OFFSHORE WIND SUBMARINE CABLING overview

Fisheries Technical Working Group

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Offshore Wind Submarine Cabling Overview

Fisheries Technical Working Group

Final Report

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Notice

Abstract

The number of submarine cables in the New York Bight is expected to increase as New York currently has three offshore wind projects with agreements to sell nearly 2,500 MW of power to the State towards the goal of 9,000 MW of offshore wind (OSW) generation by 2035. It is important that the installation and operation of submarine cables avoid, minimize, or mitigate potential impacts; both to the environment as well as to existing ocean users. Understanding the fundamentals of offshore wind submarine power cable types and construction methods are important in determining the potential impacts cables might have on the commercial fishing industry as well as how commercial fishing practices might impact the cables, once installed. The best and most effective manner to mitigate impacts to fishing interests is engagement with fishermen early in the planning process. Planning tools such as the Cable Burial Risk Assessment (CBRA) determine the recommended depth of lowering (DOL) by taking many factors into consideration, including regional fishing gear activity, type, and penetration depths. Mitigation measures to reduce impacts of fishing to cables may include cable armoring and burial for cable installed on the continental shelf. Reducing the impacts submarine cables may have on stakeholders and vice versa can be achieved by proper and diligent project planning and execution.

Keywords

OSW, submarine cabling activities, fisheries cable interactions, offshore wind cables

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Acronyms and Abbreviations

AC	alternating current
AIS	automatic identification system
ALARP	as low as is reasonably practicable
AWEA	American Wind Energy Association
BMH	beach manhole
BOEM	Bureau of Ocean Energy Management
BPI	burial protection index
BSEE	Bureau of Safety and Environmental Enforcement
CBRA	cable burial risk assessment
CLV	cable lay vessel
CMECS	Coastal and Marine Ecological Classification Standard
COP	Construction and Operations Plan
CPS	cable protection system
CPT	cone penetrometer test
DC	direct current
DOL	depth of lowering
DTS	distributed temperature sensing
DVS	distributed vibration sensing
ft	foot
GW	gigawatt
HDD	horizontal directional drilling
HVAC	high voltage alternating current
HVDC	high voltage direct current
IAC	inter array cable
ICPC	International Cable Protection Committee
KP	kilometer point
kPa	kilo pascals
kW	kilowatt
m	meter
MBES	multibeam echo sounder
MFE	mass flow excavator
MW	megawatt
NASCA	North American Submarine Cable owners Association
NID	nature inclusive designs
OOS	out of service
OSP	offshore substation platform
OSW	offshore wind
PLGR	pre-lay grapnel run
POI	point of interconnection
ROV	remotely operated vehicle
SBP	sub-bottom profiler
SCADA	supervisory control and data acquisition
SOV	service and operations vessel
SSS	side scan sonar
t	ton
TSHD	trailing suction hopper dredger
USACE	United States Army Corps of Engineers
USCG	United States Coast Guard
VC	vibracore
VMS	vessel monitoring system
VTR	vessel trip report
WEA	wind energy area
WTG	wind turbine generator
XLPE	cross linked polyethylene

Executive Summary

This purpose of this document is to provide an overview of offshore wind (OSW) submarine power cable types, installation and burial methods, and operations and maintenance. This document also summarizes potential impacts cables might have on the commercial fishing industry, as well as how commercial fishing practices might impact cables, and potential measures to avoid, minimize, or mitigate these impacts, including site assessment, risk assessment, project planning and design, and proper cable installation and burial methods.

The United States currently has two operational OSW facilities with plans for additional development in the future. The New York Bight includes an area of ocean extending from Montauk, New York, to Cape May, New Jersey. Within the New York Bight area, there are currently three OSW projects with agreements in place to sell their power to the New York State grid. Additionally, New York State has set a goal of 9,000 MW of offshore wind energy gener-ation by 2035 which will require 750 and 900 WTGs based on current industry standards.

The submarine cable component of an OSW project is critical to the economic viability of the project. Submarine cables transport power generated by the wind turbines generators (WTG) to the offshore substation platform and then to Point of Interconnection (POI) on land. The WTGs are connected in strings by array cables, and export cables transmit the electrical power from the OSP to the grid connection point onshore. Since 2000, all documented new telecommunications cables along the U.S. Atlantic Coast have targeted burial depths of at least 5 to 6 feet (ft; 1.5-2.0 meters [m]) where seabed conditions permit. Since this established burial depth, cable damage rates resulting from fishing and hydraulic clam dredging operations have been sharply reduced (to nearly zero) (NASCA 2019). The 5 to 6 ft target burial depth was established to protect telecommunications cables from damage from hydraulic clam dredging gear, which penetrates the seafloor deeper than any other fishing gear concurrently may pose the most risks to submarine cables.

There are a wide variety of sources that guide or drive cable burial recommendations, ranging from governmental agencies to industry bodies that publish guidelines and best working practices. These include the U.S. Army Corps of Engineers (USACE), the International Cable Protection Committee (ICPC), the North American Submarine Cable Association (NASCA), the Bureau of Ocean Energy Management (BOEM), the Carbon Trust, the Bureau of Safety and Environmental Enforcement (BSEE) and the American Wind Energy Association (AWEA) among others.

Successful cable installation starts with effective route planning that mitigates risk. Once the WTG layout is established, the project developer will decide how the strings of WTGs are connected. Depending upon load and capacity required, it is common for there to be multiple export cables running in parallel for larger offshore wind projects. Studies that are required for proper OSW cable siting include (but are not limited to): Preliminary Route and Landing Site Assessment (Critical Issues Analysis), Submarine Cable Desktop Study, Cable Burial Risk Assessment (CBRA), and a Cable Burial Feasibility Assessment. The CBRA in particular uses a risk-based methodology to determine the minimum recommended depth of lowering (DOL) for a cable which is important in terms of fisheries constraints and risks.

In power transmission, there are two options available to developers, Alternating Current (AC) and Direct Current (DC). Since export cables must transmit the entirety of the electrical power from the OSW facility to shore and over distance, minimizing electrical losses is critical. Therefore, OSPs step up the array cable voltages from 33 kV or 66 kV to at least 115 kV, and commonly, 245-290 kV. As distances increase and planned projects get larger, high-voltage alternating-current (HVAC) export cables are being qualified for voltages of up to approximately 420 kV. As larger projects are planned, it can be assumed that cable corridors will contain multiple, parallel cables to bring the power generated offshore to the grid. The standard for minimum cable spacing is generally two times the water depth. A cable has a maximum allowable temperature of 90 degrees Celsius (°C). Cables that are buried deeper than planned are at risk of damage due to overheating. This is the balance where developers must bury cables deep enough to mitigate risks of damage from external forces, but not over bury such that ampacity would be compromised. Saturated soils (as found in the seabed) provide better ambient cooling than what occurs on land, but the fact that increased burial depth reduces heat transmission and can cause excessive heating of the cable remains an important constraint.

As stated above, array cables connect the WTGs, and export cables transit the power from the OSP to the POI. Array cables are three-core, armored, medium-voltage alternating-current cables containing one or more fiber optic bundles. Export cables are typically HVAC three-core cables and are of a much greater diameter than array cables and require different installation equipment. Prior to any submarine cable installation, the route must be cleared of obstacles that could interfere with the installation and burial operations or cause post-installation damage to the cable.

This work includes the identification of any out-of-service (OOS) cables and boulder removal. Export cable installation can be broken into three discrete phases: the shore landing, the main lay and then the pull into the OSP. Array cable laying also occurs in three phases: first end installation, main lay, and second end installation.

The three methods of cable installation include simultaneous lay and burial, post-lay burial, and pre-lay burial. The choice of which method to use on a project is driven by factors such as the soil type, installation tool availability, as well as the operation itself; such as whether it's array cabling, export cabling or bundled HVDC installation. In areas where target cable burial is unfeasible, additional cable protection measures may be implemented. Once cables are buried, follow-up survey activities are typically conducted to confirm cable burial and detect any cable movements.

Geophysical and geotechnical data can provide key information on the composition of the seabed to determine the best techniques and equipment to use in a specific area. Once potential cable corridors have been identified, a high-resolution geophysical and geotechnical survey campaign is conducted to collect site-specific data and refine the routing. Steep slopes, ravines, canyons, deep channels, undersea landslides, and volcanic/seismic activity are all geologic and sedimentary risks to cables and are to be avoided entirely. Another major external aggression risk to submarine cables stems from commercial shipping and the deployment of anchors, whether deliberate, accidental, or due to an emergency. The risks of anchor strike can be at least partially calculated by analyzing the AIS data along with the associated vessel types/sizes and soil data to establish the penetration depths of the anchor flukes for each scenario.

Historical and current trends in commercial and recreational fishing are another major consideration when planning a cable route. The best and most effective manner to avoid, minimize, or mitigate impacts to fishing interests is engagement with fishermen early in the planning process. The two major considerations cable route engineers review with respect to fishing interests are identifying and avoiding heavily fished grounds where possible during upfront planning and developing fishing gear-type and seabed composition-based mitigation measures. The fisheries studies identify the types of fishing undertaken, along with the types of fishing gear utilized. This knowledge, as well as the knowledge about the seabed composition, is used to determine the maximum likely penetration depth of the fishing gear, and therefore is one of the factors taken into consideration when completing the CBRA.

Over 300 fish species occur in the New York Bight, many of which are of recreational and commercial value. Commercial fishing methods are more likely to interact with subsea cables and may cause more cable damage than recreational fishing. Common types of bottom fishing used by commercial fishermen include otter trawling, scallop dredging, hydraulic clam dredging, gill netting, longlining, and pots/traps. Bottom gear has the potential to damage subsea cables enough to affect transmission, known as a "fault". Despite gear interactions with the seabed, most fishing vessels never interact with cables. However, to ensure the lowest likelihood of faulting, there are several mitigation measures employed by cable operators, including cable armoring and burial for cable installed on the continental shelf (CSRIC 2014).

Potential impacts resulting from subsea cable activities may be realized during cable installation, operational, and decommissioning phases and include physical seabed disturbances, sediment resuspension, underwater noise emission, and habitat disturbances (Meissner et al. 2006; Vize et al. 2008; Carter et al. 2009; OSPAR Commission 2012; NIRAS 2015; Taormina et al. 2018). Longer-term impacts may occur during cable operational phases, including changes in electromagnetic fields (EMF), heat exchange, and reef effects. Generally, the spatial extent of such impacts is limited to the cable corridor and immediately surrounding environment. The main areas where mitigation measures are adopted are during selection of cable route and cable burial method (Vize et al. 2008). Low-impact routes are selected based on avoidance of protected areas, environmentally sensitive areas, and/or valuable areas as well as; avoidance of route lengths longer than necessary, and avoidance of crossings with existing cables and pipelines (OSPAR Commission 2012). Once cable routes are selected and the cable is installed, the burial of the cable itself may function as a mitigation measure to minimize interaction with the cable once installed.

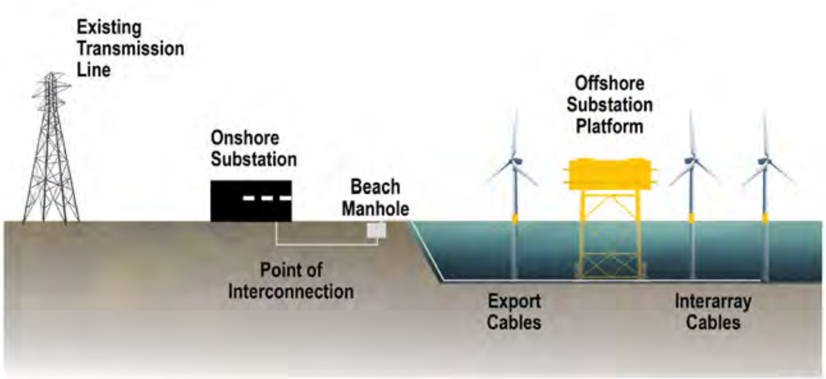
1.0 Introduction

This report has been commissioned by the New York State Energy Research and Development Authority (NYSERDA) for their Fisheries Technical Working Group (F-TWG). This document provides an overview of offshore wind (OSW) submarine power cable types, installation and burial methods, and operations and maintenance. Figure 1 provides an illustration of a typical offshore wind configuration. The document also summarizes potential impacts cables might have on the commercial fishing industry as well as how commercial fishing practices might impact cables and potential measures to mitigate these impacts.

Offshore wind submarine cables can have an impact on the commercial fishing industry as well as other seabed users, both during installation and during operations. This document explains these potential impacts as well as how they may be mitigated through site assessment, risk assessment, project planning and design, and proper cable installation and burial methods. Risks can generally be categorized as external aggression risks from shipping/vessel activity (that may lead to damage to the cable, particularly the threat from dropped or dragged anchors) or from bottom contact fishing activity. Export cables are an especially critical link for an offshore wind facility, in that any damage to them could prevent the power from an offshore wind farm from being transmitted to shore. Additionally, these larger export cables are extremely costly and can be time-consuming to repair, further prolonging potential outages and introducing the potential for large, commercial consequences and disruptions to the regional power supply.

Overseas, the offshore wind industry has reported that the submarine cabling component of projects accounts for the majority (~70 percent) of a project's insurance claims, despite accounting for just 10 percent of the capital costs. These failures are reportedly due to cable manufacturing defects, installation issues, and damage caused by external aggression after installation. It is in the interest of all parties that the industry in the United States learns these lessons and ensures that submarine cables are adequately protected from damage. This, in turn, will minimize the impacts to other stakeholders as well as minimizing the impact on the marine ecosystem as a whole.

Figure 1. Major Components of a Typical Offshore Windfarm



Common Cable Terminology:

- **Point of Interconnection (POI)—** Where the offshore wind (OSW) power is injected into the land-based power grid.
- Beach Manhole (BMH)—Subterranean structure that houses the landward end of the export cable, also referred to as a transition pit.
- Horizontal Directional Drill (HDD)— An HDD method allows cables to come onshore without trenching across a beach or dune and to remain well below the seabed until a point offshore that is beyond much of the influence of wave energy.
- Route Position List (RPL)—Series of coordinates that correlate to cable route bearing changes (referred to as "alter courses"), crossing locations (of assets or boundaries), etc. Any noteworthy location along a route will become a point in a Route Position List. Route Position List documents are often redacted when shared publicly.
- Offshore Substation Platform (OSP)— Collection point for the array cables. The power is taken from the array cables and associated Wind Turbine Generators (WTG) and sent to shore via high-voltage export cable between the OSP and the BMH to POI.

1.1 Historical and Existing Submarine Cables in the New York Bight

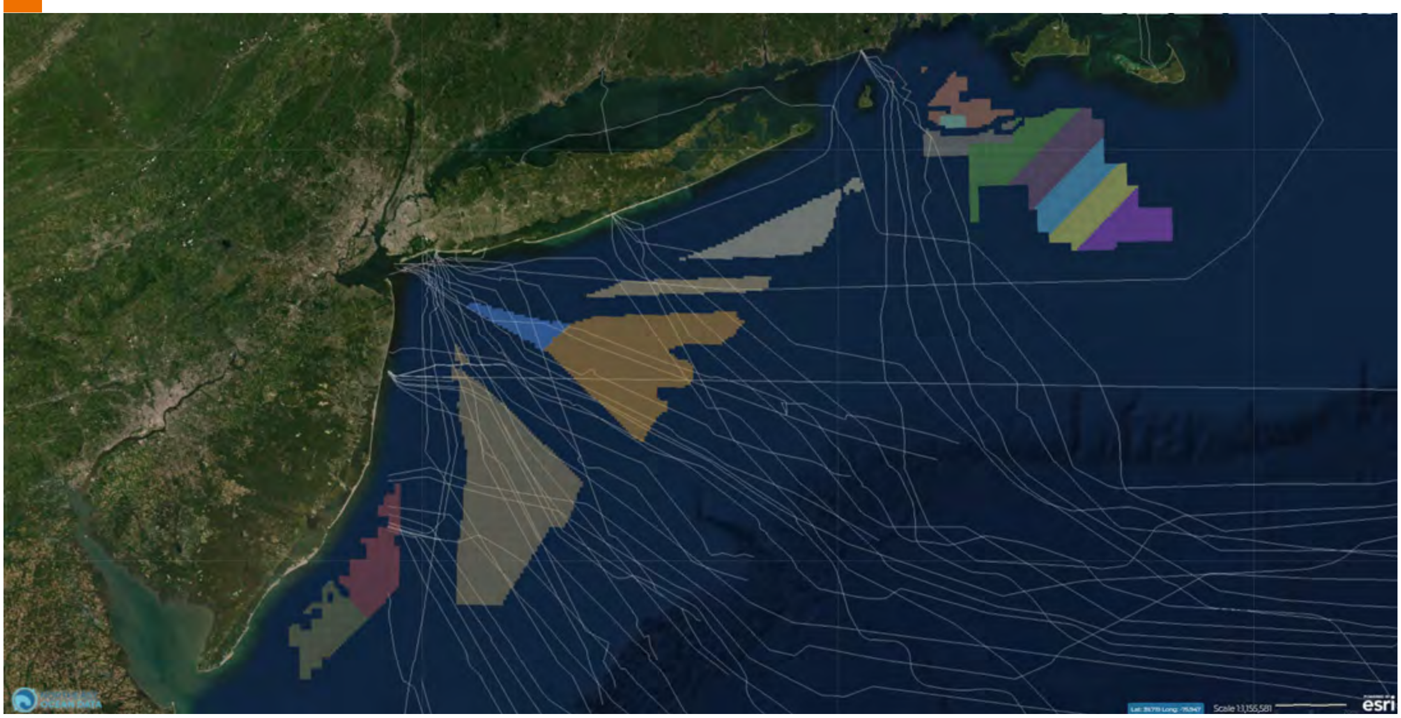
During the 1980s and 1990s, submarine fiber optic cables along the northeast coastline experienced several faults due to likely external aggression. At that time, the typical target cable burial depth was between 2 and 3 feet (ft) or 0.6 to 0.9 meters (m). However, since 2000, new telecommunications cables along the U.S. Atlantic Coast have targeted at least 5 to 6 ft (1.5 to 2.0 m) burial depth where seafloor conditions permit; cable damage rates resulting from fishing and hydraulic clam dredging operations have been sharply reduced (to nearly zero) since this change (NASCA 2019).

The new, greater target burial depth was established specifically to prevent damage from hydraulic shellfish dredges, which penetrate the seafloor deeper than any other commercial fishing gear. Where this type of fishing does not occur, shallower cable burial may be sufficient to protect cables from external aggression risks . This is particularly significant in areas where seabed conditions hinder deeper burial.

Commercial maritime vessel anchors pose additional risks to submarine cables. These anchors are typically designed to penetrate the seabed to a greater depth than fishing gear. When cables are buried deep enough to mitigate the risks from maritime vessel anchors, then potential impacts from fishing activity can be mitigated as well. The recommended depth of a cable is based on the probability of an anchor strike, which relies on data such as the types of shipping operations in a region and the presence or lack of anchorages.

It is important to remember that submarine cables in the telecommunications industry were first installed in the mid-19th century. Since then, a profusion of fiber-optic cables and submarine power cables and pipelines have been added to the New York Bight area. While submarine cables are not new to the New York Bight, the scale of these cable operations is likely to grow significantly larger as OSW facilities are constructed. Figure 2 shows Equinor’s Empire Wind project (blue), BOEM’s New York Bight Offshore Wind planning areas (light brown to gray), and existing submarine cables (white lines).

Figure 2. Existing Submarine Cable Routes and Offshore Wind Lease/Call Areas in the New York Bight *(Courtesy, Northeast Ocean Data Portal).*



2.0 The U.S. Offshore Wind Industry

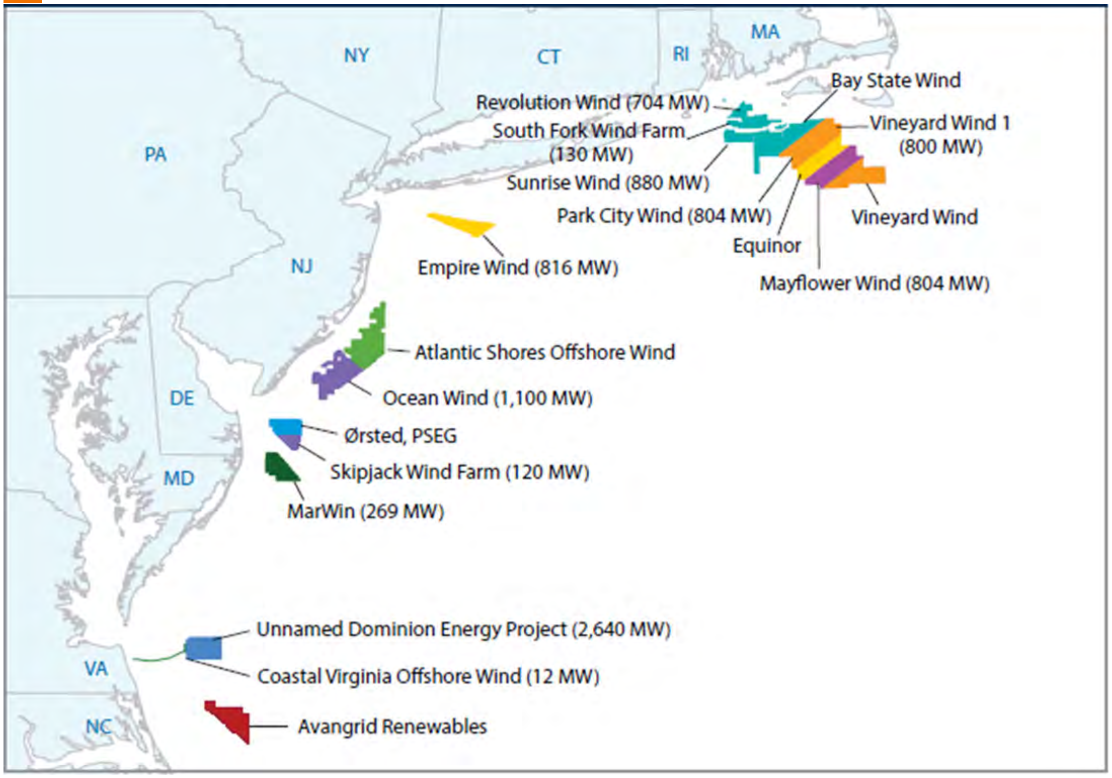
Worldwide, the demand for renewable energy is rising. This is driven by the desire to (1) reduce the impact of fossil fuels and greenhouse gas emissions and (2) encourage job growth in a rapidly expanding industry.

Europe initiated the offshore wind industry in 1991 with Vindeby, a small wind farm installed approximately 1 mile off shore from Denmark.. This project comprised 11 WTGs, with a total electrical generation capacity of 5 megawatts (MW). As of 2019, Europe had a total installed capacity of approximately 22,000 MW, consisting of 5,047 grid-connected WTGs across 12 countries. In 2019 alone, 502 WTGs were installed in Europe across 10 different sites (www.windeurope.org).

