrise Wind and SouthCoast Wind (see Figures 26 and 27) (EPA 2024a, 2024b). Important distinctions between thermal discharges from offshore converter stations and coastal power generating stations, such as Brayton Point, include:

1. Significantly lower cooling water flows (1,399 MGD versus <10 MGD)
2. Discharge to the open ocean, which allows for rapid mixing compared to a confined embayment
3. Compliance with Ocean Discharge Criteria within a permitted mixing zone, without requiring a thermal variance request

Although thermal plumes may cause localized water quality changes near the discharge, the EPA's Ocean Discharge Criteria at §125.121(c) support the conclusion that overall effects on marine organisms will be negligible, with no degradation to water quality. The three-dimensional extent and residence time of thermal plumes depend on the discharge location within the water column, prevailing currents, temperatures, and discharge volume. These variables are detailed in the thermal modelling reports for Sunrise Wind and SouthCoast Wind, submitted as part of their respective NPDES permit applications (TRC 2021; Tetra Tech and Normandeau 2023).

5.5 Secondary Effects

Offshore converter stations, while primarily associated with entrainment and thermal impacts on ichthyoplankton, may also affect other planktonic marine species, including phytoplankton and zooplankton. Phytoplankton are microscopic photosynthetic organisms that account for approximately 50% of global primary production and form the base of most marine food webs, producing nearly all primary production in offshore marine environments (Field et al. 1998; Falkowski 2012). Zooplankton include microscopic animals, such as krill or copepods, as well as larvae of larger invertebrates. The following sections describe several potential indirect, or secondary, effects on these planktonic organisms that may result from offshore converter station operations.

5.5.1 Entrainment of Marine Mammal Prey Species

Zooplankton make up the foraging base of many higher trophic-level species. Copepods, such as *Calanus* spp. and *Psuedocalanus* spp., serve as important prey for marine mammals, including the endangered North Atlantic right whale (*Eubalaena glacialis*) within the New York Bight region. Because of this ecological importance, researchers have used copepods as model organisms to analyze potential impacts of entrainment in the context of cascading ecosystem effects, as demonstrated for other stressors such as fishing and climate change (Casini et al. 2008; Casini et al. 2009).

Similar to ichthyoplankton, copepods are vulnerable to entrainment due to their small size and limited swimming ability. In the New York Bight region, copepods, like other zooplankton, exhibit seasonal fluctuations in abundance based on phytoplankton and other nutrient availability (Head and Pepin 2010). Laboratory experiments have shown that entrainment associated with cooling water intakes typically causes copepod mortality due to both biocide exposure and thermal stress, which are influenced by duration of exposure (Ershath et al. 2019).

As previously mentioned, the EPA generally assumes 100% mortality of all early life stage organisms through a CWIS when site-specific verification studies are unavailable (EPA 2001; 2014). However, site-specific studies at various facilities have demonstrated that actual entrainment mortality can be substantially less than 100% for certain taxonomic groups and under certain operational parameters (e.g., discharge temperature, physical abrasion, chlorination levels), particularly for some marine planktonic crustaceans species (Bamber and Seaby 2004; EPA 2001, 2004, 2014; EPRI 2009). While individual facility studies at individual facilities can quantify site-specific mortality rates, the wide variation in species' tolerance to these stressors, differences among source water bodies and cooling water systems, and natural variability in population dynamics make broad extrapolation difficult. This is particularly true when considering the confounding effects of multiple entrainment stressors occurring simultaneously (EPRI 2005).

Researchers may estimate the potential effects of copepod entrainment on whales by referencing assessments conducted for other facilities using seawater cooling systems in the northeastern U.S. For example, the Environmental Assessment for the Northeast Gateway Offshore LNG Terminal Project in Massachusetts Bay included a bioenergetic model to evaluate the impacts of removing zooplankton and small fish on marine mammals, and whether cooling water system entrainment would remove biomass beyond natural variability and recovery rates (Kenney et al. 1985). Based on whale metabolism research, the estimated daily and annual prey consumption rates for an individual North Atlantic right whale are 518–774 kilograms per day (kg/day) and 46,587–69,985 kilograms per year (kg/yr) while present off the Massachusetts coast (Kenney et al. 1985; Trites and Pauly 1998; Northeast Gateway 2012).

The Northeast Gateway Project estimated that operations could potentially remove approximately 1,700 kg/yr of zooplankton and small fish (while using up to 56 MGD), a volume considered negligible relative to the prey requirements of individual whales and regional populations (Northeast Gateway 2012). Offshore converter stations, which typically operate with even smaller intake flows, would be expected to entrain proportionally lower numbers of prey species. However, the actual impact depends on site-specific factors such as local prey density, seasonal abundance patterns, and the spatial overlap between intake locations and critical feeding areas for marine mammals.

5.5.2 Algal Blooms and Cold Pool Nutrient Dynamics

No studies have evaluated whether the thermal discharge produced from offshore converter stations influences the occurrence and intensity of algal blooms in the marine environment. However, elevated water temperatures can enhance growth rates of certain phytoplankton species, potentially leading to algal blooms under similar conditions (Paerl and Huisman 2008). Such localized blooms may alter nutrient dynamics and light penetration. Several factors influence whether thermal discharges contribute to algal blooms, including the magnitude of temperature increase, nutrient availability, and hydrodynamic conditions (Wells et al. 2015).

Oceanographic processes such as nutrient upwelling, which moves deep, nutrient-rich water to the surface, typically result from wind patterns or ocean circulation (Di Lorenzo 2015). In the New York Bight and broader Mid-Atlantic Bight regions, a strong thermocline develops at approximately 66 ft (20 m) depth across the continental shelf, isolating a continuous mass of cold bottom water known as the Cold Pool (Kohut and Brodie 2019). The Cold Pool holds nutrients over the shelf during warmer months, but localized upwelling can transport Cold Pool water to inshore and surface waters, potentially driving large phytoplankton blooms and influencing fish distribution and behavior (Nye et al. 2009; Lentz 2017; Kohut and Brodie 2019; Horwitz et al. 2023). Localized warming from a converter station’s thermal plume might interact with the Cold Pool’s natural stratification depending on spatial overlap. This interaction may enhance nutrient availability in the upper layers of the water column near offshore converter stations, likely confined to the immediately discharge area, and may create favorable conditions for algal blooms. Site-specific studies would be needed to confirm the extent and nature of such interactions and potential impacts.

Rapid mixing and dilution of thermal discharge in open ocean environments, as demonstrated by CORMIX modelling, may mitigate these conditions by limiting the spatial extent and duration of elevated temperatures conducive to bloom formation. Site-specific assessments may be necessary to evaluate potential impacts of thermal discharges on algal blooms. Additionally, ocean modelling studies would improve understanding of offshore wind energy's effects, including converter station intake and discharge, on ocean mixing and seasonal stratification (Horwitz et al. 2023).

6 Best Technology Available

CWA §Section 316(b) directs the EPA to ensure that the location, design, construction, and capacity of cooling water intake structures reflect the BTA for minimizing adverse environmental impact. Onshore facilities use various technologies to minimize entrainment and impingement at intake structures or against screens during water intake. However, some of these technologies may not be feasible or available for uncrewed, offshore facilities. While the EPA has established guidelines and standards for determining BTA through various rulemakings, the owner or developer must conduct a site-specific analysis, particularly for offshore facilities, which face unique challenges not typically encountered onshore. The existence of a technology (e.g., air cooling, closed-cycle cooling) does not automatically imply that it is available for a specific facility.

The permitting agency authorized to implement the NPDES program typically makes the final determination of BTA for a specific facility. Developers must finalize cooling system technology selections well in advance of the Commercial Operations Date to ensure adequate time for engineering design and studies over the facility's lifespan (30-plus years). For facilities or industries not explicitly covered by existing regulations or rulemaking, the permitting authority may use site-specific BPJ to determine appropriate BTA requirements for each NPDES Permit associated with offshore wind converter stations. This section presents the various BTA options and rationale for each (Table 8), along with additional discussion of technologies considered potentially feasible for offshore converter stations.

Table 8. Technology, Operation, and Design Features Considered for Offshore Wind Offshore Converter Stations

Category	Technology, Operation, or Design Feature[a]	Anticipated Status at Offshore Wind Offshore Converter Stations	Fish Protection Potential[c]		Feasibility for Consideration (current or future applications)
			Impingement Mortality[b]	Entrainment	
Flow Reduction, from DIF	Single pump operation	Operations may include this	Maybe	Yes	Potentially feasible: Operators can achieve a flow reduction when they can safely operate using only one pump (assuming design is based on two pumps), with proportional entrainment reductions expected. However, this is a site-specific design parameter that determines whether facilities can implement this option.
	Closed-cycle recirculating cooling (closed-loop): cooling towers	Design does not include this	Maybe	Yes	Not feasible: Engineers have not yet developed commercially viable closed-cycle cooling designs for uncrewed offshore applications, and current evaluations find them commercially infeasible for offshore wind converter stations. Unlike oil and gas platforms, designers expect offshore converter stations to operate as uncrewed facilities. Given the high cooling loads and the critical nature of the reliability of a CWIS for uncrewed operations, engineers have not made closed-cycle cooling systems (cooling towers) available for this type of offshore facility, based on existing supplier and engineering capabilities for HVDC converter stations of this type (Middleton and Barnhart 2022). Closed-cycle systems also require additional cooling tower equipment. Engineers must consider space and weight constraints on an offshore converter station, which already must accommodate electrical substation and converter station equipment, as well as meet safety and operability requirements. These challenges are particularly acute at an uncrewed facility. As an uncrewed facility, an offshore converter station generally lacks the infrastructure to support a closed-cycle recirculating cooling water system (e.g., cooling towers), and supplies currently offer limited or no market-available technology for uncrewed offshore converter stations. As discussed in the New York Bight Final PEIS, closed-cycle (closed-loop) cooling remains an emerging technology for offshore converter station applications (BOEM 2024).

Table 8. (continued)

Category	Technology, Operation, or Design Feature[a]	Anticipated Status at Offshore Wind Offshore Converter Stations	Fish Protection Potential[c]		Feasibility for Consideration (current or future applications)
			Impingement Mortality[b]	Entrainment	
Flow Reduction, from design intake flow (DIF)	Closed-cycle recirculating cooling (closed-loop): air cooling	Design may include this	Yes	Yes	Potentially feasible: Engineers can implement air-cooling systems on offshore converter stations, but these systems require further testing and depend on several site-specific design factors, including substantial platform size, customization of standardized contractor designs, equipment placement, and exposure to the marine environment. The marine atmosphere may cause unacceptable failure rates for equipment and necessitate frequent component replacement. Air cooling may only be feasible on crewed platforms. However, most currently proposed U.S. projects involve uncrewed platforms only (DNV 2021). As discussed in the New York Bight Final PEIS, air cooling is considered an emerging technology for offshore converter station applications. Some developers may choose to evaluate the feasibility of this option further, depending on project-specific engineering constraints (Middleton and Barnhart 2022; BOEM 2024).
	Closed-cycle recirculating cooling (closed-loop): Subsea coolers[d]	Design not expected to include this	Yes	Yes	Potentially feasible, with additional design and testing: Suppliers have not made subsea heat exchangers available for uncrewed offshore facilities, based on current engineering capabilities for HVDC converter stations of this type. Subsea heat exchange systems are typically located directly on the seafloor, which would create space conflicts with interarray cables and submarine export cables approaching an offshore converter station. These systems would also require a separate vessel work area for installation and decommissioning. Engineers have not designed standard offshore converter stations to accommodate subsea heat exchangers, and the market currently does not offer this technology for uncrewed offshore facilities (Middleton and Barnhart 2022). As discussed in the New York Bight Final PEIS, subsea coolers are considered an emerging technology for offshore converter station applications (BOEM 2024).