In the U.S., the initial focus of the industry is along the Atlantic Coast, with lease areas and call areas identified from Georgia up to the Gulf of Maine; the greatest concentration of projects are between New Jersey and Massachusetts. Offshore wind generation will be extremely effective in this region due to (1) the proximity of the load centers to project locations, and (2) the relatively shallow water depths, which are conducive to utilizing well-established fixed foundation technology and installation methods. Currently, there are two operational OSW facilities in the U.S.: (1) the 5-turbine, 30 MW Block Island Wind Farm project owned by Ørsted, which was commissioned in 2016 and (2) the Dominion Energy Coastal Virginia Offshore Wind (CVOW) pilot project, a two-turbine, 12-MW project located 27 miles off Virginia Beach, commissioned in 2020.

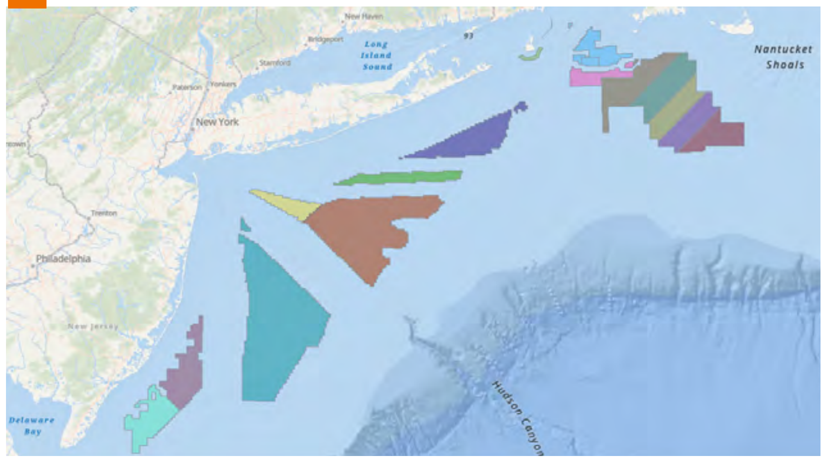
Despite the scale of these initial projects, future OSW plans in the U.S. are very ambitious. Figures 3 and 4 show the current lease areas and proposed project locations. The latest estimates from the American Wind Energy Association (AWEA) are that between 20,000 MW and 30,000 MW of offshore wind capacity will be installed and operational in the U.S. East Coast region by 2030. Therefore, if these plans come to fruition, the U.S. will have created an industry comparable in size to the industry in Europe, in approximately 14 years.

Figure 3. U.S. East Coast OSW Projects and Lease Areas
(Courtesy, AWEA U.S. Offshore Wind Power Economic Impact Assessment, March 2020).



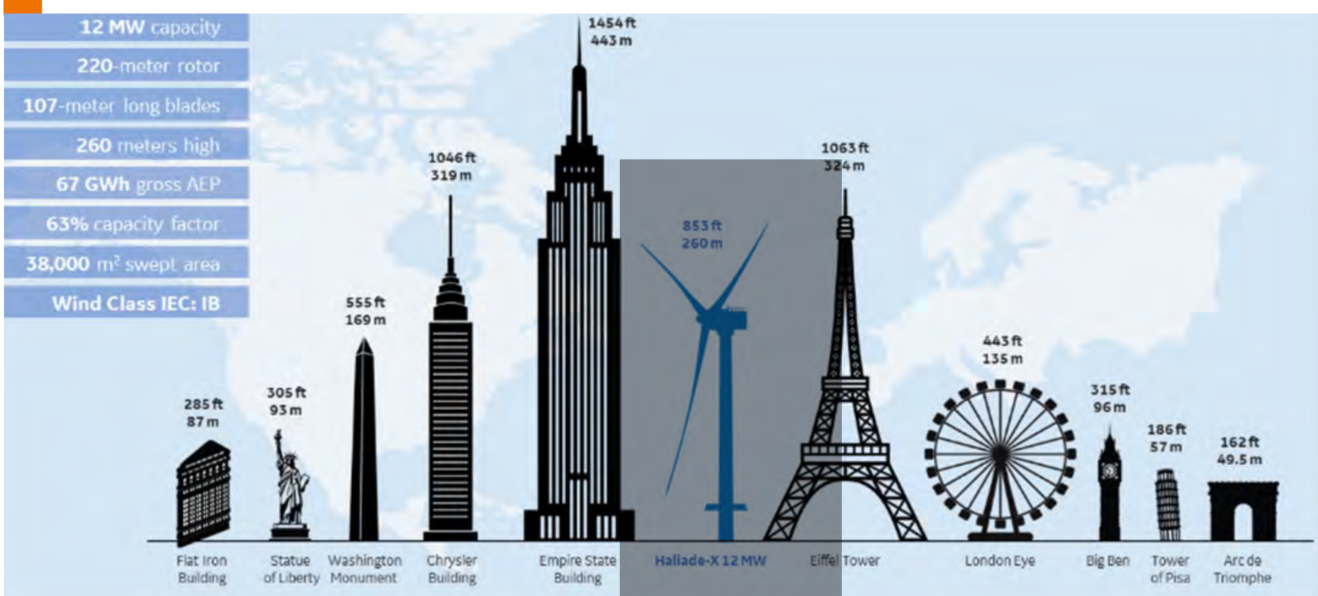
Continuing to focus on the New York Bight area, there are currently five OSW projects, Empire Wind 1 (816 MW), Empire Wind 2 (1,260 MW), Beacon Wind (1,230 MW), Sunrise Wind (880 MW), and South Fork (130 MW). The projects total over 4,300 MW and have agreements in place to sell their power to the New York State grid. Although the South Fork, Sunrise, and Beacon Wind projects will be located off Rhode Island and Massachusetts, the plan is for the power to be transmitted to shore in New York State. The State has set a goal of 9,000 MW of offshore wind energy generation by 2035. This goal has been codified into law (Climate Leadership and Community Protection Act), which furthermore directs the State to be 100 percent carbon free by 2040 and to reduce greenhouse gas emissions to 85 percent of 1990 levels by 2050 (https://climate.ny.gov/).

Figure 4. New York State Area OSW Lease/Call Areas *(Courtesy, NYSERDA F-TWG lease map).*



To put this in context, 9,000 MW of installed power will require between 750 and 900 WTGs based on a current industry standard of 10-MW WTGs, with 12-15 MW turbines in the pipeline. It is expected that the newest and most powerful turbines, GE Haliade 12-MW WTGs, will be installed at the United Kingdom's Dogger Bank Offshore Wind Farm (3,600 MW), which is currently under construction. Figure 5 compares the size of a General Electric Haliade to other structures.

Figure 5. GE Haliade-X 12-MW WTG, Size Comparison *(Courtesy, Gray Matter Systems, General Electric).*



3.0 Submarine Cables in Offshore Wind Projects

The submarine cable component of an OSW project is critical to the economic viability of the project. Cables are vulnerable to damage from external forces and, in turn, can (if poorly planned and installed) impact other seabed users as well as marine life and marine habitats. It is imperative that the risks posed both to and from submarine cables are well understood during the planning and permitting stages of the project. This is achieved through a blend of diligent planning and engineering, strategic assessments and stakeholder outreach, thorough and robust permitting, and adherence to industry standards and best practices.

This section describes cable planning requirements, types of power cables, marine cable installation operations and technologies, cable burial methods, and operations and maintenance of an offshore wind project.

3.1 State and Federal Regulatory Requirements: Industry Guidance

There are a wide variety of sources that guide or drive cable burial recommendations, ranging from governmental agencies to industry bodies that publish guidelines and best working practices. It is common for submarine cable projects to receive burial depth requirements from the U.S. Army Corps of Engineers (USACE) as a part of the permitting process. USACE burial depth requirements particularly pertain to areas where there are identified and maintained shipping and navigation channels as well as anchorages. The specified burial depth requirements are intended to allow for future dredging activities, channel deepening, widening, and lengthening, for example.

Even though the USACE burial depth requirements vary by location, there are guidance and regulatory requirements from a variety of other sources, including the International Cable Protection Committee (ICPC), the North American Submarine Cable Association (NASCA), the Bureau of Ocean Energy Management (BOEM), the Carbon Trust, the Bureau of Safety and Environmental Enforcement (BSEE), and the American Wind Energy Association (AWEA), among others.

BOEM is an agency, under the auspices the U.S. Department of the Interior, responsible for environmentally and economically managing the development of the nation’s offshore resources (BOEM 2020). The main permitting document that offshore wind developers must assemble to BOEM’s satisfaction is the Construction and Operations Plan (COP).

Table 1 summarizes some of the main sources and guidance pertaining to submarine cable burial depth.

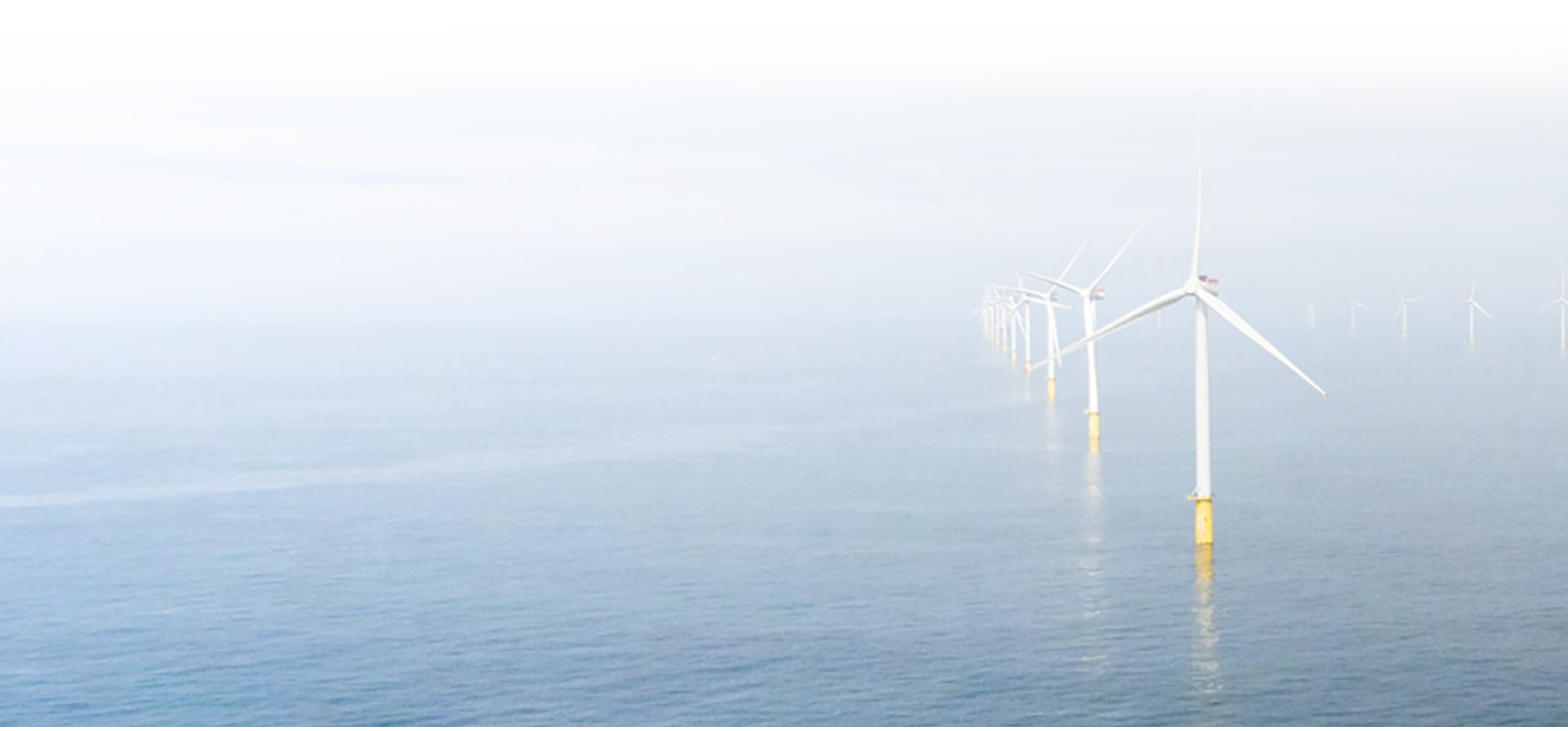


Table 1. Summary of Guidance, Regulations, and Industry Recommended Practices

Organizations	Document/Responsibility	Content
BOEM Bureau of Ocean Energy Management	*COP Guidelines; Attachment A: Best Management Practices*	**Seafloor habitats:** • Lessees and grantees should employ appropriate shielding for underwater cables to control the intensity of electromagnetic fields. • Lessees and grantees should take all reasonable actions to minimize seabed disturbance and sediment dispersion during cable installation. **Fisheries:** • Lessees and grantees should avoid or minimize impacts to the commercial fishing industry by burying cables, where practicable, to avoid conflict with fishing vessels and gear. • Lessees and grantees should employ appropriate shielding for underwater cables to control the intensity of electromagnetic fields. • Lessees and grantees should take all reasonable actions to minimize seabed disturbance and sediment dispersion during cable installation. • Lessees and grantees should avoid or minimize impacts to the commercial fishing industry by burying cables, where practicable, to avoid conflict with fishing vessels and gear operation. If cables are buried, lessees and grantees should inspect cable burial depth periodically during project operation to ensure that adequate coverage is maintained to avoid interference with fishing gear/activity. **Coastal habitats:** • Lessees and grantees should avoid hard-bottom habitats, including seagrass communities and kelp beds, where practicable, and should restore any damage to these communities.
	COP Guidelines; Attachment E: Information Requirements for NEPA and Other Relevant Laws	**Hazards:** Other potential needs for COP approval: Additional information may be needed to support the evaluation of hazards and physical impacts, including but not limited to: • Stability analysis of seafloor morphology. • Modeling of disturbances associated with foundation installation, cable jetting and burial, and cable landfall.
US Army Corps of Engineers®	*Jurisdiction over federally maintained shipping lanes and anchorages*	Requires a depth of lowering (DOL) of 15 ft (4.7 m) below the level to which they are required to maintain by dredge a shipping lane or anchorage area. Prior recommendation for power cables include a DOL of 4 to 6 ft (1.2 to 1.8 m) for power cables in locations outside of navigation lanes and anchorages (Sharples 2011).
BSEE Bureau of Safety and Environmental Enforcement	*Offshore Wind Submarine Cable Spacing Guide (December 2014)*	Offers guidance on the spacing of submarine power cabling. Also states that cable burial depths at landfalls should be determined on a case-by-case basis and depend upon llocal utilities, local municipalities, or other civic resource.

Table 1 continued — Summary of Guidance, Regulations, and Industry Recommended Practices

Organizations	Document/Responsibility	Content
LOCAL STATES	*Cable burial depth requirements vary via state if they exist at all*	State requirements regarding cable spacing and burial depth vary (if in fact they do exist) from state to state. An example is that of New Jersey: The state has a minimum burial depth requirement in waters of 5 ft (1.5 m). While New York State does not have an explicit minimum burial depth requirement, agencies are charged with protecting water dependent uses like commercial and recreation fishing and maritime commerce. Additionally, the permitting process required by subsea cables greater than 125 kilovolts (kV) traversing State waters is considered a "major transmission facility" (NY Public Service Law, Article VII).
DNV·GL An international registrar and classification society headquartered in Norway.	*The recommended practice document 'DNV-GL-RP-0360' is the main one pertaining to submarine cable burial*	This document provides guidance throughout the lifecycle of a submarine power cable, but focuses on the risk analysis and mitigations most applicable to shallow water applications.
CARBON TRUST A United Kingdom-based global organization with the stated mission of accelerating the transition to a sustainable, low carbon economy	*Cable Burial Risk Assessment Methodology – Guidance for the Preparation of Cable Burial Depth of* ***Lowering Specification (February 2015)*** ***Application Guide for the specification*** *of the DOL using the Cable Burial Risk* ***Assessment methodology (2015)***	This guidance provides the methodology for undertaking a probabilistic, risk-based CBRA as described in section 3.2.1.
International Cable Protection Committee	*Recommendations Documents ICPC Guidance (2019)*	The ICPC recommendations are a set of industry best practices that serve as a guide for burial planning. Since the ICPC Guidance (2019) is designed to be both generalized best practice as well as global in application, it does not publish a recommended depth of burial, as appropriate burial depth varies by risk profile and regulatory regime, along with a host of other factors. The International Cable Protection Committee is a member-driven organization founded in 1958.

Other Industry Guidance and International Legislation

- Offshore Electrical Cable Burial for Wind Farms: State of the Art, Standards and Guidance & Acceptable Burial Depths, Separation Distances and Sand Wave Effects (Sharples 2011).
- Export transmission Cables for Offshore Renewable Installations – Principles of Cable Routing and Spacing (The Crown Estate 2012, Gert Hemmingsen).
- Guideline for Leasing of Export Cable Routes/Corridors, Export Transmission Cables for Offshore Renewables Installations (The Crown Estate 2012).
- Design of Offshore Wind Turbines, Bundesamt Für Seeschiffahrt Und Hydrographie (Federal Maritime and Hydrographic Agency of Germany (BSH 2007).
- Review of Cabling Techniques and Environmental Effects Applicable to the Offshore Wind Farm Industry (Vize et al. 2008).
- Guidelines for Providing Geological and Geophysical, Hazards and Archeological Information Pursuant to 30 CFR Part 285 (U.S. Department of the Interior 2011).
- Improvements in Submarine Cable System Protection (R. Hoshina and J. Featherstone 2001).
- Procedure for Subsea Cable Route Selection (Scottish and Southern Energy 2004).
- Interference Between Trawl Gear and Pipelines (DNV-RP-F111 2010).
- The United Nations Convention on the Law of the Sea, 1982 (legislation).
- The Geneva Convention on the High Sea, 1958 (legislation).
- The Geneva Convention on the Continental Shelf, 1958 (legislation).
- International Convention for the Protection of Submarine Telegraph Cables, 1884 (legislation).
- Third-Party damage to Underground and Submarine Cables (International Council on Large Electrical Systems [CIGRE], 2009).
- DNV-RP-J301 Subsea Power Cables in Shallow Water, 2014.
- DNV-RP-F107 Risk Assessment of Pipeline Protection, 2010.
- Guidance Notes for the Planning and Execution of a Geophysical and Geotechnical Ground Investigation (The Society for Underwater Technology 2014).
- International Guidelines on the Risk Management of Offshore Wind Farms, Offshore Code of Practice

3.2 Cable Route Planning

Successful cable installation starts with effective route planning and mitigates risk. Specific lease area and site conditions often determine the number and ideal layout or location of the individual WTGs. While some flexibility exists for site layout, depending on site conditions, layouts can be constrained by onshore grid interconnection points and associated shore landings and approaches.

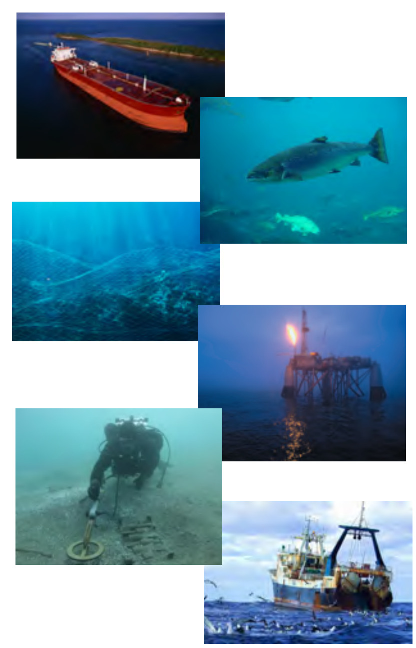
Once the WTG layout is established, the project developer will decide how the strings of WTGs are connected. Submarine cables that connect WTGs together or connect the strings of WTGs to the offshore substation platform (OSP) are referred to as array or inter-array cables. Redundancy is built into a project with the installation of extra array cables joining the ends of WTG strings together, for example. However, in practice, it is customary for array cables to be as straight as possible between WTGs to simplify installation and reduce cable spans and costs. However, routes consider geophysical and geotechnical conditions and other hazard or exclusion zones; therefore, the route may deviate from a straight line.

The submarine cables that connect the OSP to the onshore grid connection point are referred to as the export cables. Depending upon load and capacity required, it is common for there to be multiple export cables running in parallel for larger offshore wind projects. The end points of export cables may have little flexibility, but the routes that are traversed (the cable corridor) can be modified based upon the results of cable surveys and studies.

The main studies required include, but are not limited to, the following: Preliminary Cable Route and Landing Site Assessment (Critical Issues Analysis); Submarine Cable Desktop Study; and Cable Burial Risk Assessment (CBRA). The CBRA and an overview of the geological, environmental, and fisheries constraints that feed into that assessment are discussed further in this section.

The Preliminary Cable Route and Landing Site Assessment uses publicly available and client-supplied data to develop several corridor alternatives. The aim of this assessment is to identify possible cable corridors that present the fewest seabed hazards, fewest potential impacts to stakeholders, and least risks. The outcome is to identify potential cable corridors that avoid (or minimize interactions with) the following features or conditions:

- shipping channels
- dredged areas
- dumping grounds (active or historic)
- known fishing grounds
- obstructions such as shipwrecks
- areas with potential for unexploded ordnance
- existing and planned seabed structures (cables, pipelines, tunnels, fish havens, aquaculture areas, oil and gas assets, etc.)
- areas of shoals or ledges
- strong currents
- protected areas of environmental and/or cultural importance
- areas where the seabed isn't conducive to cable installation and/or burial, such as steep slopes or boulder fields

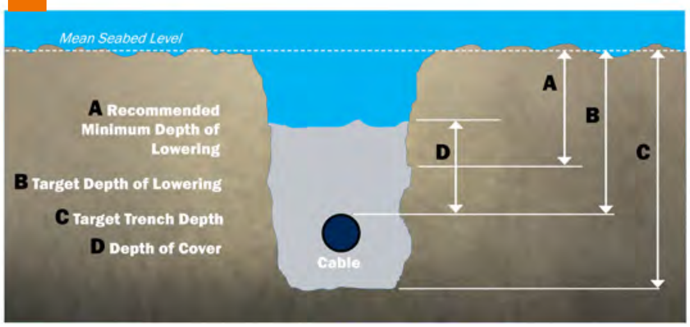


Based on these results, the developer commissions hydrographic surveys to further detail the seabed, thereby allowing detailed CBRAs and Cable Burial Feasibility Assessments to be undertaken.

3.2.1 Cable Burial Risk Assessment

The CBRA uses a risk-based methodology to determine the minimum recommended depth of lowering (DOL) for a cable. As shown in Figure 6, the outcome of the CBRA is a recommended, minimum DOL (A) at each point along the cable route. To achieve this minimum DOL, a contractor will select a cable installation and burial method to achieve the target DOL (B), which allows for a slight margin for error in case of unexpected challenges. This extra margin allows for any backfill that may occur prior to the cable sinking into the trench, for example. To achieve the Target DOL, a burial tool capable of the Target Trench Depth (C) is specified.