Table 8. (continued)

Category	Technology, Operation, or Design Feature[a]	Anticipated Status at Offshore Wind Offshore Converter Stations	Fish Protection Potential[c]		Feasibility for Consideration (current or future applications)
			Impingement Mortality[b]	Entrainment	
Flow Reduction, from DIF	Seawater lift pumps with VFDs	Design may include this	Maybe	Yes	Potentially feasible: Operators can use VFDs to regulate the volume and rate of water withdrawn from circulating pumps to optimize minimum flows needed to meet cooling needs. This approach can reduce entrainment proportionally, compared to the design flow. However, not all facilities include VFDs in their design, so engineers must incorporate them early in project planning. Regulators selected VFD operation at 0.5 ft/s as the BTA for the Sunrise Wind Final NPDES Permit and the SouthCoast Wind Draft NPDES Permit.
	The use of fresh water or grey water for cooling	Design not expected to include this	Maybe	Yes	Not feasible: Operators cannot access an adequate supply of fresh or grey water in open ocean environments, making this option infeasible for offshore converter station cooling needs.
	Scheduled outages during periods of peak impingement mortality and entrainment	Operations not expected to include this	Maybe	Yes	Not feasible: Operators do not anticipate implementing seasonal outages as part of offshore converter station operations.
Physical Barriers	Depth of withdrawal (intake caisson depth)	Design may include this	Maybe	Yes	Potentially feasible: Engineers can configure intake and discharge locations in the water column to mitigate adverse environmental impacts from both water withdrawal and discharge. By positioning the intake structure vertically in the water column, operators can maximize CWIS thermal efficiency, reduce overall cooling needs, and minimize impacts on entrainment and sensitive benthic habitats.

Table 8. (continued)

Category	Technology, Operation, or Design Feature[a]	Anticipated Status at Offshore Wind Offshore Converter Stations	Fish Protection Potential[c]		Feasibility for Consideration (current or future applications)
			Impingement Mortality[b]	Entrainment	
Physical Barriers	Barrier net/marine life exclusion system	Design not expected to include this	Yes	Yes	Not feasible: Engineers use barrier nets, multi-filament nylon mesh barriers that span CWIS openings, to exclude debris, fish, and other aquatic organisms from the intake. The effectiveness of these nets depends on the hydraulic conditions of the intake, size, target species, and debris load. Although operators have used barrier nets effectively at onshore CWIS during peak impingement events (EPRI 2012), they require labor-intensive debris and biofouling control, which makes them impractical for uncrewed offshore facilities. Operators would also face challenges managing entanglement risks. This technology is not proven for open ocean settings.
Behavioral Barriers	Velocity cap intake	Design not expected to include this	Yes	No	Not feasible: Engineers use velocity caps, physical structures with horizontal openings fitted over the top of vertical-facing water intakes located on the bottom of a water body, to convert vertical flow to horizontal, which can trigger avoidance responses in fish (EPRI 2004b). While this method can reduce impingement, it does reduce the entrainment of smaller, passive organisms. Current applications are limited to onshore coastal facilities. At offshore converter stations, platform structures surrounding the intake would obstruct ambient water flow, limiting the cap's effectiveness. Designers meet impingement mortality compliance standards by incorporating a low intake velocity of 0.5 ft/s.

Table 8. (Continued)

Category	Technology, Operation, or Design Feature[a]	Anticipated Status at Offshore Wind Offshore Converter Stations	Fish Protection Potential[c]		Feasibility for Consideration (current or future applications)
			Impingement Mortality[b]	Entrainment	
Behavioral Barriers	Strobe light, acoustic deterrents, air bubble curtains (only effective for certain target species)	Design not expected to include this	Maybe	No	Not feasible: Operators use light and sound barriers to trigger behavioral responses in aquatic organisms, either repelling them from intakes or attracting them toward a bypass. Although these technologies have shown some effectiveness for reducing impingement (EPRI 2006), they do not reduce entrainment mortality for smaller, passive organisms. Their effectiveness is limited to certain target species, and operators generally pair light and sound barriers with other impingement reduction technologies. These barriers have seen limited applications and are unproven in open ocean environments. Air bubble curtain systems aim to elicit avoidance responses in fish by pumping air through a diffuser, creating a continuous, dense curtain of bubbles. These curtains deter fish through a combination of visual, sound, and tactile effects. Evaluations of air bubble curtains at onshore power generation facilities and hydropower turbine inlets have shown limited success in diverting fish from CWIS. Their effectiveness is highly species-specific and depends on ambient conditions such as water velocity, turbidity, and lighting. Air bubble curtains have shown limited success in deterring fish from CWIS and require regular maintenance to control biofouling, which is impractical at an uncrewed offshore location.

Table 8. (continued)

Category	Technology, Operation, or Design Feature[a]	Anticipated Status at Offshore Wind Offshore Converter Stations	Fish Protection Potential[c]		Feasibility for Consideration (current or future applications)
			Impingement Mortality[b]	Entrainment	
Collection/ Diversion Systems	Modified traveling water screens (TWS) with standard mesh, slot mesh, or fine mesh, including Ristroph features (e.g., buckets, fish return)	Not expected to be part of the design	Yes	Maybe	Not feasible: TWSs exclude debris and organisms from cooling water systems. Typically, they are installed in screen arrays downstream of the CWIS intake opening, following a set of bar racks that remove larger debris. TWSs consist of either coarse or fine mesh screen panels equipped with collection baskets that rotate vertically to collect impinged debris and organisms. Operators alternate coarse-mesh screens within an array to avoid debris loading. Fine-mesh screens operate continuously during the seasonal impingement duration. The system collects impinged material in baskets and removes it using a spray wash system, which directs it to a sluice system that diverts it either back to the waterbody or to a debris collection area. Fish-friendly TWS designs incorporate features to reduce organism mortality, including smooth surface meshes, collection bucket flow spoilers, low-pressure spray wash, and fish return systems. When combined with water-velocity-reducing systems, they effectively reduce impingement mortality. However, TWSs are not feasible for offshore uncrewed substations. Engineering constraints, such as the need for frequent maintenance due to biofouling and lack of an intake bay structure, make installing TWSs at offshore converter stations impractical. Offshore converter station configurations do not support traveling screens. Furthermore, the anticipated low intake velocity of 0.5 ft/s meets impingement mortality compliance standards.

Table 8. (continued)

Category	Technology, Operation, or Design Feature[a]	Anticipated Status at Offshore Wind Offshore Converter Stations	Fish Protection Potential[c]		Feasibility for Consideration (current or future applications)
			Impingement Mortality[b]	Entrainment	
	Cylindrical wedge wire screens	Design not expected to include this	Yes	Yes	Not feasible: Cylindrical wedge wire screens use wires with a "V" or wedge-shaped cross-section secured in parallel to a frame. Installed perpendicular to the water body, they operate passively under low screen velocity intake conditions and rely on crosscurrents to slough off impinged material. These screens require routine maintenance to prevent biofouling and may integrate air burst or mechanical brush systems. This technology is likely infeasible for offshore uncrewed substations. It has seen limited use in marine environments, mainly at onshore/coastal facilities in the Lower Hudson River with slot widths of 0.75 to 2 mm. It remains unproven for open ocean, uncrewed settings. Engineering challenges, biofouling concerns, and maintenance needs make installation impractical. Offshore converter station platform configurations also inhibit ambient water flow, further limiting the practicality of cylindrical wedge wire screens. Installing these screens at the bottom of a pump caisson introduces additional engineering challenges. Biofouling would pose a substantial maintenance burden that cannot be addressed at an uncrewed facility. Wedge wire screens have only seen limited use in freshwater environments and none at an uncrewed facility. The technology is unproven for offshore platforms, with engineering constraints, biofouling, and maintenance as primary concerns (EPRI 2012).