Figure 6. Industry Standard Cable Burial and Trench Parameters *(Courtesv. The Carbon Trust).*



It is important to establish a realistic or optimized target DOL to achieve the following objectives:

- Mitigate the threat to the cable from external aggression and natural processes such as mobile sediment.
- Reduce potential impacts from exposed cables to other seabed users and the environment.
- Allow for the widest selection of installation and burial tools, leading to more cost-effective cable installation.
- Ensure that the ampacity (power carrying capacity) of the cable is not compromised due to over burial.
- Ensure access to the cable for recovery, repair, or inspection operations.

The CBRA is a standardized method, based upon unique and site-specific data and uses probabilistic methods to determine a target DOL that is technically and economically feasible and provides adequate cable protection. It is impossible to protect a cable from all threats, but the CBRA adheres to the "As Low As is Reasonably Practicable" (ALARP) philosophy. For example, one of the CBRA's inputs is vessel traffic, whereby Automatic Identification System (AIS) data (as well as fisheries-specific data such as Vessel Monitoring System [VMS] and Vessel Trip Reports [VTR] data) may be used to determine the type and frequency of marine traffic in proximity to cable routes. If, after studying that data, it is found that the frequency of container ships (for example) is negligible, then the corresponding risk to the cable due to anchor strikes from that type of vessel anchor is also low. Therefore, the particular type of anchor and the possibility or frequency of a strike from that type of vessel/anchor can be discounted when undertaking the CBRA. This could result in a shallower target DOL if the remaining vessels and their anchor types are smaller with a corresponding lower depth of penetration.

A comprehensive CBRA includes the following information:

- Navigational charts and tide and current tables.
- All burial requirements issued to the project by consenting authorities, as well as any other agreements reached with stakeholders (crossed **asset owners, fishermen etc.).**
- Geotechnical data (e.g., soil type, grain size, shear strength, organic matter) gathered using Cone Penetrometer Tests (CPT), Vibracore (VC), Gravity Core, Piston Bore, grab sampling, etc., followed by lab analysis. (These data provide an overview of conditions that may be encountered at any point [often using referenced kilometer posts or KPs] along the cable route.)
- **Geophysical data (e.g., seabed profile, the presence** of any obstructions of the seabed, the strata of sub-bottom sediment layers, and the presence of ferrous objects including possible unexploded ordnance or ship wrecks) using Multibeam Echosounders (MBES), Side Scan Sonar (SSS), **Sub-bottom Profilers (SBP)** and Gradiometers/Magnetometers.
- Ground Models generated by OSW developers to establish a comprehensive understanding of the seabed across the project.
- **Publicly available, local, and region-specific** documentation including historical or publicly available geological data, marine wildlife data, etc.
- **Automatic Identification System (AIS) vessel traffic data that show the type and frequency of marine traffic** to support analysis of anchor types and frequency of deliberate or accidental anchor deployment.
- Fisheries study to identify the commercial and **recreational fishing activities that occur in the** area, including vessel and gear penetration depths.
- Mobility study to determine historical changes in the seabed topography such as the movement of sand waves/sand ripples, and erosion/accretion due to currents, sediment type, etc.
- **Preliminary cable design and specifications.**
- Future development plans such as potential dredging works to deepen or lengthen shipping channels, anchorages, etc.
- Other activities such as dumping grounds, areas of subsea mining, dredging for beach replenishment.
- Information on existing and planned seabed **infrastructure, including fiber optic and power** cables, pipelines, sewer outfalls, etc.
- Seismic activity and the risk of submarine landslides.

The CBRA incorporates a probabilistic, risk-based analysis to ensure that the cable will be buried to a suitable depth to protect it, and external users from impacts, as far as is reasonably practicable. The CBRA relies on existing data coverage, such as AIS, bottom features, and other inputs to inform the risk analysis, with the recognition that not all vessels utilize AIS. The CBRA provides input for the Cable Burial Feasibility Assessment that summarizes the geophysical and geotechnical data and identifies suitable burial methods most likely to achieve the targeted burial depths.

3.2.2 Geologic Constraints and Concerns

One of the key data sets required for cable route planning is the composition of the seabed. Great care is taken to avoid areas of hard or extremely soft seabed sediments, as well as slopes, sand waves, etc., wherever practicable. Early concept route planning is often based upon publicly available data, or data obtained from other seabed users, published bathymetric charts, etc. Once potential cable corridors have been identified, a high-resolution geophysical and geotechnical survey campaign is conducted to collect site-specific data and refine the routing. These surveys are executed using a combination of regulatory guidance and developer experience, so that all data required for both permitting and design are acquired at the same time, ensuring project schedules are met.

Geologic constraint data can be broken down into two categories: geophysical and geotechnical. Geophysical data refers to the surficial features of the seabed, including:

- ater depth
- Slopes
- Ravines
- Crevasses
- Submerged channels
- Boulder fields
- Sand waves
- Mega ripples
- Reefs
- Shoals
- Ledges
- Other seabed features

Geophysical data can help determine whether an area is appropriate for cable installation, provide information about the potential effectiveness and longevity of burial techniques, and inform developers about seabed stability.

Geotechnical data refers to the composition of the seabed, including the following:

- The soil descriptions and seabed strata
- The presence and percent composition of organic matter, which affects the thermal properties of sediment where a cable will be buried
- Physical properties of the seabed soils, such as shear strength, relative density, thermal properties and grain size
- The presence of differing subsurface strata or bands of differing sediment types
- The presence of bedrock, subsurface boulders, and subcropping rock

All of these factors contribute to the success of a cable burial, and provide decision-makers with information regarding the best techniques and equipment to use in a specific area. These data also help analysts categorize external aggression risks to cables posed by factors such as bottom contact fishing gear and vessel anchors, as penetration depth will vary depending on sediment conditions.

3.2.3 Environmental, Fisheries, and Fishing Impacts

When planning a cable route, as well as assessing potential risks to cables, the commercial and recreational fishing industries are always a major consideration. The best and most effective manner to mitigate impacts to fishing interests is engagement with fishermen early in the planning process.

There are two primary considerations for cable route engineers with respect to fishing interests:

(1) The first consideration is to identify heavily fished grounds during upfront planning, and to avoid these areas whenever possible.

(2) The second consideration is to develop appropriate mitigation that is focused on types of fishing gear and seabed composition. The fisheries studies identify the types of fishing undertaken, along with the types of fishing gear encountered. This knowledge, as well as the knowledge about the seabed composition, is used to determine the maximum likely penetration depth of the fishing gear, and therefore, is one of the factors taken into consideration when completing the CBRA.

3.3 Cable Types

As discussed in the previous section, the general layout of an offshore wind farm, as well as the functions of the main components, including the array and export cabling, is well established. The following sections detail typical cable types that may be encountered as the industry grows in the New York Bight.

In power transmission, there are two options available to developers, Alternating Current (AC) and Direct Current (DC). AC is an electric current that periodically changes direction a certain number of times per second (frequency). For example, AC in the U.S. reverses direction 60 times per second, for a frequency of 60 Hz. The domestic power supply in the U.S. operates at 120 V so switches between +120 V to –120 V every 1/60th of a second.

Conversely, DC is unidirectional, whereby the flow of current is always in the same direction, as is the case with a battery, for example. Table 2 provides a simplified, high level comparison between the two technologies.

Table 2. Basic HVAC to HVDC Technology Comparison

Parameter	HVAC	HVDC
Cable Cost	HIGH	MEDIUM
Electrical Losses	MEDIUM	LOW
Practical Maximum Length (without mitigation)	~100 km	Theoretically Unlimited, Current Longest is about 600 km
System Reliability	HIGH	MEDIUM-HIGH
OSP/Converter Platform Cost	MEDIUM	HIGH
OSP/Converter Platform Weight	1,500-3,000 T	~12,000 T (Borwin Beta Germany)
Max Power Per Cable	~ 400 MW	Currently Western Link; transmits 2,200 MW
Onshore Footprint	MEDIUM	LARGE

In any cable system, the goal is that the cable or cables transmit the required power in a consistent manner. Ohm's law states that Power in Watts (P) = Current in Amps (I) x Volts (V). For an offshore wind farm, the power will be fixed and known. For example, an 800-megawatt (MW) nameplate capacity will produce a percentage under that capacity but never more. It's worth remembering that the current-carrying capacity (ampacity) of a cable is determined by the size (or cross-section) and type of the electrical conductor (Table 3).

Table 3. Cable Type and Size Comparison
(All numbers are approximate. Numbers change with advances in technology).

Parameter	HVAC Arrays	HVAC Export	HVDC
Outer Diameter Range	4.25 in–6.3 in (110 mm–160 mm)	10 in–13 in (250 mm–320 mm)	Approx. 6 in (150 mm) NOTE: Return cable is of smaller diameter
Weight in Air	13 lbs/ft–34 lbs/ft (20 kg/m–51 kg/m)	Up to approx. 85 lbs/ft (125 kg/m)	Approx. 40 lbs/ft (60 kg/m) for entire bundle
Minimum Bend Radius	~ 6 ft (2.0 m)	~ 15 ft (5.0 m)	Varies
Conductor Cross-Section	3 x 120 mm^2– 800 mm^2	3 x 800 mm^2– 1400 mm^2	Up to approx. 1800 mm^2
Voltage Rating	< 66 kV	< 420 kV (more commonly 220–290 kV)	Up to approx. +/- 600 kV

Furthermore, electrical losses increase as current increases. This means in practice that to reduce the size (and therefore cost) of the cable, as well as to reduce transmission losses, it is desirable to have as low an electrical current on a cable as possible. For a given power rating, this means making the voltage higher.

The quest to reduce electrical losses as well as to reduce cable sizing as much as possible has resulted in the transition of WTGs operating at 33 kV toward 66-kV machines. This means that array cabling must also be rated to operate at that voltage level.

Perhaps more importantly, export cables must transmit the entirety of the electrical power from the OSW facility to shore and over distance; therefore, the question of electrical losses becomes even more critical. Therefore, OSPs step up the array cable voltages from 33 kV or 66 kV to at least 115 kV, and commonly, 245 to 290 kV. As distances increase and planned projects get larger, high-voltage alternating-current (HVAC) export cables are being qualified for voltages of up to approximately 420 kV.

The power capacity of a single HVAC export cable varies due to many factors but, as a rule of thumb, 400 MW is a realistic maximum. Therefore, for an 800-MW project, two export cables would be required, and the cables would most often run parallel to one another but may diverge to land at multiple points of interconnection. As larger projects are planned, it can be assumed that cable corridors will contain multiple, parallel cables to bring the power generated offshore to the ratepayers.

It is considered an industry best practice to install parallel cables at a specified distance apart for two reasons:

- Ensure access for future operations, such as surveys, inspections, and repair.
- *Prevent electrical losses, which can occur when HVAC cables are too close.*

The typical minimum cable spacing is two times water depth; but installers, developers, and maintenance experts all advocate for greater distances. To put it simply, if the water depth is 60 feet, there should be a minimum of 120 feet spacing between parallel cables. However, with proper planning and design, this separation can be reduced, except for shallow water, where separation may need to increase.

The limit to a cable's current carrying capacity (ampacity) is temperature. As the current increases, so does conductor temperature inside the cable core. The industry-standard electrical insulation material for submarine power cabling is cross-linked polyethylene (XLPE). This material has a maximum allowable temperature of 90 degrees Celsius (°C) before insulation damage may occur. This is important for many reasons and is one of the key drivers in determining the cable conductor size selected.

Cables that are buried deeper than planned are at risk of damage due to overheating. As little as 1.6 ft (0.5 m) of over burial, especially in soils that have high thermal insulation factors, can necessitate larger cable cross-sections. This is the balance where developers must bury cables deep enough to mitigate risks of damage from external forces, but not over bury such that ampacity would be compromised. Saturated soils (as found under the sea) provide better ambient cooling than dry soil on land, but the fact that extra burial reduces heat transmission and can cause excessive heating remains a valid concern.

Three-phase electricity is generated by WTGs. In an AC system, this requires three electrical conductors for each electrical circuit. In submarine cabling, this configuration can be done in one of two ways: either as three, single core cables or as a single cable containing three power cores. The offshore wind industry uses the latter, for a variety of reasons, not least of which is the reduced cable corridor requirements and speed of installation and burial. High-voltage direct-current (HVDC) technology, on the other hand, requires fewer power conductors, just one in the case of a monopole system, or (more commonly) two in the case of a bipole system. In the latter case, two single core cables are installed simultaneously and bundled together during installation.

However, the convertor stations required to convert AC to DC current offshore, and the corresponding DC to AC station onshore are large, expensive, may have long lead times to procure, and can be less reliable than more conventional, AC technology. HVDC system voltage levels vary, but currently range up to 600 kV, as is the case for the Western Link project that connects Scotland to Wales. Figures 7 through 9 compare HVDC and HVAC cables.

Figure 7. Bundled HVDC Cable Deployment *(Courtesy, Prysmian Powerlink).*

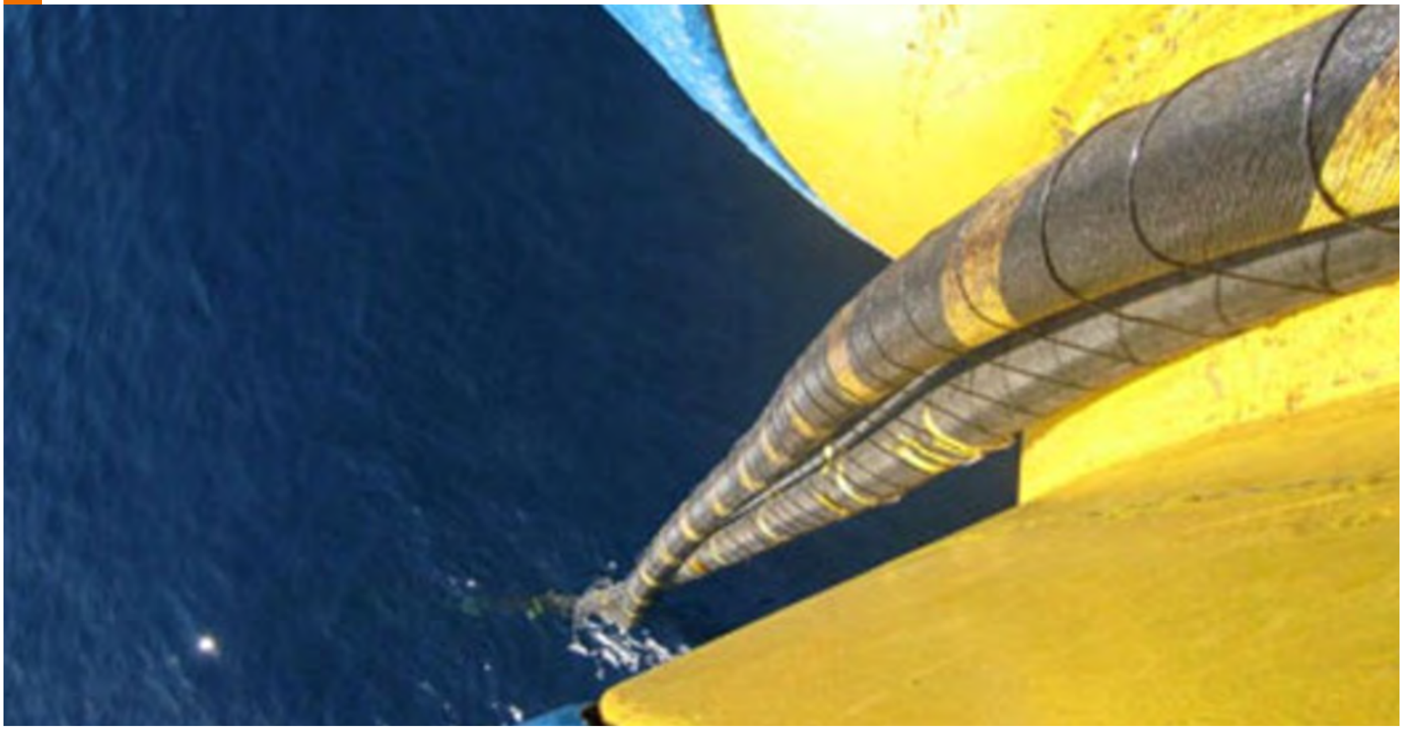


Figure 8. Image of Three Core HVAC Inter-Array (left) and Export Cables (right) Showing Relative Dimensional Differences; See Table 3 for Typical Size Ranges *(Courtesy, EM Works Inc.).*

Figure 9. Image of Basslink Submarine HVDC Cable Showing Relative Dimensions of Components; See Table 3 for Typical Size Ranges *(Courtesy, Prysmian Powerlink).*

3.3.1 Functions (Export versus Array)

An OSW facility comprises a lease area containing the WTGs and one or more OSPs as well as a cable corridor running from the wind farm to the shore landing site. The WTGs generate electrical power at (usually) 33 kV or 66 kV. The OSP collects this power and generally steps the voltage up to between 115 kV and 290 kV to allow for more efficient power transmission and to reduce the required cable size of the export cables.

The WTGs are connected in strings by array cables, which are three-core, armored, medium-voltage alternating-current cables containing one or more fiber optic bundles. Array cables vary in size depending upon their location within the string. The cable that carries the highest load requires larger electrical conductors and therefore may have a greater diameter. The array cables are contained wholly within the lease area. Sections 3.3 and 3.5 further detail the cables and how they are installed and buried.

Export cables transmit the electrical power from the OSP to the grid connection point onshore. The route that the export cable follows is called the cable corridor. The power capacity and the distance from land determines the number of, and sizing, of the export cables. However, it is common to have two or more export cables running parallel for a commercial scale offshore wind farm.

Unlike array cables, export cables are generally armored HVAC three-core cables containing at least one fiber optic package. The optical fibers are used for the windfarm's supervisory control and data acquisition (SCADA) system as well as for temperature (and occasionally acoustic) monitoring systems. However, export cables are of a much greater diameter than array cables and require different installation equipment.

An alternate to HVAC technology is HVDC. HVDC can carry greater power than HVAC and experiences lower transmission losses over distance. However, HVDC systems require large, convertor (AC to DC and vice versa) stations/platforms at either end, rather than simpler, voltage transformers. A rule of thumb is that HVDC technology starts to come into consideration when export cable lengths reach 100 kilometers (km, 62 miles [mi]) or more.

While all the above cable types contain a single layer of galvanized steel armoring, they are very susceptible to damage from external forces. The armoring generally is intended to maintain the physical integrity of the cable and to protect it from over bending and damage during installation, as well as against minor anticipated impacts during its operational life. For example, direct impacts from vessel anchors or fishing gear may damage the cable and quickly lead to failure. The primary line of defense for all submarine cables, and the most effective means of protecting it, is proper burial.

Figures 10 through 12 compare the basic components of an offshore windfarm with HVDC and HVAC systems. Typically, HVAC systems are used unless the transmission distances are too great, in which case HVDC with reactive compensation stations may become more efficient. Please refer to section 3.3 for more details.

Sections 4.3 and 5.2 provide further detail regarding risks to and from the fishing industry.

Figure 10. Simplified Components of an Offshore Wind Farm, Both for HVAC and HVDC Configurations *(Courtesy, Rodrigues et al. 2016).*

(A) Wind Turbine Generator
(B) Array cables
(C) Export cables (HVAC to the left, HVDC to the right)
(D) Offshore Substation Platform (AC)
(E) HVDC converter platform
(F) Meteorological mast
(G) Onshore substations (HVAC & HVDC)

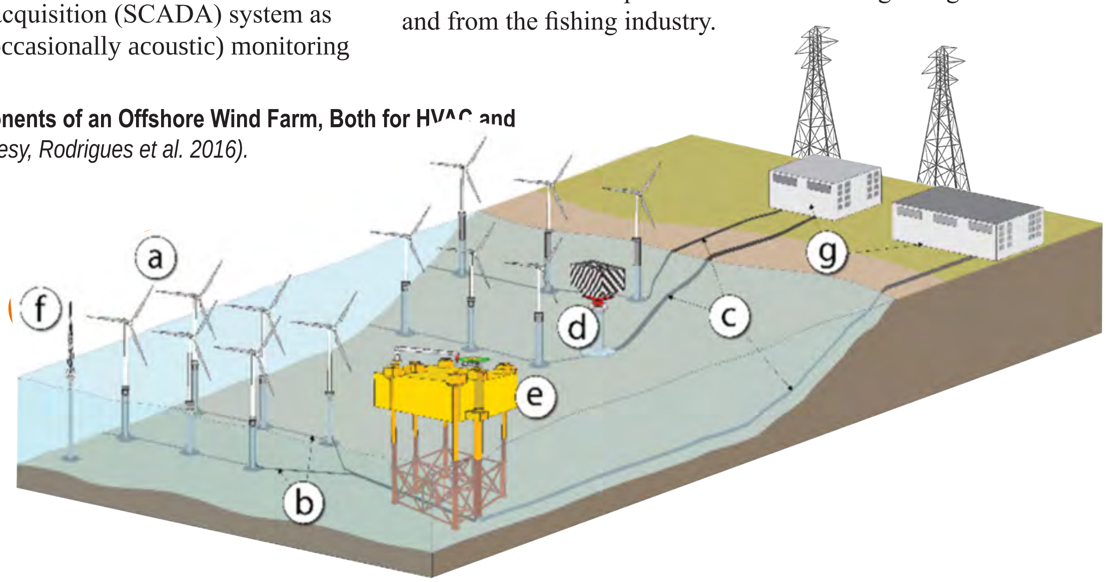


Figure 11. Gemini Offshore Wind Farm HVAC Offshore Substation Platform *(Courtesy, Windpower Engineering & Development).*

Figure 12. Dolwin Alpha HVDC Converter Platform *(Courtesy, TenneT).*

3.3.2 Array Cable Detail

As discussed previously, array cables link the WTGs together, and connect the strings of WTGs to the OSP. Whether rated for 33 kV or 66 kV, they consist of a three-core cable, containing one or more fiber optic packages. The cable is armored with a single layer of galvanized, steel armor wires that are wrapped in bitumen-infused polypropylene yarn that is known as “serving.” Figure 13 shows a three-core, array cable, cross-section. The conductor cross section will depend upon the location of the cable within the turbine string. It is common for there to be three or more different array cable sizes on any project. The largest common array cable has an outer diameter of ~150 mm (6 inches). This design has ethylene propylene rubber electrical insulation yet most array cables use XLPE insulation.

3.3.3 HVAC Export Cable Detail

The configuration of an HVAC export cable is like that of array cable in that there are three power conductors in a trefoil layout plus one or more fiber optic packages contained within a single layer of galvanized steel armoring. However, export cables have a much greater diameter (up to approximately 320 mm [13 inches]) and weight (up to approximately 100 kg/m or 70 lbs/ft) (Figure 14).

Figure 13. Cable Cross Section, Array Cable
(Courtesy, Prysmian Powerlink).