[a] Presentation of technology or operational measure does not imply that a particular technology or operational measure will be implemented at an offshore converter station facility.

[b] "Maybe" refers to the potential for reducing impingement mortality or entrainment under certain conditions.

[c] Status indicates whether the technology in question offers protection or mitigation strategy for impingement or entrainment.

[d] Includes passive non-contact cooling via "subsea cooler," which has been considered but is not currently commercially or technically viable. No full-scale systems with similar service are in operation. Technology qualification for this alternative system would need to be carried out, including testing and ensuring that accepted engineering standards are met. The replacement and retrieval method of subsea cooler modules is still immature, and the current supply chain is not sufficiently developed.

The importance of site-specific BTA analysis is well-demonstrated in recent NEPA alternatives analyses for offshore wind projects. The NEPA process requires federal agencies to evaluate reasonable alternatives to proposed actions. For offshore wind, recent NEPA analyses specifically evaluated alternative cooling technologies for offshore converter stations. For example, the Sunrise Wind Farm FEIS (BOEM 2023b) provides a detailed description of how theoretical cooling alternatives were evaluated against practical constraints of offshore implementation, validating many of the feasibility considerations presented in Table 8.

The FEIS evaluation examined several alternatives, including air cooling systems that, while offering the benefit of eliminating seawater intake impacts, were determined to be technically infeasible due to ambient air temperature constraints at the project location. The analysis also evaluated closed-loop cooling systems that, although technically feasible in some applications, revealed significant implementation challenges. These challenges would reduce energy efficiency, require larger topside and support structures, and substantially increase both capital and operational costs.

The evaluation also considered emerging technologies such as subsea-mounted coolers, but found them technically infeasible due to their experimental nature and lack of proven commercial-scale implementation. Determining BTA for offshore converter stations must balance the theoretical availability of cooling technologies against site-specific technical, operational, and economic constraints. This NEPA alternatives analysis provides documented justification for why certain technologies, despite their potential environmental benefits, may not constitute BTA for specific offshore applications at their current stages of project-level development and implementation.

6.1 Flow Reduction

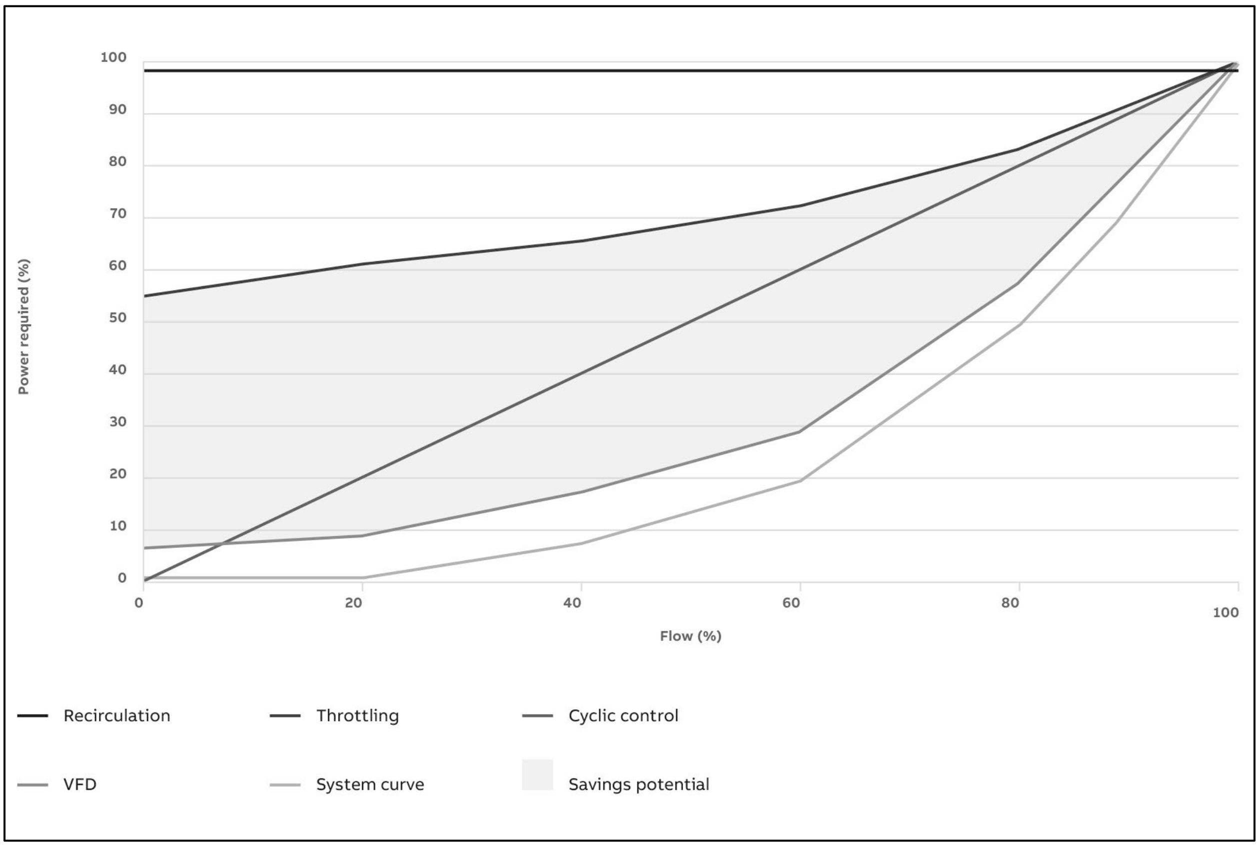
Flow reduction results in a proportional reduction of entrainment for once-through cooling water (EPA 2014). Simply operating a single pump, instead of two, reduces flow by 50% from the design intake flow. A more advanced method of flow reduction and optimization uses variable frequency drives (VFDs) on seawater pump motors (Figure 28). VFDs regulate pump motors and control the volume and rate of water being withdrawn from circulating pumps. This enables a facility to tailor flow operations to maximize water use efficiency while meeting cooling needs. VFDs manage intake flow to match cooling demand, which can fluctuate due to seasonal changes in water temperature and electrical demand.