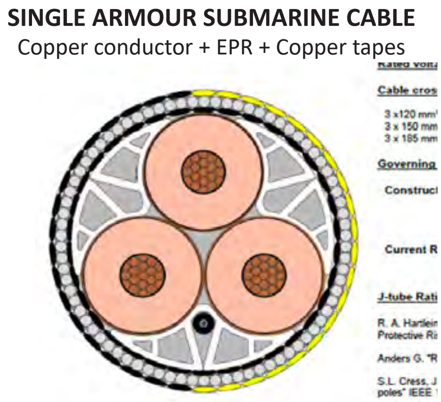
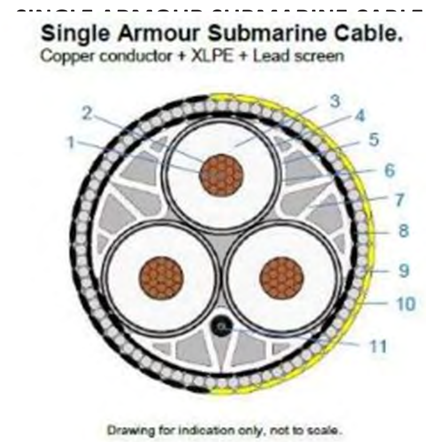


Figure 14. Components of Typical HVAC Export Cable
(Courtesy, Prysmian Powerlink).



3.3.4 HVDC Export Cable Detail

As previously described, it is likely that at some point in the future, the offshore wind industry in the U.S. will utilize HVDC technology. Whether this is for export cables or even a shared transmission system remains to be seen, but the impacts from such cabling would essentially be the same.

There is already one HVDC interconnector cable in operation in the New York Bight area. Figures 15 through 18 illustrate the cable installation and route. The Neptune project links Sayreville in New Jersey to North Hempstead on Long Island, NY and transmits up to 660 MW of power at 500 kV from the PJM grid to Long Island (https://neptunerts.com/). The cable was installed in 2007 and is buried between 4 and 6 feet deep offshore. Any offshore wind export cables that land between Raritan Bay, NJ and Jones Beach, NY will have to cross the Neptune cable.

Figure 15. Neptune Cable Laying Operations
(Courtesy, Neptune Regional Transmission System).

Figure 16. Neptune HVDC Cable Bundle
(Courtesy, Neptune Regional Transmission System).

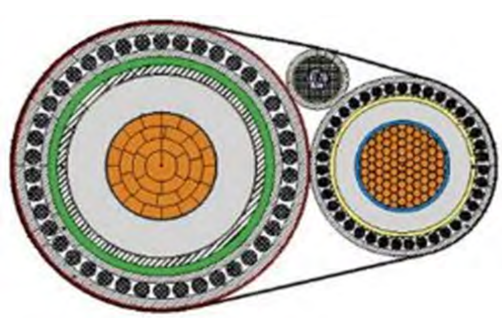


Figure 17. Neptune HVDC Cable Being Bundled during Marine Installation Works *(Courtesy, Neptune Regional Transmission System).*

Figure 18. Neptune HVDC System Route *(Courtesy, Neptune Regional Transmission System).*

3.4 Submarine Cable Installation and Burial

3.4.1 Route Clearance and Pre-lay Grapnel Run

Prior to any submarine cable installation, the route must be cleared of any obstacles that could interfere with the installation and burial operations, or cause post-installation damage to the cable. This work includes the identification of any out-of-service (OOS) cables.

Out-of-service cables are usually cut at points on either side of a new cable's installation corridor and the section crossing the cable corridor removed and scrapped/recycled onshore. The remaining free ends of the OOS cables are usually buried and may have a clump weight attached to pin them prior to burial if required.

Other tasks undertaken prior to cable installation could include boulder removal, although this is not common practice. Every effort is made to micro-route the cable around boulders but occasionally it has been necessary to remove boulders to ensure room for the cable to be laid and buried in European OSW project areas. This may be required for ecological reasons, for example various fish species that use particular boulders for shelter or spawning purposes.

Boulders are usually lifted by a vessel mounted tine grab. Some of these machines have sophisticated control systems, thrusters and positioning equipment to enable them to accurately position themselves over a boulder to facilitate removal (Figure 19).

Figure 19. Boulder Relocation Grab
(Courtesy, Utility ROV Services).

Another method of clearing the route of boulders is by performing a route clearance run using a pre-lay plow (Figure 20). This is a large, towed, steel plow with wings that are designed to be dragged along the seabed prior to a cable installation. The wings are angled outward and push boulders and other obstructions to the side. The below image is of a pre-lay plow that can clear a variable corridor of either 33 or 50 ft (10 or 15 m) in width. The tool weighs 50 tons (45 metric tons) and is about 50 ft (15 m) in length.

The last route clearance activity prior to cable installation is the Pre-lay Grapnel Run (PLGR). This activity is designed to remove any other obstructions that may have been deposited since the surveys, or perhaps were not known about previously. Items typically removed during PLGR operations are wires, ropes, abandoned fishing gear, pipes and tubes, and general debris. It is standard practice to undertake this operation immediately prior to the cable lay operation.

A PLGR can be undertaken by either the cable installation vessel itself, or a suitable third-party vessel such as a tug, small supply vessel, flat back, etc. A typical set of grapnels can be seen in Figure 21, along with a set recovered after it has hooked a wire rope Normally at least one pass is made along the route of each cable, in which grapnels are hauled in every so often to remove any captured debris.

Figure 20. Pre-lay Plow for Route Clearance
(Courtesy, Oceaneering).

Figure 21. Typical PLGR Grapnel Rig
(Courtesy, Offshore Marine Management).

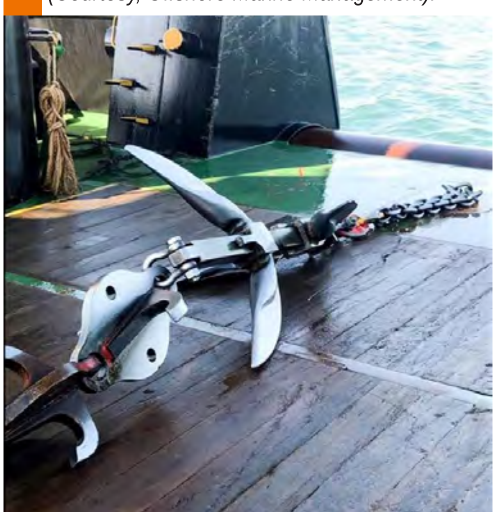


Figure 22. Grapnels Containing Wire Rope Recovered to Deck
(Courtesy, C&S Offshore Services).

3.5 Cable Installation–Export

Once the cable route has been cleared, the cable installation operations can commence. As previously detailed, export cables are significantly larger, heavier, and more expensive than array cabling. Additionally, the export cable route is longer spanning from the offshore substation to the shore landing with (ideally) as few cable joints as possible.

The above factors mean that the vessels utilized to install export cables generally differ from those that install array cables. Export cables benefit from as few offshore joints as possible; making vessels with large cable capacities advantageous over small vessels. Array cable installation vessels must maneuver around WTGs as well as be flexible enough to load cable that can be delivered in a variety of ways to a variety of locations, such as on reels, cut to length and in various lengths. See section 3.6 for further clarification. Another important point is that HVAC export cables in general can't be coiled and tanked. This means that a powered turntable is required on the Cable Lay Vessel (CLV) as the cable cannot be coiled into either a fixed or temporary cable tank.

A typical export cable will weigh approximately 275 pounds per yard (100 to 125 kg/m) in air; therefore, every mile of cable weighs approximately 240 tons (t). A vessel with a turntable capacity of 5,000t can only lay 20 miles of cable before having to return to the cable factory or port where the cable is stored before loading. Selecting a vessel of increased cable capacity (for example to 10,000t) significantly eases the logistical constraints as well as reduces the number of offshore joints required through the reduction of required cable segments. A few typical export CLVs are shown in Figures 23 to 25.

NKT's vessel Victoria (shown in Figure 23) is a DP3 CLV, delivered in 2017, 460 ft (140 m) in length, a 100-ft (30-m) beam with a Gross Tonnage of 16,171 GT. She has two powered turntables, a 7,000t basket carousel on the main deck and a 4,500t basket carousel below decks. However, she is only rated for a combined cable capacity of 9,000t. Additionally, the vessel is designed to be "beachable" (27-ft [8.25-m] beaching draft), which means the vessel can sit on her hull, grounded if need be in order to get as close to the shore as possible when performing shore landings.

Figure 24 shows Van Oord's CLV, the Nexus. She is a 403-ft (123-m) DP2 CLV built in 2014. The Nexus can carry 5,000t of cable in a single above deck cable carousel.

Figure 23. NKT Victoria *(Courtesy, NKT Cables).*

Figure 24. Van Oord Nexus CLV *(Courtesy, Van Oord).*

The newest CLV currently under construction is Prysmian's Leonardo da Vinci (Figure 25). The keel was laid in September 2019 with delivery planned for Q2 2021. She will have a length of 561 ft (171 m), a beam of 112 ft (34 m) with a total cable capacity of 17,000t in two carousels, one of 10,000t and the other of 7,000t.

Figure 25. Leonardo da Vinci CLV
(Courtesy, The Prysmian Group).

As sections 3.5.1, 3.5.2, and 3.5.3 describe, installing an export cable can be broken into three discrete phases: the shore landing, the main lay and then the pull into the OSP. If the cable can be laid in one continuous length (very rare due to the long lengths involved), the decision has to be made whether to lay from shore out towards the OSP, or from the OSP towards shore. In either case, the second end installation is the more complex of the two operations. Most often, export cables cannot be laid in one continuous length, and one or more offshore splices or joints are required. In this case, both the shore end and OSP pull in can be the simpler (and less risky) first end pulls. Each of the phases is described in greater detail below.

3.5.1 Shore-End Installation

A shore landing, or cable landing point is the location at which a submarine cable makes landfall. It most often pertains to the section of submarine cable stretching from the beach manhole or transition pit (where the submarine cable joins onto the land cable) out to deep enough water that the CLV can safely operate. Figures 26 through 29 illustrate installation of the export cable.

The Beach Manhole (BMH) or transition pit is constructed at a suitable location onshore in advance of the cable laying operation. The export cable will be pulled into this pit via winch. There are two main ways in which the export cable will approach the transition pit. The most common way is via a duct installed by Horizontal Directional Drilling (HDD). The other is via direct burial. The latter method involves digging a trench using an excavator, which is subsequently backfilled after the cable is installed, while HDD is a trenchless method designed to minimize impacts at the cable landing.

Most often, the main CLV will approach the shore and get as close as practical. This is usually the 10 m water depth contour, but as seen previously, some CLVs are capable of operating in shallower water or even beaching if the tidal range and seabed conditions permit. Next, the pullwire or rope will be connected to the cable end and the pull-in operation begins. The cable will be pulled into the BMH via a shore mounted winch, through the HDD duct or on rollers in the case of direct burial. If the CLV cannot get close to the HDD duct exit, it may be necessary to pull the cable in towards shore on floats to avoid dragging the cable along the seabed. The cable is then positioned properly, and the floats are disconnected one at a time, allowing the cable to land precisely along the planned Route Position List.

Once the cable end has reached the transition pit, it is secured firmly, the floats are removed via divers or small boats and then the CLV can lay from the beach towards the wind farm. If a plow is being used to bury the cable (see section 3.7.1), this can be placed on the beach (direct burial) or in shallow water near the offshore end of the HDD, the cable will be pulled in through it so that plow burial operations can commence in as shallow water as is possible. The following photos show some of these operations with greater clarity.

Figure 26. Triton Knoll Offshore Wind Farm Export Cable Pull-In at the Transition Pit *(Courtesy, Triton Knoll).*

Figure 27. Horizontal Directional Drilling (HDD) Operations *(Courtesy, Dudgeon Offshore Wind Farm).*

Figure 28. Image Showing Preparations for Pulling the Export Cable into the HDD Duct, with the Offshore End of the Duct Above the Low Water Line *(Courtesy, C-Power).*

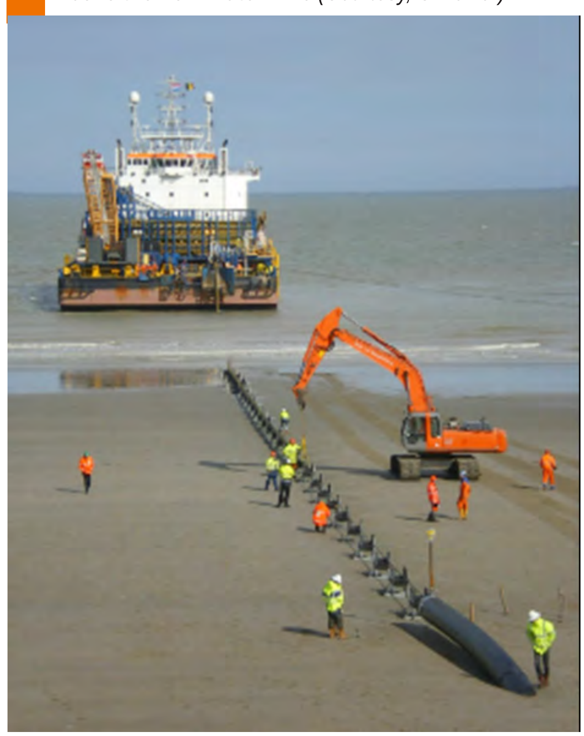


Figure 29. Image Showing Preparations for Pulling the Export Cable into a Plow *(Courtesy, VBMS/Boskalis).*

3.5.2 Main Lay

Once the shore landing is in place, the installation of the main submarine export cables can commence. There are two main installation and burial methods. Surface lay is when the cable is laid on the seabed and is subsequently buried in a separate operation shortly afterwards. Simultaneous lay and burial is when the cable is laid and buried in the same operation. Sections 3.7.1 and 3.7.2 explain these in greater detail. The choice of installation and burial methodology will be determined by:

- The water depths and soil types encountered along the route
- The required burial depth
- The equipment available within the marketplace
- Preference of the project developer or permitting authority requirements

The tension at which the cable is laid is critical. Too little tension, and the cable will overbend at the touchdown point or loop around itself; however, too much tension and the cable will not conform to the seabed or accommodate burial. The cable lay is planned and often modeled in advance using specialized software, then this software is used to ensure that the cable is laid in accordance with the plan.

It is usually necessary to splice together several sections of export cables during installation, to create the length required between the OSP and BMH. This is because the weight and volume of cable is too great to be loaded onto the CLV as a single span. There are two basic configurations of offshore cable splices. The first is an in-line joint, the second is an Omega joint.

In-line Cable Joint

During cable lay operations, it is possible to splice the start of a new cable section onto the end of the previously laid section. Once the joint is complete, it is laid over the stern prior to the lay of the rest of the cable section. This joint ends up on the seabed in line with the cable route, hence the name.

Omega Joint

It is common that during the lay and required during a cable repair that an Omega joint will be utilized (Figures 30 through 32). In this situation, the two cable ends are overlapped, and the joint is usually performed by a vessel of opportunity. This is because a power cable joint takes approximately a week to construct. This is expensive if done on a CLV, which are often in great demand as well. An Omega joint has this name because it results in a bight of cable laid to the side of the main cable route that looks like an ‘Ω’ when viewed from above. The three images below show some typical power cable joints being deployed. As can be seen below, they are considerably larger than the cable itself and can be quite unwieldy for the handlers. Generally, these cable joints are buried to the same depth as the rest of the cable. Some of the burial techniques applicable are Mass Flow Excavation, post lay burial by jetting Remotely Operated Vehicle (ROV), or pre-dredging followed by backfill. Section 3.7 contains further details regarding these burial techniques.

Figure 30. Cable Repair Joint with External Cable Protection *(Courtesy, Thanet Offshore Windfarm).*

Figure 31. Lifting Cable Repair Joint with External Cable Protection *(Courtesy, NKT Cables).*

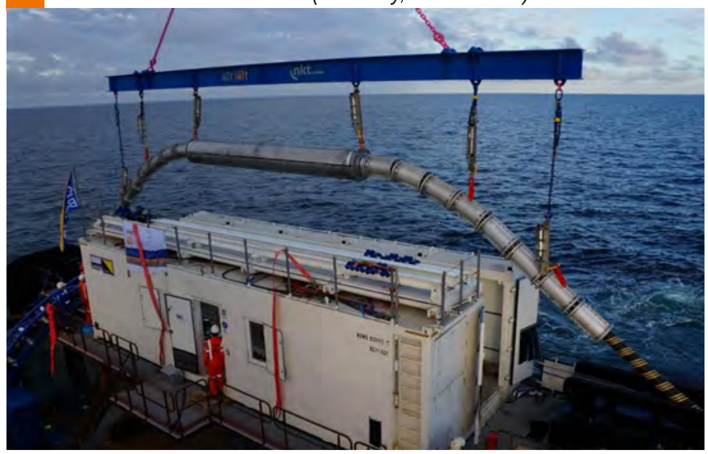


Figure 32. Deploying Cable Repair Joint *(Courtesy, NKT Cables).*

3.5.3 Offshore Substation Platform

As previously described, the OSP is an offshore structure containing electrical switchgear and transformers that steps up the WTG power voltages to transmission voltage. One or more, usually between two and four, export cables link the OSP to shore.

As with the shore landing, the export cable installation at the OSP can either be a first-end pull, or a second-end pull. A first-end pull is by far the preferred method. It involves the CLV backing up to a position close to the OSP and receiving a messenger wire from the J Tube (a J Tube is a steel structure that protects the cable between the seabed and the foundation). This messenger wire is retrieved and attached to the cable end onboard the CLV. Then, a winch on the OSP hauls in the messenger wire and the cable while the cable engines on the CLV pay out the cable carefully under appropriate tension. The cable is then retrieved through the J tube before being anchored onto the OSP at a point called the “cable hang-off.” This is a clamp at the top of the J tube where the cable’s armor wires are secured while the cable is connected.

The second-end installation is far more complicated because the lay vessel already has the cable leading towards shore in the water. This process is difficult and risky for a large export cable that must be handled carefully. For further details on second-end installation see section 3.6.3. Once the hang-off is installed, the CLV can commence cable lay operations away from the OSP towards shore. These are further depicted in Figure 33, which shows an illustration of an OSP with submarine cables leading in towards the J tubes. Note that these cables would be protected by a Cable Protection System (CPS) and would be buried. Additionally, scour protection would be placed around the foundations of the OSP. Additional details regarding cable protection are included in section 3.7.5. Additionally, Figure 34 shows an export cable pull-in operation taking place. In this example, once the cable is clamped, the vessel will deploy the plow and then simultaneously lay and bury from the OSP towards the shore.

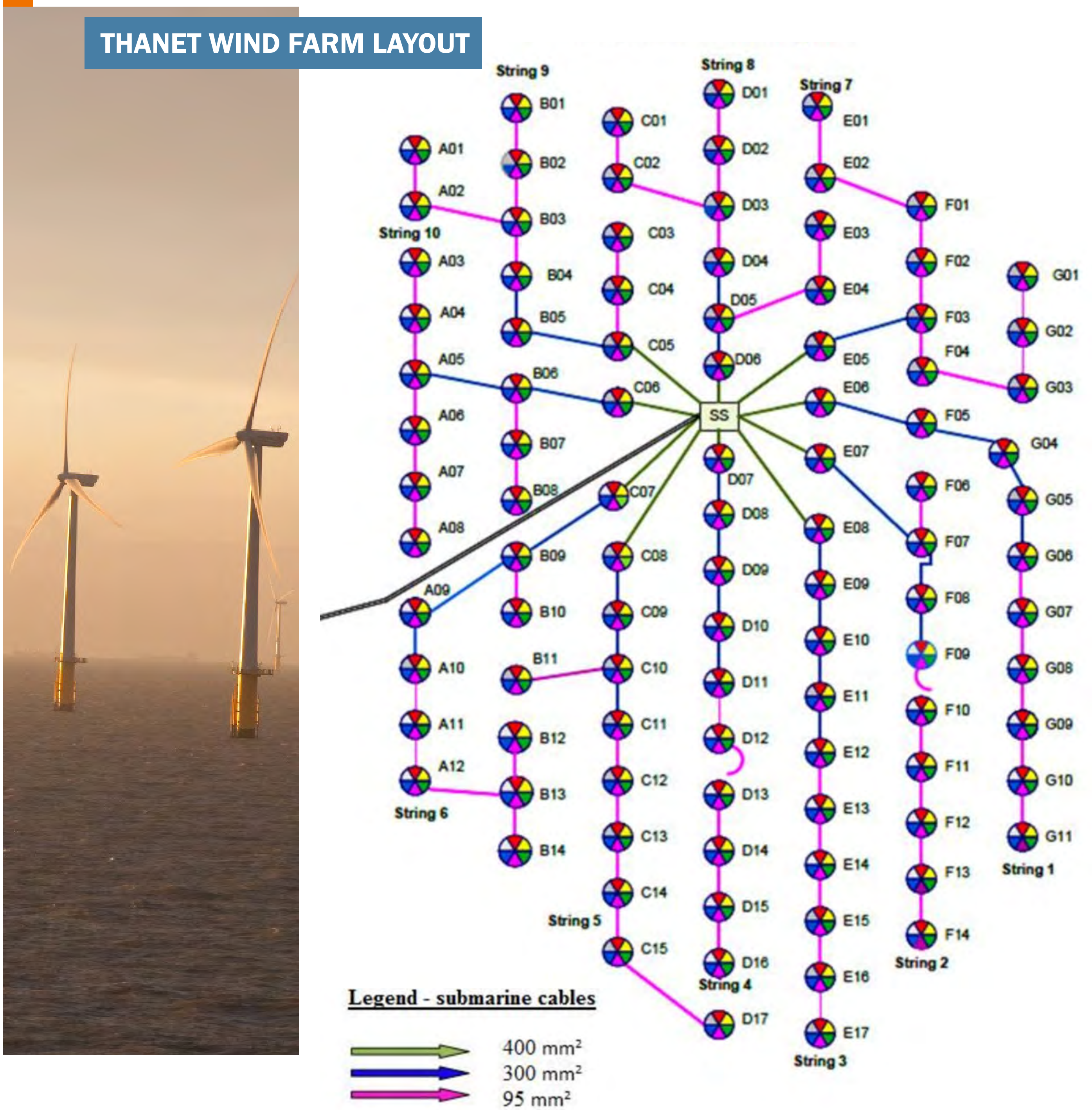
Figure 33. OSP Illustration Showing the Submarine Cables *(Courtesy, Ramboll UK).*

Figure 34. Export Cable Pull-In and Plow Deployment at the OSP *(Courtesy, Boskalis).*

3.6 Cable Installation—Array Cabling

As previously described, array cables join the individual WTGs together and connect the strings of WTGs to the OSP, which are subject to developer-specific engineering constraints. Figure 35 shows a layout schematic of the Thanet offshore wind farm off the South East of the UK. This project consists of 100 turbines in 10 strings, connected via array cables of three different cross sections. The bigger cables, with the larger electrical conductors are at the "inboard" end of each string and connect to the OSP. The outer turbines in each string are connected by the smaller cables.

Figure 35. Thanet Offshore Wind Farm Layout and Photo *(Courtesy, Vattenfall).*



While the mechanics of laying array cables are mostly the same as for export cables, in practice, there are key differences. Array cables can be delivered in a variety of ways as they must fit the containment areas on the vessels that install them, including:

- On individual reels, one array cable per reel;
- In short lengths, separately but loaded into cable carousels on the vessel
- In long lengths and then cut to length during installation

Array cable installation projects involve a series of repetitive actions, for example, multiple first and second-end pull-ins per day. Therefore, the speed and efficiency of each operation is critical. WTGs are approximately up to 1 nm apart, so vessels need to be maneuverable. The work involves landing teams of people onto the WTGs. Array cables are buried, but plowing is problematic because:

- Launching and recovering a plow is time-consuming, this would need to be done for every cable
- Plows are towed; therefore, it is hard to achieve burial close to the WTGs

Therefore, post-lay burial is the preferred burial methodology for array cables.

3.6.1 First-End Installation

As stated previously, a first-end pull is the simpler pull-in operation (Figure 36). The vessel will approach the WTG and retrieve the messenger wire that will have been pre-installed into the J-Tube. There will have been a team already placed on the tower, either by crew vessel or via a heave compensated gangway from a Service Operations Vessel (SOV) or crew transfer vessel (CTV).

The vessel will attach the messenger wire to the cable end, a CPS will have been applied to the cable prior to this. The CPS is an interlocking system that latches into the end of the J-Tube (or aperture on the foundation) and prevents the cable from overbending. It also mitigates the risks of damage from foundation scour protection and affords cable protection in the area of transition to burial.

A winch on the WTG will pick up, while the CLV pays out cable until the cable end and CPS are at the J-Tube bell mouth (Figure 37). This operation will be monitored via ROV to ensure proper installation. Once the cable end is in the J-Tube, a weak link will break by design, which leaves the CPS latched in place while the cable is free to be pulled up through the J-Tube into the WTG, where it is then temporarily clamped in place.

Figure 36. First-End Pull-In *(Courtesy, Jan de Nul).*

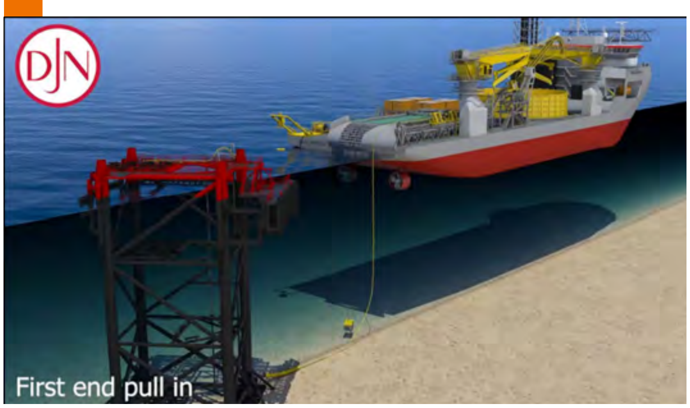
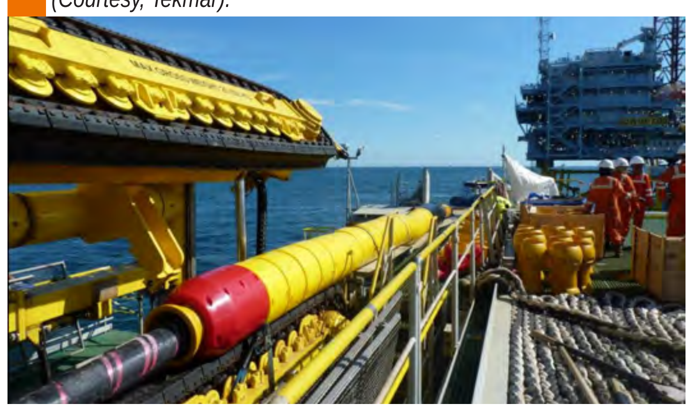


Figure 37. Cable Protection System Prior to Installation *(Courtesy, Tekmar).*



3.6.2 Main Lay

Once the first end is in place and clamped, the CLV will move away towards the second WTG. As stated above, while it is theoretically possible to plow the array cables in, this practice is very seldom done due to time constraints and the impossibility of burying the entire array cable, which would necessitate remedial burial every time.

Once the first end has been pulled in and is secure, the vessel will move towards the second WTG, paying out cable as it goes. This can be a quick process as the distance between WTGs is generally up to 1 nm. Once the vessel approaches the second WTG, it will stop and prepare for the second-end installation (Figures 38 and 39).

Figure 38. Array-Cable Installation Vessel (Foreground) and Service Operation Vessel (SOV) Background *(Courtesy, Seaway 7).*

Figure 39. Array-Cable Installation *(Courtesy, Nordsee Ost Windfarm).*

3.6.3 Second-End Installation

The second-end cable installation is more complex, time-consuming, and riskier than the first-end installation. Over time, the industry has seen a variety of ways to accomplish the second-end installation, but the method that has had the most success is the utilization of a deployable quadrant (seen on deck in Figure 40 and deployed in Figure 41). The basic steps of a second-end pull-in are as follows:

- Vessel lays cable on the seabed from the first end toward the second end.
- Once the vessel nears the second Wind Turbine Generator (WTG), it holds station.
- The cable is cut onboard, ensuring there is enough slack to reach up the J Tube to the cable deck on the WTG.
- The CPS is applied to the cable end.
- The cable end is sealed and a pulling head is attached.
- The messenger wire from the J Tube is recovered and attached to the cable pulling head.
- The tower team winches in the messenger wire as the vessel deploys the quadrant and lowers it to the seabed. The vessel maneuvers during this time as needed.
- Once the quadrant is at the seabed, it is toppled to release the cable, any slack is pulled in from the WTG.
- The operation is monitored by an ROV to ensure the cable is not compromised.

Figure 40. Cable Deployment Quadrant on Deck *(note CPS sections stored below) (Courtesy, Merkur Windfarm).*

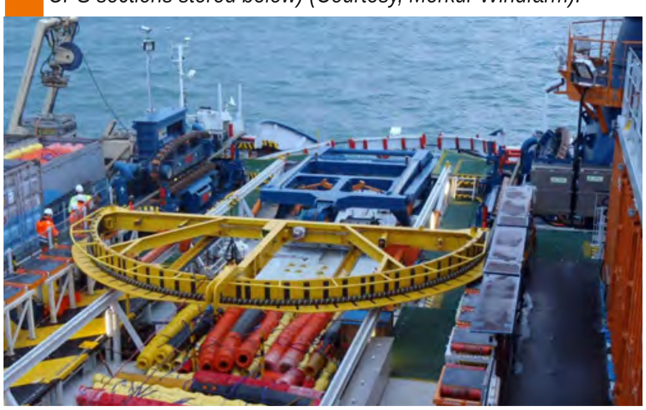
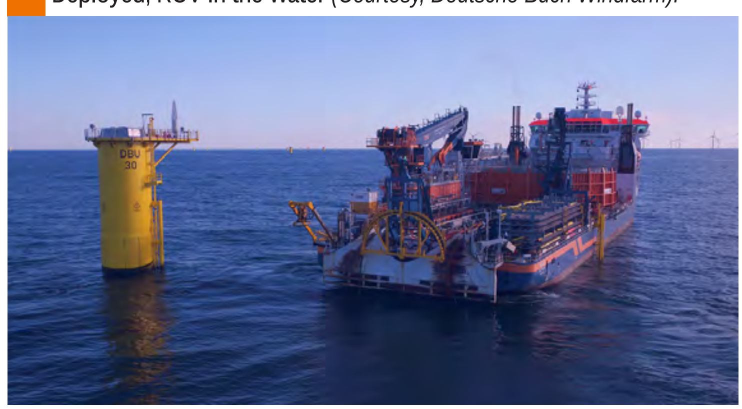


Figure 41. Second-End Array Cable Installation, Quadrant Being Deployed, ROV in the Water *(Courtesy, Deutsche Buch Windfarm).*



3.7 Cable Burial

The primary method of both protecting submarine cables, and ensuring the viability of the offshore project is achieved via burial. To recap, the depth of burial is specified by:

- Government regulations, such as USACE requirements as permit conditions.
- A CBRA that takes into consideration the threats (shipping anchors, fishing activity, etc.) and the soil types to determine the required depth of burial that will minimize risks to the cable.

There are three main installation methods when it comes to cable burial, these are:

- **Simultaneous lay and burial:** The cable is buried as it is laid, in the same operation and by the same vessel.
- **Post-lay burial:** The cable is laid on the seabed and is subsequently buried during a separate operation, either by the CLV itself or via a trenching support vessel.
- **Pre-lay burial:** A trench is excavated into which the cable is laid. This can then be backfilled or left to backfill naturally.

The choice of which method to use on a project is driven by factors such as the soil type, the installation contractor and their tool availability as well as the operation itself, such as whether it is array cabling, export cabling or bundled HVDC installation. Lastly, certain cable burial methodologies may be encouraged or prohibited by the regulatory authorities.

Figure 42. Power-Cable Plow *(Courtesy, Soil Machine Dynamics Ltd.).*

Figure 44. Power-Cable Plow on the Beach at Export Cable Pull-In *(Courtesy, VBMS/Boskalis).*

3.7.1 Simultaneous Lay and Burial

Simultaneous lay and burial involves the CLV burying the cable as it is installed. This is rarely done for array cables but common for export cables. There are several ways that this can be achieved.

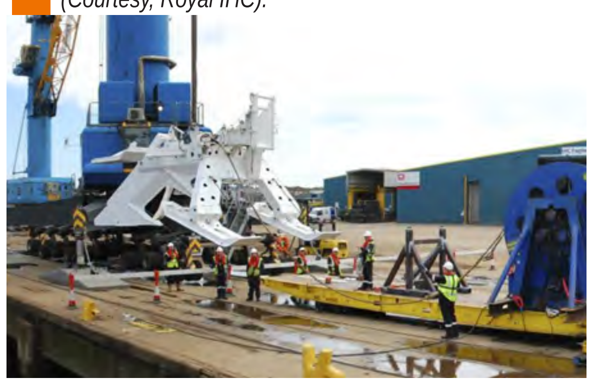
Cable Plows

A cable plow is a towed tool that passively cuts the seabed with a plow share, into which the cable is simultaneously inserted whilst progressing forward (Figures 42 through 45). Plows can have a water jetting function, which is a means of reducing towing forces required for cutting, rather than increasing burial depth. The latest power-cable plows can typically bury the cable to 10 ft (3 m). These plows weigh approximately 50 tons and are approximately 50 feet in length and 20 feet in both width and height.

Cable installation specialists can bury cables in a wide range of soils, with shear strengths of 5 kilopascals (kPa, a unit of pressure used to quantify the tensile strength of the soil) up to about 350 kPa, which is much harder soil than can be jetted. The downsides of installing in stiff soils include a high bollard pull requirement, difficulty in approaching/burying close to structures and the need for careful management of the cable catenary to prevent damage to the cable during installation.

Figure 43. Power Cable Plow Burying Cable in an Intertidal Zone *(Courtesy, Boskalis).*

Figure 45. Sea Stallion Power-Cable Plow *(Courtesy, Royal IHC).*



Towed Jetting Sleds

Another method of simultaneous lay and burial is using a towed jetting sled (Figures 46 and 47). These are sometimes referred to as "plows," which often lead to confusion. These machines range in size from those capable of 5-ft (1.5-m) burial depth up to some of the largest versions that are capable of approximately 25-ft (8-m) burial depths under the right sediment conditions.

The key features of a jetting sled are:

- The sled is towed behind a vessel or barge.
- It achieves cable burial by means of a jetting tool that straddles, or encapsulates the cable that is then lowered into the seabed once the sled moves forward.
- The water for the jetting system is usually supplied from water pumps mounted on the host vessel.
- They can operate in very shallow water, or even on the beach, but typically are restricted to a maximum water depth of approximately 100 ft (30 m).
- They work well in soft soil conditions but can struggle in harder soils (as do all cable burial systems that employ jetting as their burial methodology).

Figure 46. Jetting Sled Suspended From a Crane, Showing the Water Jet Pattern of the Burial Tool *(Courtesy, ETA Engineering Ltd.).*

Figure 47. Large Jetting Sled (BSS-II) Suspended from a Crane During Launch *(Courtesy, Boskalis). This sled can bury cable 25 ft (8.0 m) and also has a rock cutting tool capability.*

Tracked Trencher

A variation of a jetting sled is a tracked trencher (Figure 48). Tracked trenchers primarily use water jetting as means of achieving cable burial but instead of passively being towed by a host vessel, they drive on tracks, usually made of a hard, plastic material.

This category of burial tool encompasses simpler machines that obtain their jetting water supply from vessel mounted pumps, all the way through to sophisticated machines that have onboard water pumps and can possess chain or wheel cutters to enable trenching in harder soil conditions. Tracked trenchers come in a variety of configurations. Some simultaneously bury as the cable is laid, others post-lay and bury and some can do either. Even though a tracked trencher is technically an ROV, they are heavy in water and do not have thrusters. This means that they are not able to maneuver within the water column as a traditional ROV can, so the trenchers are generally categorized as tractors.

Since these trenchers use water jetting, they have similar limitations as jetting ROVs in that soil strengths of approximately 100 kPa are likely their maximum. However, due mostly to the fact that these trenchers are so heavy, they offer more traction than a free-flying ROV and are often are more successful in burying through harder soils. Conversely, they struggle in softer seabed conditions as they can sink into the soil due to their weight.

Many of these tracked trenchers can deploy a chain cutter or less frequently use a cutting wheel to enable cable burial in high strength, cohesive soils, and even through soft rocks. This process is quite slow and expensive as well as time consuming, both requiring intensive maintenance programs. Some of these trenchers can only deploy a rock cutter if they're in simultaneous lay and burial mode, others can position over a previously laid cable and pick it up off the seabed, thereby allowing the deployment of a chain cutter. The below images show several tracked trenchers, from the smaller, simpler tools to the extremely large and most powerful machines.

The trencher "Otter," seen in Figure 48, is 25 ft (8 m) in length, 14 ft (4.2 m) in width and weighs 8.2 tons in air. It has two jet tools, one capable of burial depths of 5 ft (1.5 m) and the other of 7 ft (2.2 m), in sandy or clay-dominant soil types of up to 25 kPa shear strength. Additionally, there is an optional chain cutter capable of cutting a 7-ft (2.2-m) trench depth in stronger sands, clays, and soft rocks. This machine is most suitable for the post-lay burial of array cables due to the maximum cable diameter of 7 inches (180 mm).

Figure 48. Tracked Trencher "Otter" Deployed During Array-Cable Burial Operations *(Courtesy, ETA Engineering).*

Some larger, more powerful tracked trenchers include I-Trencher, Deep Dig-It, CBT2400, and T3200.

I-Trencher (Figures 49 and 50) is a large, tracked trencher, weighing approximately 80 tons in air that is designed to trench hard seabed using a chain cutting tool and cut trenches up to 9 ft (2.7 m) deep. It can operate in water depths of up to 4,921 ft (1,500 m), so it has onboard water pumps and hydraulic power units. I-Trencher can trench hard soils and clays of up to 600 kPa (as claimed by Canyon Helix), as well as trenching through fractured rock, albeit at a slower forward speed. This machine does not use jetting as a burial technique, so is usually paired with a jetting ROV to ensure that one vessel can bury cable in a variety of soil types. I-Trencher is a post-lay burial machine. It is deployed to straddle the surface-laid cable, which the trencher then picks up with fore and aft mounted grabs. The chain cutter is then swung into position and the cable is lowered into the trencher's cable pathway. I-Trencher then moves forward, grading the burial tool and cable into the trench as it moves along.

Deep Dig-It (Figure 51) is a tracked trencher owned and operated by Van Oord, a Dutch marine contractor. The machine has a jetting and cutting tool that can bury cable to 19 ft (5.8 m). It has 2,400 horsepower of onboard power but, as shown above, obtains jetting water from pumps mounted on the host vessel.

Similar trenchers are Boskalis's CBT2400 (Figure 52) and DeepOcean's T3200 (Figure 53 and Figure 54). Each operator will have differing requirements and specifications, meaning there will be many subtle differences amongst superficially similar machines. However, all these tractors are heavy in water, meaning they cannot move using thrusters, but instead are deployed to the seabed on a high-strength lifting umbilical or via crane for shallow water machines.

Figure 52. Boskalis CBT2400 at Final Inspection Prior To Delivery
(Courtesy, Soil Machine Dynamics).

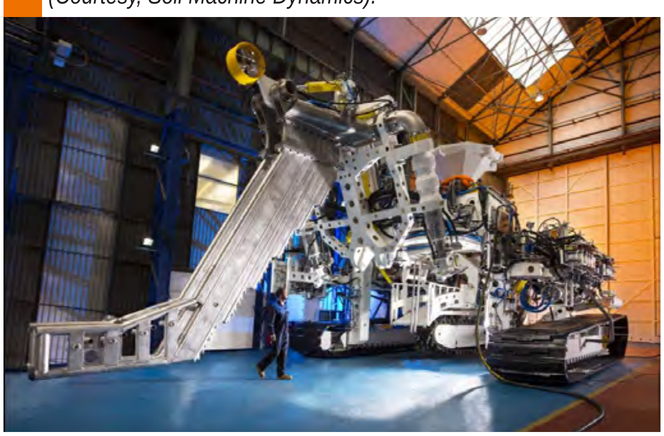


Figure 49. I-Trencher On Deck
(Courtesy, Royal IHC/Canyon Helix).

Figure 50. Launching I-Trencher
(Courtesy, Royal IHC/Canyon Helix).

Figure 51. Launching Deep Dig-It
(Courtesy, Van Oord).

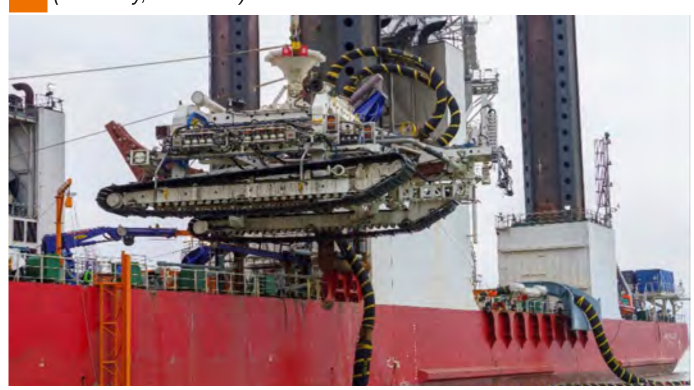
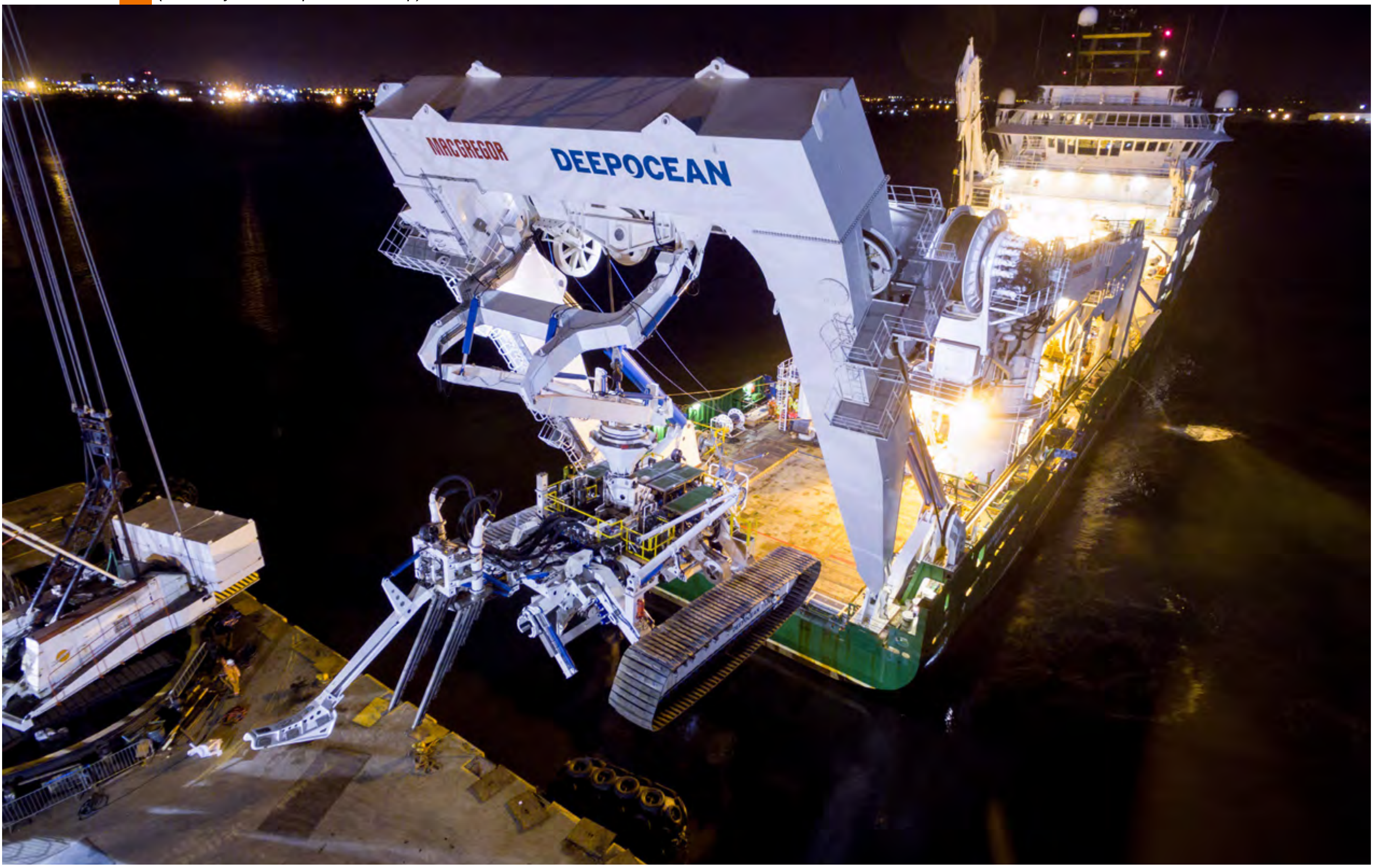


Figure 53. DeepOcean T3200 Lifted from Quayside
(Courtesy, the DeepOcean Group).

Figure 54. DeepOcean T3200 Mobilized onto the Havila Phoenix *(Courtesy, the DeepOcean Group).*



To summarize, these tracked trenchers come in a variety of sizes, configurations, capabilities, and are flexible tools in that they can achieve deep cable burial in a range of soil conditions. Several marine contractors use these types of machines, which means the project developers should not be limited by the supply chain when it comes to bidding the cable supply and installation scopes. Additionally, as the trenchers are self-propelled (not towed), they do not need a high-bollard pull vessel to operate. A disadvantage to these tools is their weight, causing them to struggle in soft soil conditions. This weight, conversely, gives them excellent traction in stiffer soil conditions.