Reducing flow volume can effectively minimize impingement and entrainment mortality and reduce costs associated with operating circulating water pumps at full capacity. Configuring VFD systems into the intake structure design at offshore converter stations may be an effective option for reducing impingement and entrainment mortality.

Operating VFDs to maintain a through-screen velocity of less than 0.5 ft/s complies with §316(b) low intake velocity impingement BTA standards and has been routinely selected and approved at many U.S. facilities. Regulators selected operation VFDs to optimize minimum flow volumes and maintain intake velocities of 0.5 ft/s or less as part of the BTA determination for the Sunrise Wind Final NPDES Permit and the SouthCoast Wind Draft NPDES Permit.

Figure 28. Representative Flow Reductions Achieved Using a Variable Frequency Drive Compared to Other Methods

Source: ABB (2025).



6.2 Closed-Cycle (Closed-Loop) Cooling

Closed-cycle (or closed-loop) cooling options typically range from cooling towers to air cooling technologies, which have been used for many decades at onshore power-generating or industrial facilities. However, engineering limitations and space constraints have largely prevented their adoption at offshore facilities. While cooling towers will likely never become feasible for once-through cooling at offshore facilities, emerging technologies such as subsea coolers and air cooling may offer viable options in the future as design considerations and engineering advances.

6.2.1 Cooling Towers

Evaporative closed-cycle cooling systems, or wet cooling towers, dissipate waste heat generated from a facility's heat exchange process through latent (evaporative) heat transfer by exposing spent cooling water to ambient air. This process enables cooling water to be recycled several times. Depending on site-specific characterization and design specifications, wet cooling towers can reduce the volume of cooling water by as much as 97% compared to conventional once-through systems (Tetra Tech 2008).

The efficiency of wet cooling towers depends on the temperature differential between cooling water and atmospheric temperature, as well as relative humidity, which determines the saturation level of the surrounding atmosphere. Combined atmospheric temperature and relative humidity are measured as the "wet-bulb" temperature. Environments with low temperature and relative humidity can more effectively accommodate evaporative heat loss.

Due to the evaporative process and build-up of dissolved solids, cooling towers require a portion of the water, known as blowdown, to be discharged. This results in heated effluent discharge and creates a demand for additional cooling water to replace the discharged water.

Wet cooling towers are not feasible on uncrewed offshore converter stations. Installing a large cooling tower would require a substantial amount of additional space and weight-bearing capability, which uncrewed substations are not equipped to support (Middleton and Barnhart 2022), which Figures 29 through 31 illustrate.

Figure 29. Natural Draft Cooling Towers at Brayton Point Station, 2011–2019

Source: SCI Engineering (2025).

Figure 30. Mechanical Draft Cooling Towers: Operating Diagram

Source: Sharif and Eslayem (2022).

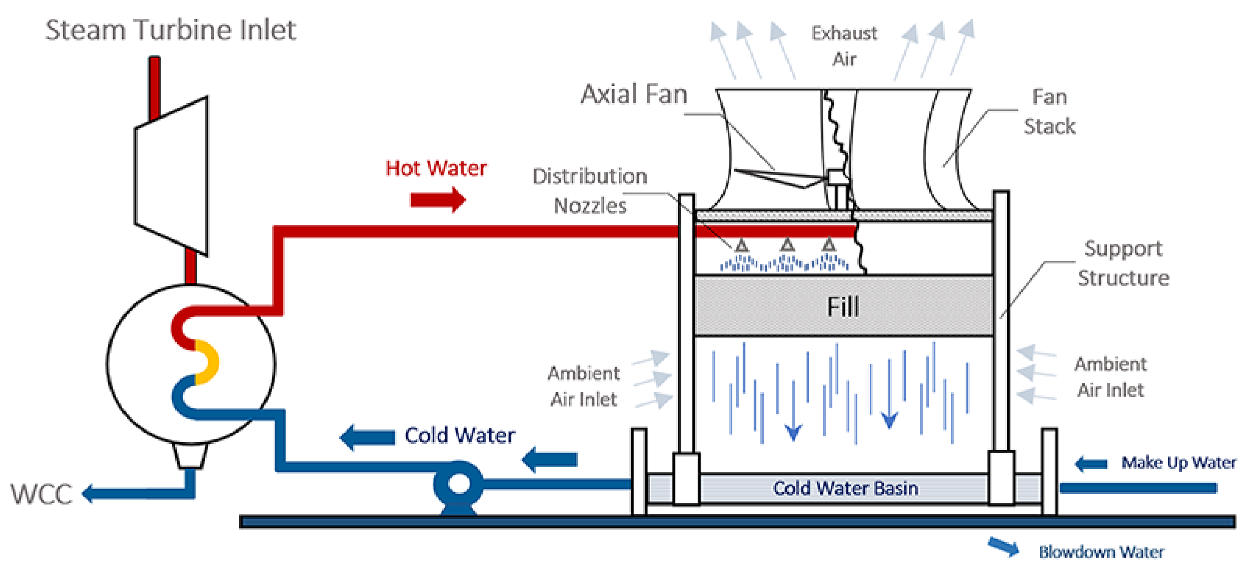


Figure 31. Mechanical Draft Cooling Tower

Source: Tetra Tech (n.d.e.).

6.2.2 Subsea Coolers

Subsea coolers (heat exchangers) are closed-loop systems that dissipate heat from spent cooling water by circulating heated water through pipes exposed to cooler ambient seawater (Figure 32). These systems are mounted on the ocean floor, using deeper water to maximize cooling potential. A circulation pump regulates the flow of cooling water to maintain an ideal target temperature range. The system design is relatively simple and requires minimal power, which substantially reduces cooling water needs. However, biofouling of the exposed surfaces creates an artificial hard-bottom habitat and reduces heat exchange efficiency over time. Maintaining these systems requires periodic cleaning by remotely operated vehicles or divers to sustain optimal performance, which could present challenges at uncrewed facilities.

Figure 32. Subsea Cooler: Development and Testing

Source: Bronswerk (2025).