Vertical Injector

Vertical injectors are barge-mounted tools that are suspended in the water via crane and are connected to the barge via winch mounted wires (Figures 55 through 57). These simultaneous lay and burial tools utilize water jets to fluidize soil to create a trench for the cable deployed from the tool's depressor foot, while the vertical injector is kept in a stable vertical position by a crawler crane and horizontally by pennan wires. This enables operation of the vertical injector independently from seabed slopes and sand waves. It is able to deal with significantly steeper seabed slopes than any skid or tracked operated burial tool. They are capable of 33 ft (10 m) of burial depth in the right (soft) soil conditions. It is possible to attach rock cutting tools to the injector for use in hard soil or grapnel hooks for pre-lay jetting runs, but injector tools are commonly used purely in water-jetting mode and can achieve deep burial in soft soils. They are limited to water depths of a maximum of approximately 100 to 130 ft (30 to 40 m) and can operate in very shallow water due to the fact that they're deployed from an anchor moored barge with pumps that supply the jetting water. Only a handful of marine contractors operate vertical injector tools, which can limit the installation options available to project developers.

Figure 55. Vertical Injector Tool Schematic *(Courtesy, NSW/General Cable).*

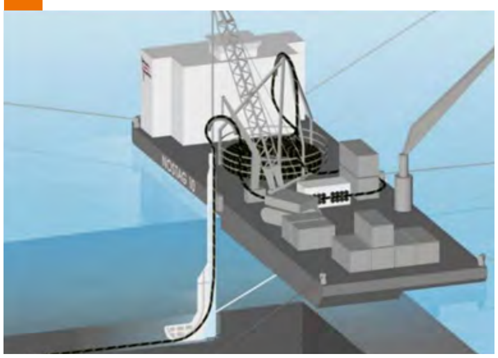


Figure 56. Vertical Injector Tool Schematic and View on Deck (for scale) *(Courtesy, Burbo Bank Wind Farm).*

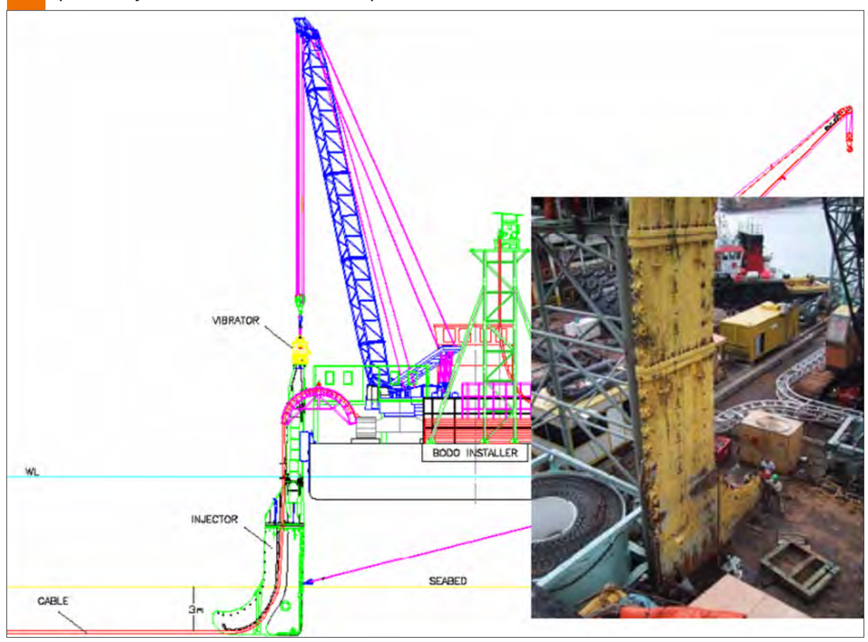
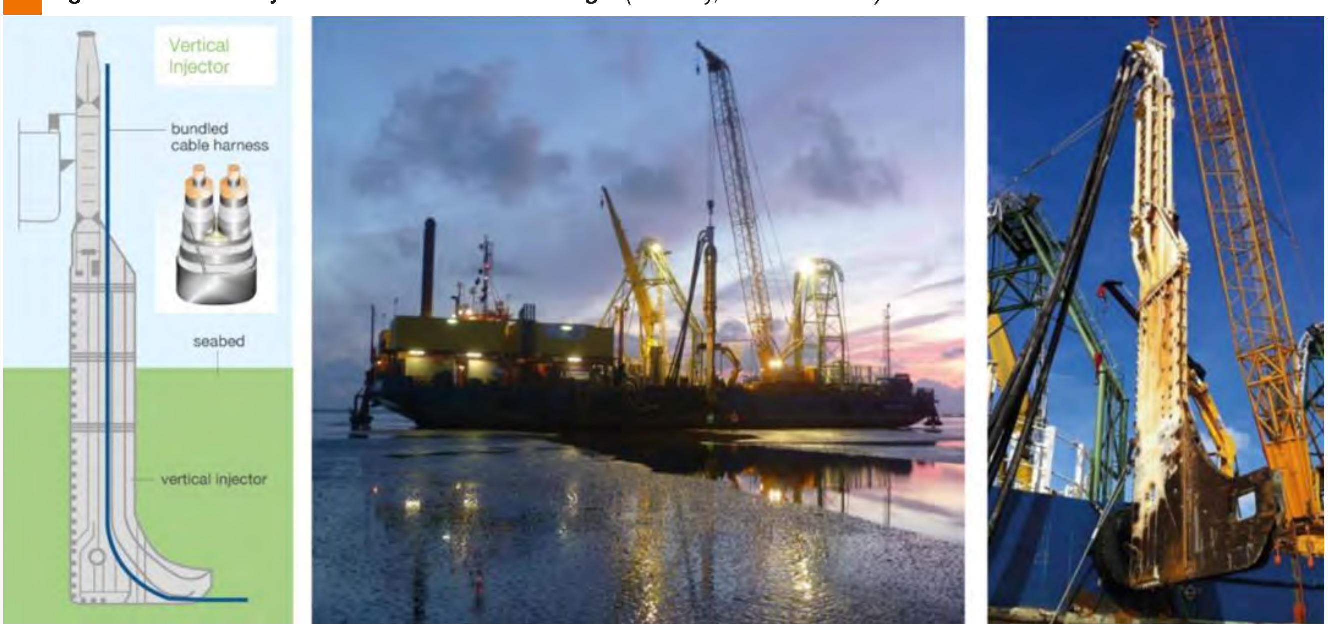


Figure 57. Vertical Injector Tool Schematic and Images *(Courtesy, TenneT/Nordlink).*



3.7.2 Post-lay Burial

As described previously, submarine cables can be buried, either during the lay operations, or in a separate operation after laying. In this latter case, the burial method terminology is Post-lay Burial, which is done for several possible reasons:

- The cable laying operations go far more quickly, thus saving time and reducing costs. The CLV is usually more expensive than a support vessel performing burial operations.
- This approach maximizes weather windows. In simultaneous lay and burial operations, a longer weather window is required as the CLV cannot easily stop in the middle of a cable section to run and avoid poor weather. Waiting for such a weather window can add long delays to a project. Short duration weather windows are far more frequent, which means a shorter installation duration for the CLV, as well as more frequent opportunities to make progress with burial operations.
- Simultaneous lay and burial is quite complicated for array cable installations; therefore, post-lay burial is more efficient.
- Cable joint housings are buried post-lay or the joint can be laid into a pre-dredged area and subsequently backfilled if the exact location is known; however, joints cannot be plow buried. (see section 3.7.3.)
- Post-lay burial tools are capable of burying cables adjacent to structures, crossings, etc., thereby ensuring that burial is achieved along the entire cable length.
- When soil conditions are better suited for post-lay burial and water jetting methodologies, this is the better option.

Remotely Operated Vehicle (ROV)

The most common post-lay burial tool is an ROV (Figures 58 through 60). These are unmanned vehicles deployed from a host vessel and controlled from the surface. They are connected to the host vessel via an umbilical that contains the electrical connections for vehicle power, as well

Figure 58. T-1200 Trenching ROV *(Courtesy, Helix Energy Solutions).*

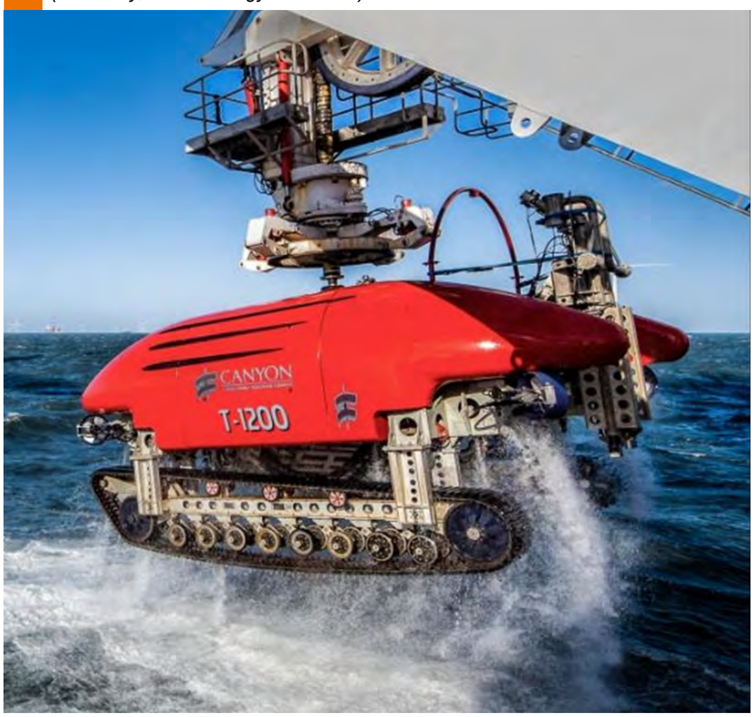


Figure 59. T1000 Trenching ROV *(Courtesy, DeepOcean).*

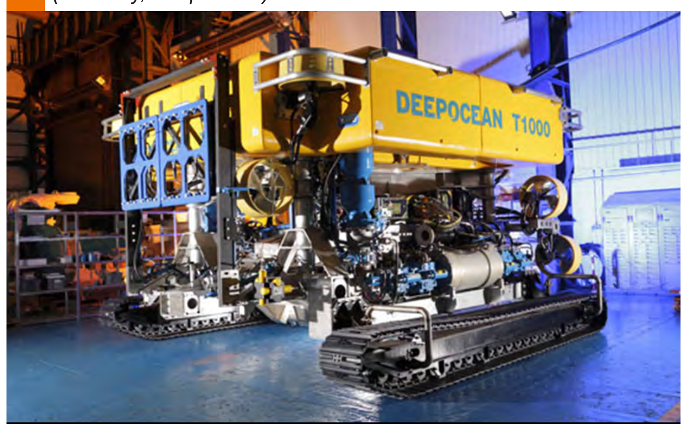


Figure 60. Trenching ROV in Free-Flying Mode Showing Jetting Tool *(Courtesy, Soil Machine Dynamics).*

as fiber optics for video and data transmission. ROVs come in all shapes and sizes, from small observation class vehicles up to large, powerful work class vehicles. This section concentrates on the latter as work class vehicles are required to meet cable burial demands.

All ROVs work on similar principles in that the vehicle will have a variety of hydraulic and electrical systems onboard. The electrical power from the surface will drive one or more of the hydraulic power units onboard the ROV. Hydraulic power is generally used for the vehicle thrusters, track drives, various tooling deployment, water pumps (which also can be electrical), and manipulator arms, etc.

All ROVs achieve cable burial via water jetting. The ROV will align itself over the cable and then move off, grading in the burial tool while jetting. The number and combination of jetting nozzles can be configured to consider local soil conditions. For example, small, high pressure nozzles will cut stiffer soils but larger nozzles with greater flow will remove greater volumes of soft sediments. As before, the philosophy of jet trenching is that the jet tool fluidizes the sediment, thereby allowing the cable to sink down under its own weight. The length of time that the soil is fluidized for is important as the longer it is in a fluid state, the greater the chance of the cable sinking down through it to the targeted burial depth.

Jetting will always create some localized turbidity, the severity and duration of which is mainly determined by the soil type, the size of the fluidized trench, bottom currents, and tidal currents in the area.

Some of the larger trenching ROVs have a means by which to relocate sediment away from the trench as burial occurs. This mechanism is often termed an "educator." This dredges out the sediment from the trench and relocates it to either side, thereby allowing the cable more time to settle down to the bottom of the cut. These are not used as a matter of course but are an option in soils where coarser sediments may settle back down into the trench before the cable sinks, thereby preventing proper cable burial.

ROVs differ slightly from the previously described tracker trenchers because they are in general neutrally buoyant, or negatively buoyant in seawater. This means that they exert a low ground pressure and have the ability to "fly" or move in the water column by using their thrusters. ROVs often have tracks, which provide more traction and use less power than maneuvering on thrusters alone when progressing across the seabed.

It takes quite a bit of power to move forward when the jet tool is lowered down into the soil, so ROVs, which are far lighter than tracked trenchers, will struggle in stiffer soil conditions due to less traction. Conversely, in softer soils, they have a lower chance of bogging down as they exert a lower ground pressure. Some examples of cable burial ROVs can be seen below.

Trenching ROVs range in power from about 200 hp at the bottom end up to around 1,500 hp for the most powerful. As can be expected, more power translates into greater water jetting ability, which does a combination of three things:

- Increases trenching speed.
- Increases trench depth.
- Increases the maximum soil shear strength that can be jetted.

Lower powered ROVs are used for fiber optic cable burial, where the small cable size dictates a small trench width. Export cables are commonly buried by ROVs in the 1,000 hp+ range due to the large cable diameter.

Mass Flow Excavators

One versatile tool that can be used either to post-lay bury or to remove sediment from an area prior to cable installation (for example to remove the top of a sand wave, or to prepare an area for a joint deployment) is a Mass Flow Excavator (MFE), sometimes referred to as a Controlled Flow Excavator (CFE). See Figures 61 through 64.

These tools when in operation direct water via a ducted nozzle containing a propeller at the seabed with flow rates and velocities that can be quite high (generally up to 14,000 liters/second and 14 m/s although not necessarily with the same tool), resulting in potential turbidity. However, the speed of the propeller and therefore the water flow can be controlled to achieve the desired trench without causing excessive turbidity when operated properly.

MFEs are deployed from a host vessel, normally via a crane and they can contain tool-mounted sensors (such as multi beam echosounders) and beacons to ensure accurate positioning and control.

It is rare to use these tools for long stretches of burial, but they are used in discrete locations such as:

- Near structures, at exit points of J Tubes.
- At cable joints that are too wide to bury via trencher.
- At cable crossings.
- Spot remedial burial where required.
- De-burial if cable recovery is required. Includes the removal of rock dump material, and the clearance of cable free spans by removing seabed high points.

MFEs come in a variety of sizes, configurations and power ratings, several examples can be seen in the following images. The depth of cable lowering that can be achieved is dependent upon the soil type as well as the specific MFE and how it is configured. Generally, however, a trench depth of 6 to 10 ft (2 to 3 m) or deeper can be achieved with these tools.

Figure 61. T4000 MFE, Maximum Flow Rate 4,000 L/second and Velocity 10 m/second *(Courtesy, James Fisher and Sons).*

Figure 62. T4000 MFE Fitted with Controllable Positioning System *(Courtesy, The Aleron Group).*

Figure 63. Deep C Blower *(Courtesy, The Deep C Group).*

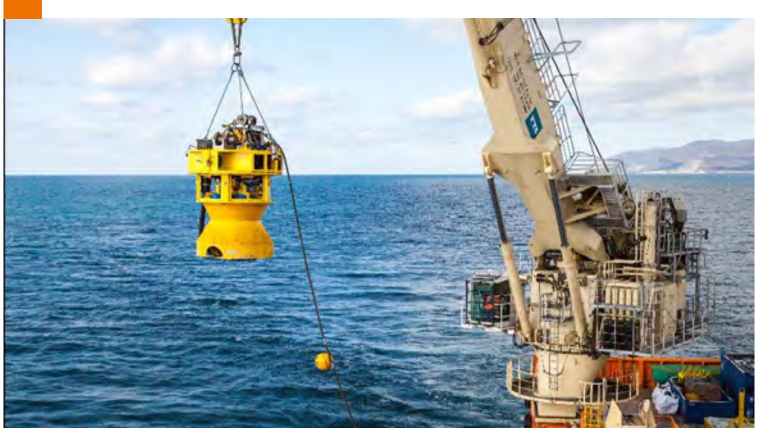
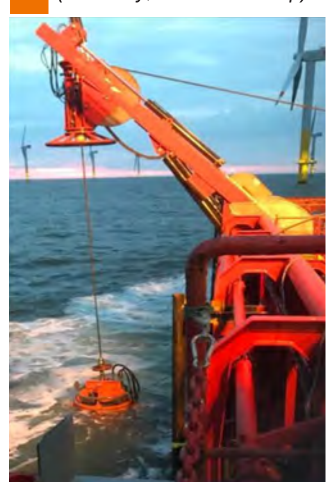


Figure 64. Sea Axe MFE, Maximum Flow Rate 5,600 L/second and Velocity 6.5 m/second *(Courtesy; The JBS Group).*



3.7.3 Pre-lay Burial

There are situations in which pre-lay burial can be considered as an option. Pre-lay burial is used to prepare the route prior to laying the cable, and is then generally followed by backfill operations, either using removed sediment or by rock-dumping. Situations for and methods of achieving pre-lay burial are described in the following subsections.

Pre-trenching

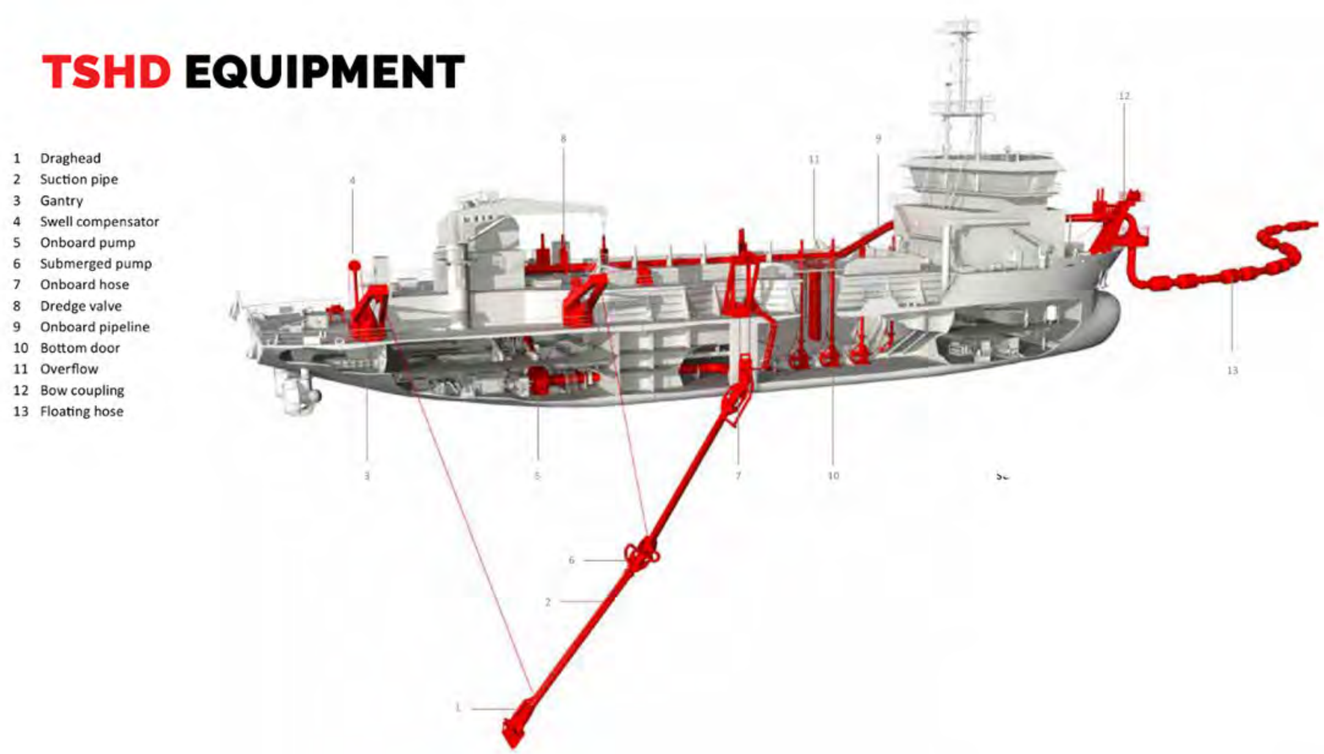
Pre-trenching involves the creation of a trench by using either a chain cutter in hard soils or a tool such as an MFE in softer soils. In the former case, the chain cutter would loosen and remove enough of the hard sediment that some type of jetting or dredging can be used to clear out any remaining loose material to allow the cable to be installed within the cleared trench. It is likely that this methodology would only be used in isolated areas of hard grounds. The achievable burial depth depends upon the use of the chain cutter tool. Generally, lowering to depths of 6 ft (2.0 m) is possible.

In the case of using an MFE, the areas of softer soils would generally include removing the tops of sand waves prior to cable installation. Sand waves do migrate, so cables laid across the tops of them are in danger of becoming exposed and suspended. Removing the top portions of sand waves (down to the trough) enables the cable to be laid at the bottom of the sand waves, which reduces the chance of cable exposure and suspension. The amount of sand that needs to be removed is entirely dependent upon the size of the sand waves at that location. Another cable burial situation where an MFE could be used is to create an excavated area where a cable joint would be located (see section 3.5.2), which would then be backfilled. The depth of this dredged area would be dependent upon the soil conditions, target cable depth of lowering, etc., but generally would be in the region of 5 to 6 ft (1.5 to 2.0 m).

Dredging

Dredging, usually via Trailing Suction Hopper Dredger (TSHD), can also be used as a method to remove the tops of sand waves, or for pre-trenching prior to cable installation. These vessels can also be used to replace sediment into a dredged trench post installation. TSHD's can also be used to dredge a corridor or an area for a cable joint deployment. The achievable depth of trench depends upon the soil conditions, but 6 ft (2.0 m) is a good rule of thumb. Normally this method is used in spot locations and not for the entire cable route. Figure 65 is a schematic of a TSHD and shows all of the main components associated with that type of vessel.

Figure 65. Trailing Suction Hopper Dredger Schematic *(Courtesy, Start Dredging).*



Pre-lay Plow

Pre-lay plows (Figures 66 through 69) are used to clear the cable route of boulders and obstructions as well as to create a 'V' shaped trench into which the cable is subsequently laid. This operation can take place off the project's critical path and can be carried out by anchor handling tugs and vessels, rather than by an expensive CLVs.

Such plows come in a variety of configurations but can normally undertake the following operations:

- **Route clearance mode.** The plow will be towed along the cable line and will be configured so that the plow would sweep obstacles such as boulders to either side. Most plows can clear a path of approximately 33 ft (10 m) wide but in this mode do not create a trench.
- **Trenching Mode.** The plow shares and mouldboards will be configured to create a 'V' or 'Y' shaped trench, sweeping the spoil from the trench to either side. The cleared path is wide enough to allow simultaneous or post-lay and burial via jetting ROV, for example. This may be necessary if the trench created by the plow self-backfills, or if slightly deeper burial is required. However, the trench created by the plow will generally allow for faster ROV burial operations than if no such pre-lay operations had occurred.
- **Backfill mode.** The plow's mouldboards will be configured to "sweep" the spoil heaps created in the trenching mode pass back over and into the trench after the cable has been laid. In this configuration, the plow is designed not to dig below the mean seabed level, thereby reducing the risk of damage to the cable.

These multifunction plows can typically create a trench up to 6 ft (1.7 m) deep in sandy and soft to stiff clay-dominated soils, reducing to about 3 ft (1.0 m) in very stiff to hard clays. A second pass will increase the trench depth in stiff to hard clays up to about 5 ft (1.5 m).

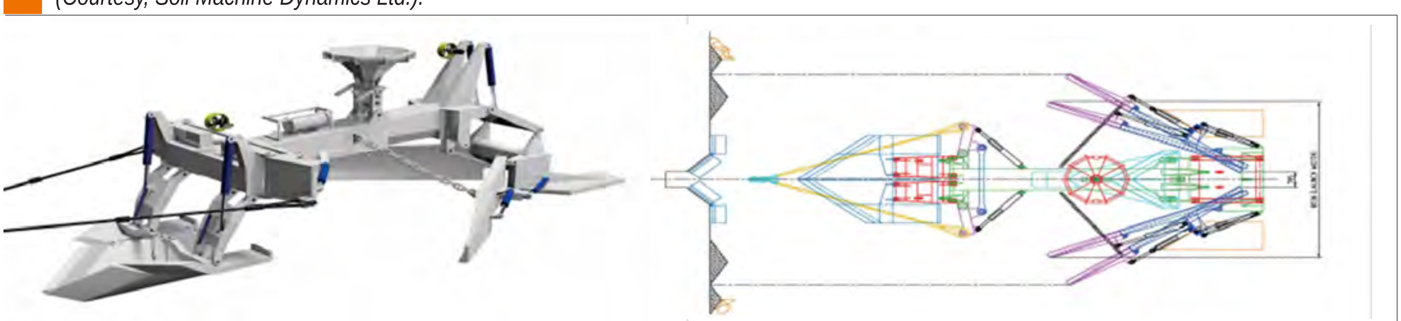
The following figures show a variety of pre-lay plows in their various configurations.

Figure 66. Multimode Pre-lay Plow in Trenching **Configuration** *(Courtesy, Soil Machine Dynamics Ltd.).*

Figure 67. Multimode Pre-lay Plow in Trenching Configuration *(Courtesy, Soil Machine Dynamics Ltd & Boskalis).*

Figure 68. Multifunction Pre-lay and Backfill Plow *(Courtesy, Global Marine Group and Osbit Engineering).*

Figure 69. Multimode Plow in Backfill Mode *(Courtesy, Soil Machine Dynamics Ltd.).*



3.7.4 Cable Burial Tool Summary Table

The various cable burial tool methods are compared in the table below.

Table 4. Cable Burial Tool Comparison

TOOL TYPE	BURIAL METHODOLOGY	SOIL TYPE	BURIAL DEPTH
 Pre-lay plow	Pre-lay burial/ route and boulder clearance	Can create a trench in soils up to stiff/hard clays	Commonly 1.0 m to 1.7 m (or more depending on sediment conditions)
 Mass flow excavator	Pre- or post-lay burial/de-burial	Various, up to 200 kPa if configured for cutting, 80 kPa as standard	Up to 5.0 m or so is possible depending upon soil types, 2.0 m commonly achieved
 Dredging (TSHD)	Pre-lay burial	Various	Varies depending upon the number of passes etc. *(but up to 5.0 m is achievable with a wide trench and a large volume of removed material)*
 Injector tool	Simultaneous lay and burial	Various but works well for deep burial in soft soils in shallow water	Up to 10.0 m (or more depending on sediment conditions)
 Jetting sled	Simultaneous lay and burial	Cohesive soils up to approximately 100 kPa, sands, silts gravels to approximately 30mm diameter	Commonly up to 2.0 m or 3.0 m (tool specific), a few very large machines can achieve 5.0 m or more
 Cable plow	Simultaneous lay and burial	Soils from approximately 5 kPa through 350 kPa	Up to 3.0 m
 Tracked trencher	Simultaneous or post-lay burial	Cohesive sands up to 100kPa in jetting mode, soft rock etc up to 600 kPa in chain cutting mode	Tool dependent, up to 3.0 m for jetting, 2.0 m for cutting quite common but ranges up to 5.0 m
 ROV	Post-lay burial	Cohesive soils up to approximately 100 kPa, sands, silts gravels to approximately 30 mm diameter or less	Up to 3.0 m

3.7.5 Other Cable Protection Measures

Cable burial is always the primary method of cable protection, but there are times when burial cannot realistically be achieved.

These are mainly due to:

- Hard soils or a thin soil veneer layer, the presence of bedrock, glacial tills, large boulder fields, etc.
- Severe slopes or subsea ravines/crevasses.
- Crossings (other submarine cables, pipelines, etc.).
- Proximity to structures, J Tube exit and entry points, etc.

In the above situations, it is likely that cable protection methods other than burial will be considered. If possible, areas of hard seabed conditions will be avoided during the cable route planning process, but it is not always possible to do this. There will often be crossings to contend with, as well as areas close to the offshore substations and wind turbines where it is not possible to achieve full protection. In these locations, alternates to burial will be considered. Potential impacts of cable protection measures are discussed in section 5.2.

Externally Applied Protection

It is of course possible to combine different protection methods. For example, if there is going to be rock dumping, the placement of concrete mattresses, or even just areas where there is an area of hard seabed, cable protection can be applied to the cable during installation.

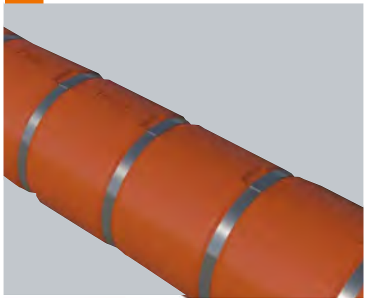
There are two main types of protection:

- **Articulated Split Pipe–**These are short, cast iron sleeves applied to the cable on the cable lay vessel during surface lay, which provide protection against crushing, impact damage, and abrasion (Figure 70). Split pipe is commonly used at shore ends as well as on the approaches to WTGs and OSPs.

Figure 70. Diver Lowering Cable in Articulated Pipe to the Seabed *(Courtesy, Wind Systems Magazine).*

- **Uraduct® or Similar–**Uraduct® is a Polyurethane system that clamps around a cable during installation and provides protection against abrasion and impacts (Figure 71). This system is commonly used at cable crossings where the cable is laid across concrete mattresses prior to having further concrete mattresses placed over the top (see section 3.9 for more cable crossing details).

Figure 71. Uraduct® Cable Protection *(Courtesy, Trelleborg).*



Rock Placement

Another method of achieving cable protection is via rock placement (Figure 72). This most commonly occurs immediately around the foundations of WTGs and OSPs, but can be considered on any area of the cable should burial prove impossible. Normally, externally applied cable protection would be installed prior to rock placement, to protect the cable from any impact damage. Potential impacts of cable protection measures are discussed in section 5.2.

Rock can also be used to backfill a trench that was (for example) created during dredging operations prior to cable installation (Figure 73 and Section 3.7.3). However, it is more commonplace to backfill with the material that was pre-dredged in this situation. The decision to use rock placement as a protection method is usually determined during the permitting phase, typically targets localized areas, and is very rarely used over long distances.

Figure 72. Rock Placement at a Wind Turbine Foundation *(Courtesy, Jan de Nul).*

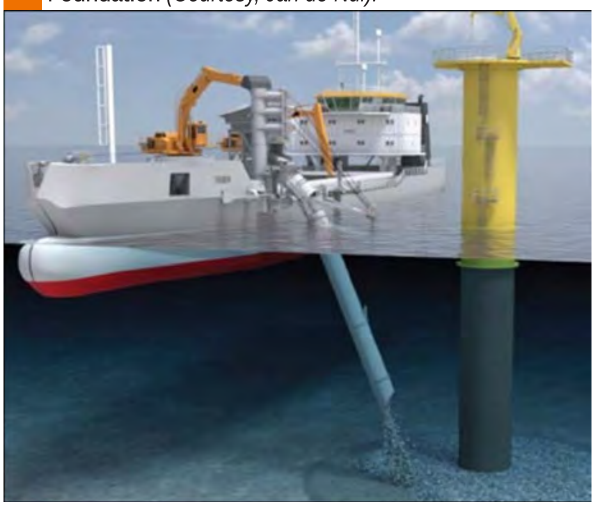
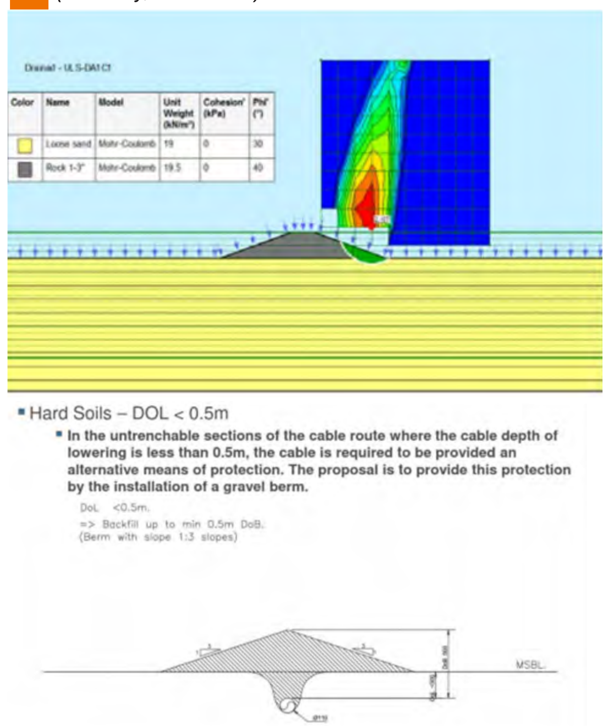


Figure 73. Rock Berm Engineering *(Courtesy, Jan de Nul).*



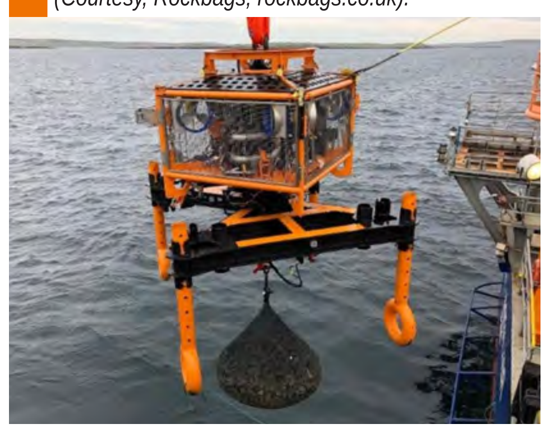
Filter Bags

Filter bags are rock-filled mesh bags that are normally used for scour protection around fixed structures (Figures 74 and 75).

The bags can also be used as cable protection at crossings and areas of small cable suspensions. They will conform quite well to any irregular seabed features and may create habitat for marine life.

Figure 74. Filter Bags on Deck Prior to Deployment *(Courtesy, Subsea Protection Systems Ltd.).*

Figure 75. Filter Bag Deployed *(Courtesy, Rockbags; rockbags.co.uk).*



Concrete Mattresses

Concrete mattresses are a type of pipeline and cable protection very commonly used, particularly at crossings where they create separation between the cable and the asset it is crossing. Additional mattresses are laid over the top to protect the cable in the crossing area where it cannot be buried to its full target depth. At crossings, the asset to be crossed may not be buried as deeply as the cable being installed, hence the reason for a relatively shallow burial and necessity for this extra protection. A concern of the fishing industry is that fishing gear may snag on seabed obstructions such as concrete mats. Many mats have tapered edges to minimize this risk (see Figure 76); the installation contractor should also ensure the mats are laid flat to reduce the risk. Potential impacts of cable protection measures are discussed in section 5.2.

Mattresses used to be deployed one at a time from the crane on an installation vessel, but in recent years, specialized deployment systems have been developed that can install several mattresses at once and position them extremely accurately (Figures 76 and 77).

Figure 76. Articulated Concrete Mattress *(Courtesy, Pipeshield).*

Figure 77. Articulated Concrete Mattresses in a Deployment Frame *(Courtesy, Pipeshield).*

Frond Mattresses

A frond mattress is used in combination with a concrete mattress to provide scour protection around a fixed structure or object on the seabed (Figure 78). These would most commonly be used around the foundations of WTGs or OSPs. Not only do such mattresses protect against seabed scour and sediment erosion, they also provide habitat for marine species.

Figure 78. Frond Mattress /Prior to Loading/ In-Situ *(Courtesy, SSC Systems and Pipeshield).*

Nature Inclusive Designs

Nature Inclusive Design (NID) is a philosophy of designing offshore wind infrastructure with the creation of suitable habitat for marine species as a parallel goal. Such infrastructure encompasses the whole windfarm, from the design of wind turbine foundations through to the previously described scour protection and cable protection. The driving force behind such NIDs has been the Netherlands Ministry of Agriculture, Nature and Food Quality. The agency commissioned Witteveen + Bos, as well as Wageningen Marine Research to compile a catalog of NID concepts and products.

The three categories outlined in the catalog and report are:

- Add on products for structures.
- Optimized scour protection layers.
- Optimized cable protection layers.

The intent of the NID philosophy is to encourage indigenous species while not encouraging invasive species. This section will focus on the NID relevant to cable protection. As previously described, the primary method of protecting cabling is via burial. Where that's impossible, alternate methods applied to, or above, the cable are employed.

The Dutch NID philosophy as it pertains to cabling utilizes techniques and products that create habitat for indigenous species. In the case of the North Sea, these have been categorized as:

- Filter units/bags, which have been previously described.
- Basalt Bags (Figure 79) are a German system similar in concept to the filter units. These bags create crevices of varying sizes, which provide shelter for various marine animals.
- ECO Mats® (Figure 80) are similar in appearance to concrete mattresses, but contain an admix that is claimed to enhance settlement by organisms; and Reef Cubes™ (Figure 81) are shaped, interlocking concrete blocks encapsulated within cages, bags, or are available as mattresses, which form habitats within and between them. Additionally, the concrete mixture contains low-carbon alkali-activated materials, said to be an excellent substrate for marine flora and fauna to adhere to.

Some feel strongly that by carefully designing and specifying the scour and cable protection necessary, it is possible to:

- Provide habitat complexity for multiple species
- Create nursing and spawning grounds
- Increase biodiversity
- Preserve species
- Improve water quality

Figure 79. Basalt Bag *(Courtesy, The Jaeger Group).*

Figure 80. Eco Mat® *(Courtesy, ECOncrete).*

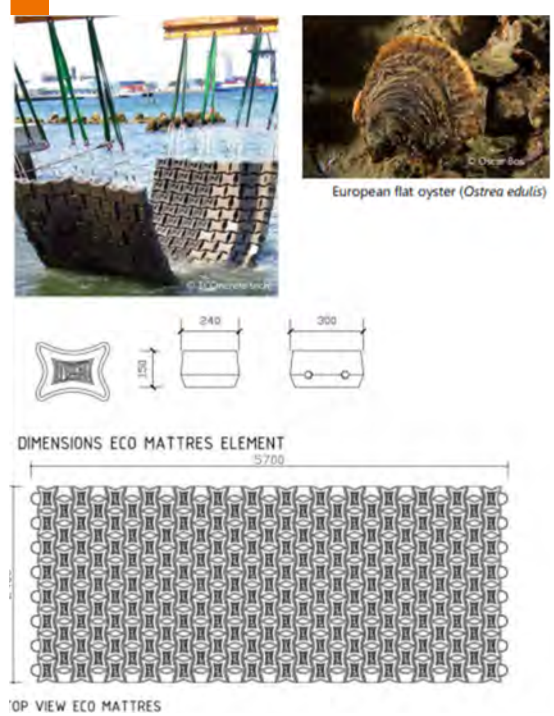


Figure 81. Reef Cubes™ *(Courtesy, ARC Marine).*

3.8 Post-lay Cable Surveys

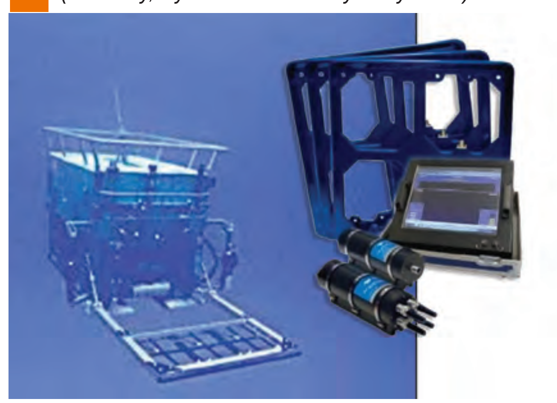
Once a cable has been laid and buried, it is important to fix its position both laterally (X-Y coordinates) as well as vertically (Figure 82). This is to ensure that subsequently, periodic surveys can be undertaken that will detect whether the cable has moved laterally, has become more deeply buried (due to shifting sediments), or is in danger of becoming exposed. A concern of the fishing industry is that fishing gear may snag on seabed obstructions such as concrete mats. Many mats have tapered edges to minimize this risk (see Figure 76); the installation contractor should also ensure the mats are laid flat to reduce the risk. Potential impacts of cable protection measures are discussed in section 5.2. There are a few ways that cable positions can be tracked, ranging from bathymetric surveys to specialized equipment and techniques.

If the cable has been simultaneously laid and buried by plow or jet sleds or tracked trenchers, the position of the plow will be known, as will the depth of the cable in relation to the seabed. This is because as the plow share cuts through the soil the cable is pushed down to the depth of the share by a depressor arm.

- An ROV-mounted system called a TSS 350 can track a cable and determine its position and depth by following a tone injected on the cable from either shore or an OSP.
- Pulse induction technology can be used to track a ferrous object (including a submarine power cable's armor wires) via the ROV-mounted TSS 440/660 system [Figure 83]).
- A submarine power cable can be magnetized during manufacture and installation and then tracked or surveyed after lay and burial by using the Innovatum Smartrak system.
- Pangeo Subsea markets a sub-bottom imaging system that uses acoustics from an ROV or vessel-mounted array to detect and track buried objects.

Figure 82. Cable Plow Showing the Cable, Cable Depressor, and the Skid *(Courtesy, Boskalis).*
The vertical difference between the bottom of the skid and the bottom of the depressor gives the depth of lowering.

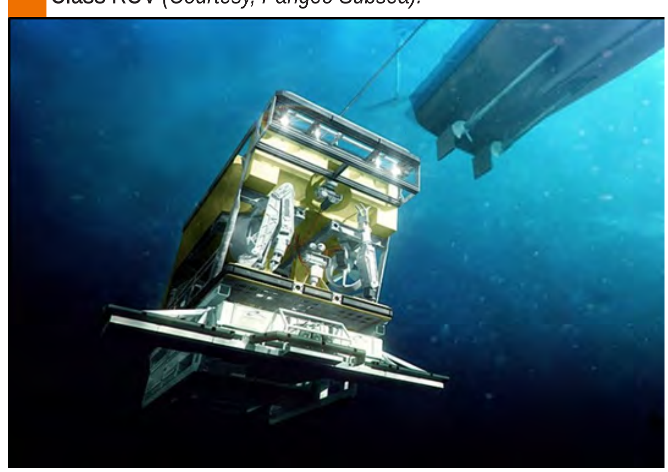
Figure 83. TSS 440 Cable-Tracking System *(Courtesy, Hydronav and Teledyne Systems).*



Historically, cable surveys have been performed via a vessel-deployed ROV. As technology moves forward, it is likely that faster, more cost-effective solutions will be utilized such as towed sensors, Autonomous Underwater Vehicles (AUVs), and resident ROVs that remain in docking stations offshore and would not require a large vessel presence at all (Figures 84 and 85).

Figure 84. Innovatum Smartrak on a Small Observation Class ROV *(Courtesy, Innovatum).*

Figure 85. Pangeo Sub-bottom Imager Mounted on a Work Class ROV *(Courtesy, Pangeo Subsea).*



3.9 Cable Crossings and Techniques

It is almost inevitable that export cables will need to cross other subsea assets between the offshore wind farm and the shore landing. These assets include fiber optic cables, other power cables or pipelines, outfalls, etc. Out-of-service cables will likely be removed to a point on either side of the planned cable corridor using the methodology described in section 3.9.2. Other assets that are in use or cannot be removed will need to be crossed. The design of the crossing must ensure that there is separation between the asset crossed and the cable in question. There must be no chance that the two assets touch, as this can rapidly lead to asset failure for both parties. As an industry best practice, the developer planning to install the cable must design a suitable crossing methodology and obtain a crossing agreement from the owner of the asset that will be crossed.

3.9.1 Legal and Regulatory Viewpoint

As described in section 3.1, the ICPC is the primary organization focused on the protection of the world's submarine cables. They produce several recommendations on issues including cable crossings, as well as the installation of cabling in proximity to other cables. These recommendations ensure that, not only are both cables/assets protected, but they are accessible for maintenance in the future. Additionally, their recommendations are often considered the industry standard, which ensures that all parties understand and accept the methodology and design of the crossing.

It is often the case that the asset to be crossed (whether pipeline, outfall, or another cable) is buried. A survey would be undertaken to pinpoint the exact location of the asset, so that any protection is installed in the correct position. Burial of the cable can be extremely challenging at crossing locations; therefore, protection has to be applied over the cable not only at the exact crossing location, but also in the areas where full burial depth is not achieved.

Finally, the U.S. has not ratified the United Nation's Convention on the Law of the Sea for a variety of reasons. This Convention contains several statements regarding submarine cables as they relate to fishing, crossing other assets and more, such that it is a benchmark for many international discussions regarding these issues. The fact that the U.S. is not a signatory of this document negates its utility in U.S. waters and can create some ambiguity surrounding crossings.

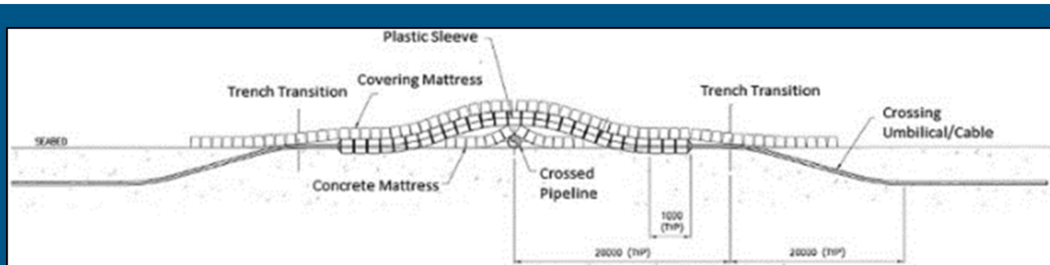
Article 79 of the convention clarifies that all Coastal States are entitled to lay submarine cables and pipelines on their portion of the continental shelf, and that states have to regard cables and pipelines already in position. Articles 112 through 115 refer to the "High Seas" (areas outside of continental shelves) and cover states (including flagged vessels) breaking/damaging submarine cables, as well as losses to vessels (including anchors, fishing gear etc.), stating that they shall be indemnified by the owner of that cable or pipeline.