Recent technological advancements in subsea cooling systems have emerged through European Union initiatives. Between 2019 and 2023, a Norwegian company, Future Technology, developed the Future Subsea Controllable Cooler (FSCC), a passive closed-loop subsea cooler technology currently qualified and ready for deployment offshore in limited applications. This technology was optimized to meet requirements for the BorWin5 and BorWin6 converter stations, incorporating advanced computational fluid dynamics into the design. The company also presented this system to U.S. developers as an engineering consideration for alternatives to once-through cooling.

Similar deployments have been tested for cooling underwater data centers, such as Microsoft's Project Natick, deployed for 2 years off the coast of Scotland in 117 ft (36 m) of water during a test phase (Figure 33; Microsoft 2018). Project Natick's equipment was fully contained within an approximately 40-ft-long cylindrical module, using a semipassive heat-exchange process with rapid mixing into the surrounding seawater (Microsoft). Data centers use a substantial amount of power—240 kilowatt (kW) for Project Natick—and require substantial cooling capacity; in some cases, CWIS from retired power generating facilities have been converted and repurposed to cool new data centers, with up to 300 MW allocated to the data center itself (Long Ridge Energy 2020). Advances in technology from data center projects may inform future applications for offshore converter stations.

Figure 33. Project Natick: Subsea Data Center

Microsoft's semipassive cooling subsea data center is being tested off the coast of Scotland.

Source: Microsoft (2018).

At the current state of development, subsea heat exchangers are not technically or economically feasible for uncrewed offshore converter stations. On oil and gas platforms, these systems are typically much larger than the systems they are cooling to effectively dissipate heat. The location of subsea heat exchangers on the seafloor would likely overlap with interarray and submarine export cables, which could create conflicts with benthic habitat and introduce additional thermal discharge consideration at the seafloor. Though this technology is not yet market-ready for uncrewed offshore converter stations (Middleton and Barnhart 2022), research and development projects are in progress to support future implementation (European Commission 2020).

6.2.3 Air Cooling

Air cooling systems are direct dry cooling systems that dissipate heat through sensible (convection and radiation) heat transfer. This eliminates the need for a continuous cooling water supply and mitigates many environmental impacts associated with once-through cooling and wet cooling towers.

Air cooling systems operate similarly to a car radiator, feeding the exhaust steam to a condenser made of a fin tube array. Electric-powered fan arrays located below the condenser draw cooler air past the fin tubes, cooling the heat transfer medium. Figures 34 and 35 show a schematic representation and example configuration of air cooling systems.

Figure 34. Air Cooler: Operating Diagram

Source: EvapCo (2025).

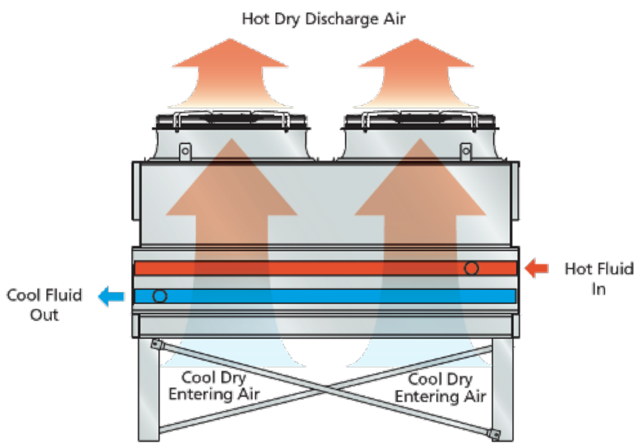


Figure 35. Air Cooling Fan Array

Source: EvapCo (2019).

Air cooling is part of the design for the TenneT 2GW Program, which includes large offshore converter stations with 2,000 MW capacity, more than double that of any of the largest currently operational offshore converter station platforms, with a significantly larger footprint. Air cooling for the TenneT 2GW Program offshore converter stations is facilitated via natural ventilation in the transformer rooms and large outside radiators (TenneT 2024b).

Once-through cooling is expected to continue for smaller (400–900 MW) Type B uncrewed platforms, while air cooling is becoming a feasible option for larger (~2,000 MW) Type A crewed platforms, such as the TenneT 2GW Program offshore converter station facilities, under DNV Offshore Substation Standards (DNV 2021).

Since 2020, offshore converter station platforms proposed in Germany must use closed-cycle (closed-loop) or air cooling as the regulatory standard, with exceptions allowable through variance requests (German Federal Maritime and Hydrographic Agency 2020, 2023).

While U.S. offshore converter station platforms have initially been designed as Type B uncrewed platforms ranging from 400 to 1,200 MW, using once-through cooling in the range of 5–10 MGD for BTA cooling requirements, some developers are considering air cooling alternatives. Future EPA rulemaking for CWA §316(b) or §316(a) compliance may include specific requirements, technologies, or performance standards tailored to the offshore wind industry, as seen in other cooling water applications.

In Europe, air-cooling systems are commercially available for larger partially crewed (up to 50 workers) offshore converter stations. TenneT plans to implement these systems within its offshore grid connection system in the Dutch and German North Sea (TenneT 2024b). While these systems may theoretically be implemented for uncrewed U.S. converter stations, current standardized designs for larger partially crewed stations would require significant customization and cost increases to adapt them for smaller uncrewed stations, under DNV standards (DNV 2021).

6.3 Depth of Withdrawal

Strategic configuration of the intake and discharge locations in the water column can mitigate adverse environmental impacts from both water withdrawal and discharge. Designers can position intake structures in the water column to maximize CWIS thermal efficiency, reducing cooling water needs, while minimizing thermal discharge impacts to sensitive benthic habitats.

Selecting intake depths also reduces impingement and entrainment mortality at offshore converter stations. EPA Region 1 has indicated that ichthyoplankton entrainment impacts in the open ocean can be minimized by optimizing withdrawal depth in the lower portion of the water column (EPA 2024a). For example, in the Sunrise Wind NPDES Permit, the EPA noted that larval fish density was substantially lower between 98 and 164 ft (30 and 50 m) depth, compared to surface levels, with densities approaching zero below 197 ft (60 m) depth (EPA 2024a).

Offshore stations in deep waters have the flexibility to select intake depths within less biologically productive areas while leveraging the deeper, cooler water temperatures found at depth. Based on these factors, agencies selected optimized intake and discharge depth as part of the BTA determinations in both the Sunrise Wind Final and SouthCoast Wind Draft NPDES Permits.

While deeper positioning offers advantages for both cooling efficiency and environmental protection, designers must consider important engineering and operational constraints. The intake must be positioned sufficiently above the seafloor to prevent sediment entrainment, which can damage pumps and reduce the system's operational longevity. Accounting for these constraints, the EPA selected optimized intake and discharge depths as part of the BTA determinations in both the Sunrise Wind Final and SouthCoast Wind Draft NPDES Permits (EPA 2024a, 2024b).

7 Mitigation and Monitoring

Some of the above BTA options already serve as mitigation measures. However, offshore converter station facilities must also demonstrate performance based on modelled thermal and entrainment estimates, with monitoring during operations to ensure compliance with §316(a), §316(b), and other regulations. The initial NPDES Permit for each facility, and each renewal within an anticipated 5-year cycle, will include monitoring requirements as a compliance measure.

The EPA is expected to coordinate with BOEM, NOAA NMFS, and other stakeholders during the NPDES permit review and development process. This coordination will inform resulting mitigation and monitoring requirements, where applicable. At a minimum, facilities are expected to conduct seasonal biological and water quality monitoring every quarter within the HZI (or as close as safely possible), starting in the first year of full-scale operation.

While some monitoring requirements may decrease after the initial 4 years of monitoring, depending on results, extended monitoring periods may be warranted for species with cyclical spawning patterns or large year classes that occur at intervals exceeding the initial monitoring period. This approach ensures that monitoring captures the natural variability in recruitment patterns and population dynamics of affected species.

Table 9 lists the monitoring measures included in the Sunrise Wind Final and SouthCoast Wind Draft NPDES Permits, which are likely to apply to similar converter station facilities based on location-specific considerations.

Table 9. Anticipated National Pollutant Discharge Elimination System Mitigation and Monitoring Requirements for Offshore Converter Stations

Based on permit conditions from Sunrise Wind (Final) and SouthCoast Wind (Draft).

Source: BOEM (2024); EPA (2024a, 2024b).

Risk/Impact	Data/Modelling Inputs	Anticipated or Required Avoidance/Minimization/Mitigation Options	Anticipated Monitoring Requirements for Compliance with NPDES Permit
HZI	Calculate the HZI radius surrounding the intake caisson and pipe.	• Site the intake to avoid or minimize the extent of the HZI, particularly within complex habitats, spawning locations, or other features.	• None.
Impingement	Calculate anticipated intake velocity based on intake parameters	• While several compliance options exist for impingement BTA (EPA 2014), design most facilities to meet the through-screen intake velocity of 0.5 ft/s or less. If applicable, operate the facility to maintain a maximum intake velocity of 0.5 ft/s to comply with impingement mortality standards. • Install a screen or other device at the intake opening with a maximum spacing ranging from 5.0 to 7.1 in. as part of the BTA to minimize impingement and reduce the likelihood of marine organism entrapment.	• Calculate and verify actual through-screen intake velocity during operations.

Table 9. (continued)

Risk/Impact	Data/Modelling Inputs	Anticipated or Required Avoidance/Minimization/Mitigation Options	Anticipated Monitoring Requirements for Compliance with NPDES Permit
Entrainment	Calculate entrainment densities based on MARMAP/EcoMon data	• Consider the depth of the intake withdrawal (intake caisson depth within the lower portion of the water column, where larval densities are lowest) as part of the design to potentially reduce entrainment. • Position the intake caisson as low in the water column as possible, without impacting benthic habitats, to substantially minimize the intake of floating debris or entrainable buoyant eggs/larvae from entering the CWIS, compared to a surface withdrawal, since the eggs of most offshore species are buoyant (Sundby and Kristiansen 2015; EPA 2024a). • Consider flow reductions from the DIF when cooling demands are minimized, through VFDs on the seawater pump motors, or equivalent. • Optimize the depth of withdrawal due to colder, more consistent water temperatures in the lower portion of the water column, compared to the surface, which requires less water demand for cooling. • Consider and evaluate emerging technologies, such as closed-cycle cooling (e.g., air cooling, closed-loop subsea cooler) as they advance for deployment on the type of offshore converter station platform proposed.	• Conduct seasonal ichthyoplankton sampling (anticipated to be collected via plankton net tows, Tucker Trawl, or similar), coordinated with other fish and benthic monitoring requirements for the overall project. • Determine sampling locations, depths, timing, and frequency on a site-specific basis to characterize the intake and discharge, using standard ichthyoplankton lab methods to enumerate and identify fish eggs and larvae to the lowest practical taxon and life stage. • Use data to calculate site-specific entrainment densities (annual and seasonal) during project operations. • Calculate entrainment estimates based on densities of sampled ichthyoplankton. • Conduct species-specific sampling for certain species of concern (e.g., Atlantic cod) based on stock status, EFH designations, fishery importance, and stakeholder input during the permitting process.
Chlorination	Parameters related to the electrochlorination system, including NaOCl concentration	• Maintain average monthly and maximum daily discharge concentrations of TRO at 7.5 µg/L and 13 µg/L, respectively, with a compliance level for TRO at 30 µg/L, acknowledging detection limits. • Optimize the depth of withdrawal to access colder, more consistent water temperatures in the lower portion of the water column, compared to the surface, thereby reducing water demand for cooling and minimizing the demand for biocide (sodium hypochlorite) injection.	• Directly measure residual chlorine (as TRO) using either an inline meter or laboratory analysis of grab samples.

Table 9. (continued)

Risk/Impact	Data/Modelling Inputs	Anticipated or Required Avoidance/Minimization/Mitigation Options	Anticipated Monitoring Requirements for Compliance with NPDES Permit

Thermal Discharge	CORMIX modelling (or similar) to predict the size and extent of the thermal plume from discharge during each season	• Maintain the cooling water discharge temperature within a maximum daily and average monthly value (to be determined on a site-specific basis).
		• Ensure the thermal plume dissipates within a mixing zone, a radius of 330 ft (100 m), such that the average monthly water temperature at the edge of the zone is within 1.8ºF (1.0ºC) of the ambient ocean temperature.
		• Optimize the depth and location of the discharge caisson and pipe to prevent heated discharge water from recirculating through the intake.
			• Conduct seasonal thermal and water quality monitoring during project operations to verify thermal model assumptions and document the extent of the thermal plume. Requirements are detailed in study design. Attachment A to the Final Permit.
			• Determine sampling locations, depths, timing, and frequency will be determined on a site-specific basis to characterize the discharge, with expected parameters to include:
			  • Temperature
			  • Salinity
			  • Dissolved Oxygen
			  • Current direction, using acoustic doppler current profiler

Other Risks and Impacts Not Yet Identified	EPA determined that the Phase I, II, or III §316(b) Rules do not specifically apply to these types of offshore converter station facilities or source (with definitions of “facility” debated within the narrative). Because the existing rules did not consider offshore wind energy facilities, EPA concluded that no current rulemaking applies. Instead, EPA will implement §316(b), using BPJ on a case-by-case basis. This approach may result in future mitigation or monitoring requirements, which EPA is expected to evaluate during each NPDES permit cycle.		

8 Future Considerations

As the demand for offshore wind development grows to meet federal and state clean energy goals, particularly in the New York Bight region, the need for efficient energy transmission will also increase. Offshore converter stations use HVDC technology to convert AC generated by wind turbine generators into DC for efficient long-distance transmission. A cooling water system manages heat generated during the AC-to-DC conversion process, using noncontact seawater in a once-through cooling system to remove excess heat.

The regulatory framework for once-through cooling water at offshore converter stations continues to evolve, particularly regarding various sections of the CWA, including §316(a), §316(b), Ocean Discharge Criteria under Section §403(a), under EPA oversight. The converter station's cooling system must comply with these regulations to minimize thermal impacts and adverse environmental impacts (i.e., impingement and entrainment of aquatic organisms). However, because offshore wind energy facilities were not considered in earlier rulemakings, they require site-specific regulatory consideration. EPA currently applies these regulations on a case-by-case basis using BPJ determinations to inform §316(b) BTA decisions. This approach is consistent with previous EPA determinations for other offshore energy facilities. As more offshore converter stations receive permits and generate operational data, future regulatory guidance may emerge.

Future site-specific biological monitoring programs will help better characterize offshore biological communities more accurately, particularly for species with cyclical spawning patterns or large year classes that short-term studies may not capture. Understanding seasonal and interannual variability in biological communities will require long-term monitoring. Analysis will combine existing datasets (e.g., MARMAP/EcoMon surveys) with new monitoring data to inform future impact assessments and permitting decisions.

BOEM evaluated cumulative impacts in the Final PEIS for the New York Bight (BOEM 2024), while EPA considers them during the individual NPDES permitting process (EPA 2024a, 2024b). Assessing cumulative effects will become increasingly important as more offshore converter stations are developed. This includes evaluating regional changes in cooling water use as coastal facilities transition to offshore wind interconnections, understanding potential interactions between thermal discharges and oceanographic features, and considering climate change effects on system performance and environmental impacts. BOEM and EPA will consider the cumulative effects of siting multiple cooling water intake structures as they evaluate future permits.

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Endnotes

[1] States with delegated authority typically have a NPDES-equivalent program, referred to as the State Pollutant Discharge Elimination System (SPDES) Program. Because offshore converter stations located in federal waters are the focus of this document, NPDES is used interchangeably and synonymously throughout and is not intended to supersede SPDES requirements of any particular state.

[2] §122.21: Permit Application and Special NPDES Program Requirements. Application for a permit: https://www.ecfr.gov/current/title-40/chapter-I/subchapter-D/part-122/subpart-B

§125.84: As an owner or operator of a new power generating facilities, what must I do to comply with this subpart? https://www.ecfr.gov/current/title-40/chapter-I/subchapter-D/part-125/subpart-I/section-125.84

§125.86: As an owner or operator of a new power generating facilities, what must I collect and submit when I apply for my new or reissued NPDES permit? https://www.ecfr.gov/current/title-40/chapter-I/subchapter-D/part-125/subpart-I/section-125.86

[3] Best technology available (BTA) is a regulatory term from §316(b) of the Clean Water Act, requiring that a facility use the best technology available to minimize adverse environmental impact. BTA applies to the location, design, construction, and capacity of cooling water intake structures. Importantly, the existence of a technology (e.g., air cooling, closed-cycle cooling) does not automatically imply that it is available for a specific facility. EPA currently uses site-specific best professional judgement (BPJ) to determine BTA for each NPDES permit associated with offshore wind converter stations.

[4] The most recent federal technology standards for cooling water intake structures are outlined in EPA's 2014 Final Rule (79 FR 48300). This rule establishes requirements for existing facilities under §316(b) of the Clean Water Act. It mandates that the location, design, construction, and capacity of CWIS reflect the BTA for minimizing adverse environmental impacts.

[5] Ravenswood is currently permitted to withdraw up to 1,527.8 MGD under water withdrawal permit (DEC 2-6304-0002400056). This reflects actual intake flow (AIF), rather than maximum design intake flow (DIF).

[6] This section focuses on cooling water volumes used by vessels, in comparison to offshore converter stations. However, other noncooling water uses by vessels can also be substantial in terms of the total volume of seawater used. For example, a typical hydraulic clam dredge vessel uses more than 2,000 gpm (equivalent to 2.8 MGD if operating continuously) of pressurized water to liquefy sediments and harvest clams within the seabed (Smolowitz and Nulk 1982; Gilkinson et al. 2003).

[7] "Fragile species" are defined at §125.90(m) as:

> …those species of fish and shellfish that are least likely to survive any form of impingement. For purposes of this subpart, fragile species are defined as those with an impingement survival rate of less than 30 percent, including but not limited to alewife, American shad, Atlantic herring, Atlantic long-finned squid, Atlantic menhaden, bay anchovy, blueback herring, bluefish, butterfish, gizzard shad, grey snapper, hickory shad, menhaden, rainbow smelt, round herring, and silver anchovy.

[8] EPA assumes 100% mortality of all early life stage organisms entrained through a CWIS, in the absence of site-specific verification studies (EPA 2001, 2014). However, as shown in site-specific studies at various facilities, actual entrainment mortality may be significantly lower for certain taxonomic groups and under certain operational parameters (e.g., discharge temperature, physical abrasion, chlorination levels). This is particularly true for some species of marine planktonic crustaceans (Bamber and Seaby 2004; EPA 2004; EPRI 2009).

Given the wide differences in response and tolerance to these stressors across taxa, and differences among source water bodies and cooling water systems, studying and broadly predicting how individuals of certain species may be impacted remains challenging, especially when considering confounding effects of entrainment stressors occurring simultaneously and within a discrete location (EPRI 2005).

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