3.9.2 Common Cable/Pipeline Crossing Methodologies

During the route planning process, great care is taken to select a suitable location for asset crossings, and to cross existing assets at as close to perpendicularly as is possible. There may be a bottom layer of protection to ensure that the cable can never sink down and contact the asset that it is being crossed. The 90° crossing angle goal provides the maximum space on both sides of each span of cable as it radiates out from the crossing. A crossing that has too acute a crossing angle creates a situation that makes burial and maintenance more difficult unless warranted by seabed or current conditions.

Additionally, there may be a layer of protection that is applied after the cable is laid on top of the crossing. The top protection covers the cable from where it comes out of full burial, through the crossing itself and then across the area prior to full burial after the crossing. Both top and bottom protection materials can be concrete mattresses or rock berms, for example. The cable may be encapsulated in a protection system such as Uraduct (labeled as plastic sleeve in Figure 86; also see Figure 71) throughout the crossing location to protect it from crush and abrasion damage that can be caused by the application of the top protection. A concern of the fishing industry is that fishing gear may snag on seabed obstructions such as concrete mats. Many mats have tapered edges to minimize this risk (see Figure 76); the installation contractor should also ensure the mats are laid flat to reduce the risk.

Figure 86. Typical Crossing Design Cross-Section
(Courtesy, Science Direct).



There are other crossing methods, such as the concrete bridge shown in Figure 87. However, these are more commonly used to cross pipelines that are not buried, or in oilfields and not in areas of fishing activity, strong currents, or soft sediments (i.e., areas where environmental impacts are of concern).

Bridges also protrude more above the mean seabed level than mattresses and are more prone to subsiding due to scouring action. That, as well as the cost of procurement and installation, has led to and made concrete mats the most common cable crossing protection system.

Figure 87. Concrete Crossing Bridge
(Courtesy, Subsea Protection Systems Ltd.).

3.10 Operations and Maintenance

Once the construction phase of an OSW project is complete, the operational phase commences. The usual operational life is between 25 and 30 years or longer. During that time, cables will be marked on navigational charts, and there will be routine, planned maintenance work as well as unexpected or emergency operations undertaken due to an unplanned event.

Regarding cabling, planned events include periodic depth of burial surveys to ensure that the cable is not becoming too deeply buried or too exposed. The frequency of these surveys is driven by several factors, most notably the permitting authorities or lease obligations, but also by the mobility of the seabed in a location. Examples of planned and unplanned cable operations are described below.

3.10.1 Periodic Depth of Burial Surveys

When a cable is installed and buried, an "as laid" plan will be created that details the depth of burial of the cable at each point along its route, as previously described in section 3.8. This burial depth would be previously specified to minimize the risk of damage to the cable as far as is reasonably practicable.

In order to ensure that the cable is not becoming unburied (increasing risk of damage) or going deeper beneath the seabed surface (reducing cable current carrying capability), depth of burial surveys are undertaken at periodic intervals to be determined as part of the permitting process.

Traditionally, these have been performed from an ROV deployed from a vessel, one survey pass per cable is required and approximately 8 to 10 km can be surveyed in a 24-hour day. Multiply this by the number of export cables and it turns into a lengthy and costly survey.

The actual survey techniques are the same options as detailed in section 3.8.

3.10.2 Cable Temperature Sensing

Becoming more widely preferred by the project developers are Distributed Temperature Sensing (DTS) systems. Typical output from these systems is shown in Figures 88 and 89. The systems are rack mounted sensors installed onshore and/or at the OSP that use the optical fibers in the export cables to measure the temperature at approximately 3-ft (1-m) intervals.

DTS systems offer many benefits:

- Real-time operating temperature of the cable ensures that 90-degree Celsius temperature limit is not reached.
- By analyzing the temperature profile versus load of the cable over time, it is possible to determine whether the cable is becoming buried more deeply, or whether the cable has less cover. This is due to how the thermal resistivity changes due to varying burial depths, which in turn affects the operating temperature of the cable at a given load.
- This ability to monitor depth of burial/cover trends allows the operator to plan remedial burial well in advance of a problem occurring by detecting very minor changes.
- An additional benefit that is accepted by the authorities in some countries (e.g., Belgium) is that this type of temperature monitoring system, in conjunction with depth of burial monitoring, reduces the statutory frequency of traditional geophysical offshore cable burial surveys during the operational phase of the project.

Figure 88. Graph Showing 25-km Submarine Power Cable *(Courtesy, Marlinks).*
Vertical blue bars show the number of weeks and locations that the cable was buried less than 0.5 m derived from the DTS data. The previously planned remedial burial campaigns (in orange) totaled 11.8 km, the DTS data showed that burial was only required for 2.0 km.

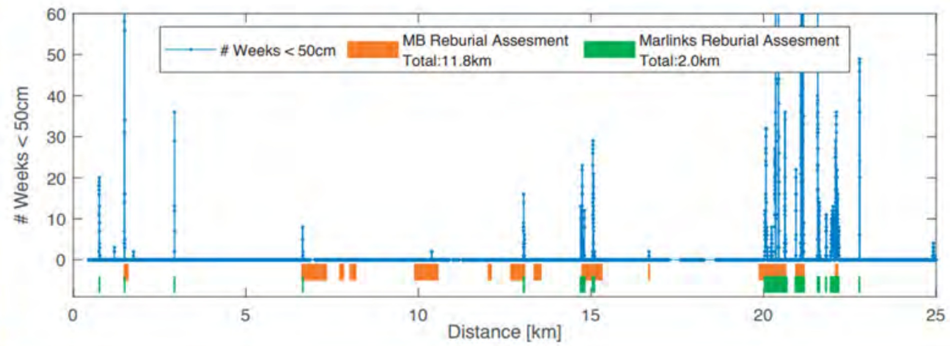
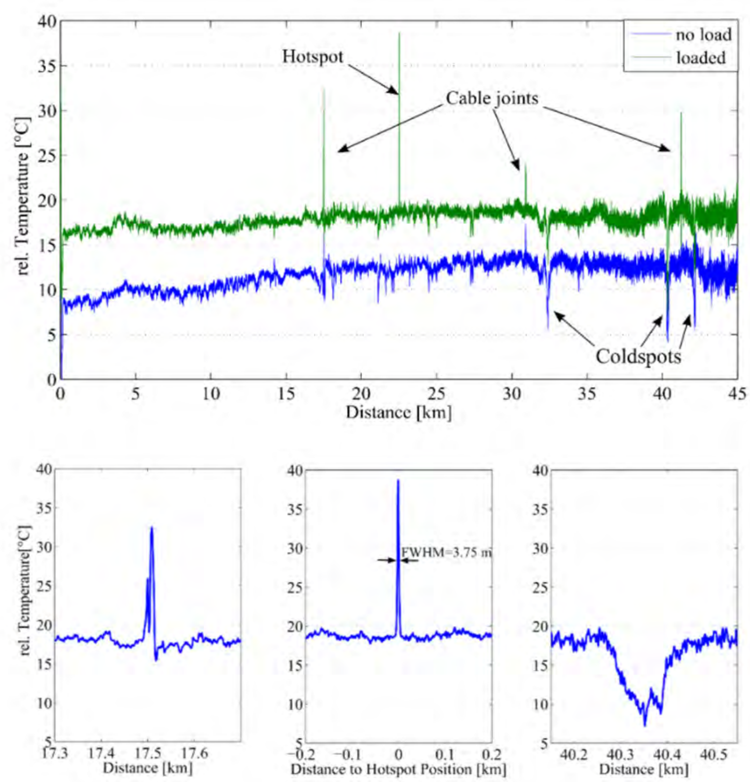


Figure 89. Temperature Profile of a 45-km Submarine Power Cable *(Courtesy, NKT Photonics).*
Vertical upward peaks show hotspots, downward peaks show cold spots.

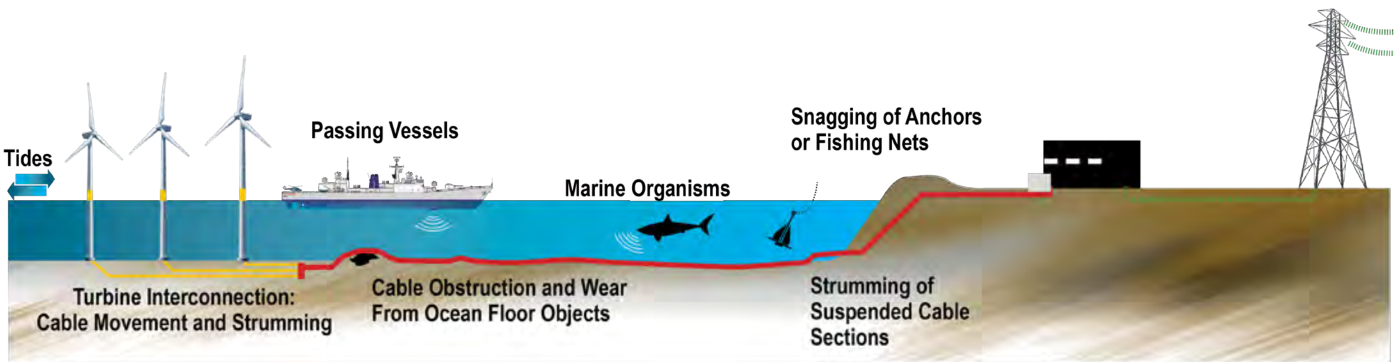


3.10.3 Cable Vibration Sensing/Distributed Acoustic Sensing

A related system to the DTS system is a Distributed Vibration Sensing system, also known as Distributed Acoustic Sensing (Figure 90). The DVS/DAS system also utilizes optical fibers in the submarine cable but instead of monitoring temperature, this system monitors acoustics. In effect, the system turns the optical fiber in a submarine power cable into a sensitive microphone that can detect ambient noise. The benefits of Distributed Acoustic Sensing systems include the following:

- An increase in background noise, which can indicate the cable is exposed or is becoming exposed.
- The detection of other ambient sounds such as landslides, marine life, etc.
- The detection of sounds such as fishing/bottom trawling activity or vessel anchor deployment. Monitoring systems exist that also monitor AIS data and can therefore identify a vessel that may have deployed its anchor and damaged the cable.
- Accurate fault locations can be provided for certain fault types.

Figure 90. Distributed Acoustic Sensing System Simplified Schematic
(Courtesy, Dr Henry Bookey, Fraunhofer UK Research).



3.10.4 Remedial Burial

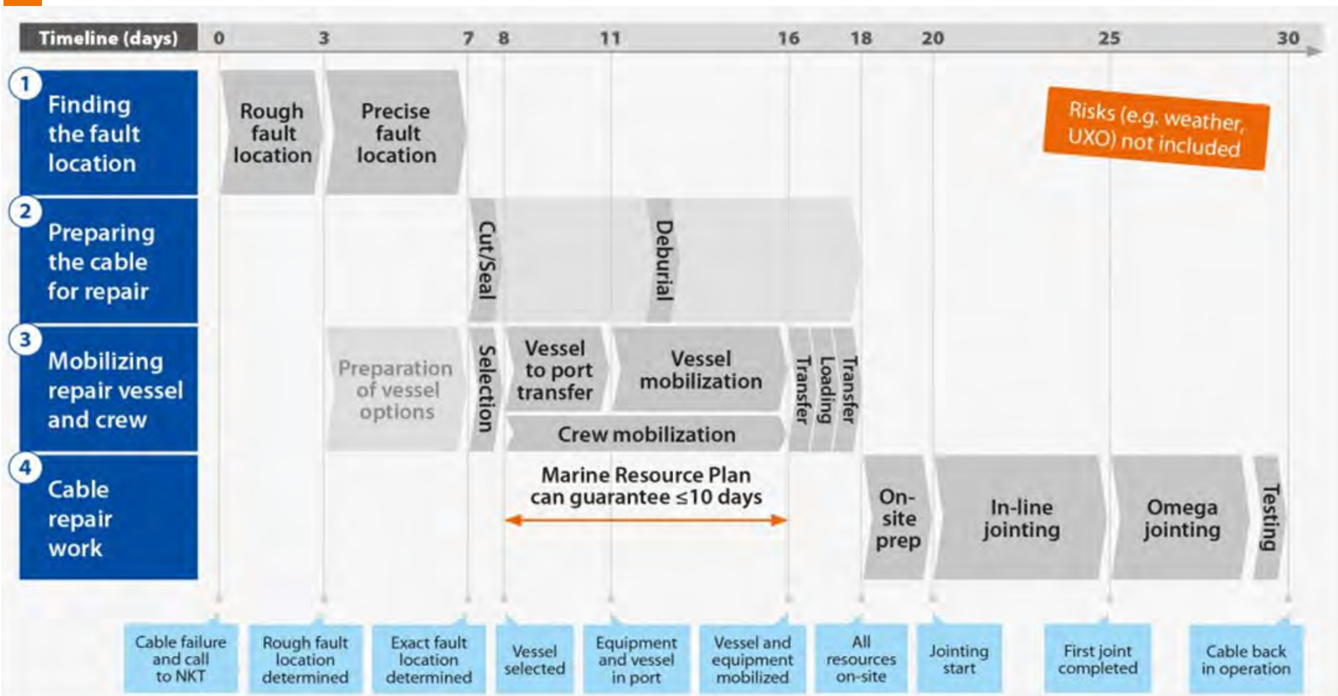
The results of the periodic survey that measures the cable's burial depth, or depth of burial indications obtained from the DTS system will result in a burial profile of the cable. Depending upon the sediment mobility along the cable route, it is possible that shifting seabed sediments will have decreased the depth of burial at certain points. In order to lower the cable to the permitted burial depth, it will be necessary to undertake remedial burial operations. The necessity of this as well as the frequency is entirely site-specific, but it could be triggered by a storm event (in shallow water), or shifting seabed sediments due to currents, etc., that may result in the need for additional cable protection measures.

As the cable is already in place and is operational (it generally doesn't have to be shut down for remedial burial operations), the most common method of performing remedial burial is via trenching ROV. If allowable, an MFE could also be used, particularly for spot burial, or for burial of larger objects such as cable joints. See section 3.7.2 for further details regarding these post-lay burial methodologies.

3.10.5 Cable Repair Operations (Array and Export)

Despite the best efforts of all parties, cable damage may occur. This will result in the need to perform a cable repair or replacement operation. Project developers will have an emergency repair plan in place; this plan should significantly cut down the amount of time needed to both plan a repair and source a marine contractor and suitable vessels. A typical repair timeline is illustrated in Figure 91. Cable maintenance services do exist, whereby a marine contractor will store suitable spare cable for use during a repair, as well as commit to responding to a fault notification within a certain time window.

Figure 91. Schematic of Cable Repair Timeline *(Courtesy, offshoreWIND.biz).*



For most cable repairs, two offshore joints must be completed. However, for shore-end replacements, a single joint is normally required and for array cables, the entire cable is usually replaced. A simplified repair sequence is summarized below:

1. Notify all appropriate parties of the cable fault and begin liaison (U.S. Coast Guard Notice to Mariners, Fisheries Liaison Officer engages relevant parties, notify regulators, etc.).
2. Pinpoint the fault location with an offshore survey, if possible.
3. Mobilize a repair vessel or barge, load spare cable, jointing equipment, and personnel, etc.
4. Transit to fault location.
5. Cut cable and recover one cable end. Test cable if possible and if the fault is on this end, cut enough cable back to clear the damaged section.
6. Seal the cable end and lay back on the seabed with a buoy attached.
7. Pick up the second end, test and clear damaged span.
8. Joint this second end to the spare cable (Initial Splice). A high-voltage power cable joint can take a week to construct with the repair vessel holding station.
9. Once the first joint is complete, lay it on the seabed via a crane.
10. Lay cable out to the first end that was left on the seabed.
11. Pick up this end, moving along the cable line while paying out the spare cable.
12. Once the cable end is in the correct place onboard and is tested to ensure that it has suffered no damage, the spare cable is cut.
13. The second joint (Final Splice) is carried out. As with the first, this can take up to a week in one location.
14. Lay the Final Splice in an Omega configuration.
15. Survey the cable and joints, then bury via post-lay burial.

3.10.6 Decommissioning

At the end of the operational life, the decision must be made whether to recover the cable or leave it in place. BOEM regulations mandate that removal of the cable is the first option, including restoration of the seabed to its original condition. If the project developer proposes to leave cables in-place, a clear benefit must be demonstrated for BOEM to consider that possibility as part of a decommissioning plan. Most submarine power cables are too new for the need to deal with the question of decommissioning versus abandonment. In the fiber-optic submarine cable industry, old cables are usually left in-situ because the environmental disturbance caused by removing them would outweigh the benefits of their removal. Each OSW facility will have its own agency-approved decommissioning plan in place that will dictate these procedures. Additionally, as these plans will not be executed until decades after they are written, there may be opportunities to revisit and revise them to ensure that the best and most up-to-date practices are considered.

4.0 Risk to Cables

4.1 Seabed Conditions—Geologic and Sedimentary

Risks to cables due to seabed conditions normally relate to the geohazards found at the project site; examples include:

- Steep slopes.
- Ravines, canyons, or deep, incised channels.
- Undersea landslides (also called turbidity flows).
- Volcanic/seismic activity.

The best mitigation measures in these cases are to avoid such areas entirely, where practicable, so effective route planning becomes critical. It is not expected that the above issues are of great concern in the New York Bight area but will likely be key concerns as the industry develops on the west coast.

4.2 Navigation Channels and Anchorage Areas

A major external aggression risk to submarine cables stems from commercial shipping and the deployment of anchors, whether deliberate, accidental, or due to an emergency. There are several official vessel anchorages in the region, as well as areas where "informal" anchoring occurs. The risks of anchor strike can be at least partially calculated by analyzing the AIS data along with the associated vessel types/sizes and soil data to establish the penetration depths of the anchor flukes for each scenario.

There are also various vessel fairways and Traffic Separation Schemes (TSS), both of which are heavily trafficked by commercial vessels in the New York Bight. In these areas, deliberate anchoring should not occur, but anchors can be deployed either by accident (a windlass failure, for example) or deliberately in the case of a vessel emergency. Once again, AIS data can be utilized to determine the number of vessels transiting along a submarine cable route in any given year. Then the frequency of vessel emergencies, or the frequency of unintended anchor deployment, can be estimated to assess the likelihood of such an event occurring within the area in question.

The local vessel types and theoretical anchor penetration depths will drive the burial depth recommendations, as will any governmental regulations. An example is the USACE requirement for a DOL of 15 ft (4.7 m) under the authorized, maintained depth of any dredged shipping channel.

4.3 Commercial and Recreational Fishing

The New York Bight includes an area of ocean extending from Montauk, New York, to Cape May, New Jersey. Over 300 fish species occur in the New York Bight, many of which are of recreational and commercial value. As such, the area supports fishing traffic on a regional scale, including vessels from neighboring states such as New Jersey, Connecticut, Rhode Island, and Massachusetts. Most saltwater recreational fishing involves the use of hook and line (rod and reel) methods, which are unlikely to interact with subsea cables or generate the force required to negatively impact cables in rare instances of snagging. Furthermore, vessel anchors deployed by recreational fishermen are smaller than those used by commercial mariners; therefore, it is highly unlikely that a recreational anchor would penetrate the seabed deeply enough to impact a buried cable. Cables buried at target depths of 5 to 6 ft (1.5 to 1.8 m) have experienced little to no interactions with fisheries (NASCA 2019).

With appropriate burial depths and cable protection measures in-place, commercial fishing gear is also unlikely to interact with subsea power cables, although the possibility of interaction does exist for gear types that penetrate the seabed. Shellfish landings comprised one third of New York State's commercial landings by dollar value in 2019; hard clams, eastern oysters, and sea scallops were three of the highest grossing species, accompanied by several species of groundfish (NOAA Fisheries 2020a). Bottom fishing is therefore a widespread practice throughout the Bight and adjacent continental slope. Common types of bottom fishing used by commercial fishermen include otter trawling, scallop dredging, hydraulic clam dredging, gill netting, longlining, and pots/traps (using fixed traps on the seabed). Such methods have the potential to damage subsea cables severely enough to affect transmission, known as a "fault". In complete break faults, cables are severed entirely, but faulting may occur at lower levels of tension or if a cable is bent, crushed, or pulled beyond acceptable limits. As of 2019, there were approximately 378 subsea cables in service globally; despite use of burial and armoring techniques, these cables collectively endure an average of 100 annual faults, roughly 40 of which can be attributed to mobile fishing gear and fishing vessel anchors (CSRIC 2014; Kordahi et al. 2015; Brake 2019; see section 5.2 for a discussion of cable impacts to fisheries). It should be noted that most of these cables and faults are fiber optic telecommunication cables that are smaller and less robust than power cables.

Otter trawls have potential to result in cable damage, due to how widespread the practice is and how much seabed is covered by a single operation (Lokkeborg 2005). Trawl designs vary according to target species, which may include butterfish, monkfish, scup, silver hake, squid, summer flounder, winter flounder, and yellowtail flounder (NYSERDA 2017). In general, an otter trawl is a conical-shaped net, tapered towards the end ("cod end") that is dragged along the seabed using a set of steel "doors" behind a vessel. Ground gear includes trawl doors, bridles connecting the doors to the wings of the net, the sweep, and tickler chains used to agitate shrimp, flatfish, and other demersal species into the net (Drew and Hopper 2009). Trawl doors, also called otter boards, are steel (or steel and wood) panels weighing up to eight tons (depending on net size, vessel size, fishery, etc.) to provide the weight to keep the trawl in contact with the seabed and generate the horizontal spreading force to keep the net mouth open (Carter et al. 2009). Gear descriptions included here are representative examples only; site-specific analysis of gear types would be included as part of the permitting process for specific projects.

The doors are intended to sweep and skim along in contact with the seabed without digging into it; otter board penetration in the seabed is typically in the range of 2 to 8 inches (5 to 20 cm), though unusual conditions such as soft mud, uneven seabed, or rigging failure may result in penetration in excess of 20 inches (50 cm, Stevenson et al. 2004; Lokkeborg 2005). Trawl doors and ground gear may damage the sheathing of exposed cables or damage the armor or insulation. Doors with curved front edges have been shown to be less likely to snag on cables and other seabed obstacles (Carter et al. 2009).

Dredging, another gear type that impacts the seabed, is a process most often used for mollusks such as clams and scallops. Dredging is typically conducted within 500-ft (150-m) depths (Carter et al. 2009). In general, a dredge is towed across the seabed with a solid metal frame in front to collect the catch. Scallop dredges drag chain bags along the seabed to collect the catch and may employ steel teeth to penetrate the seabed by a few inches (Drew and Hopper 2009). In some fisheries, deflecting bars and wheels have been added to help the gear pass over obstacles and prevent entanglement (Drew and Hopper 2009).

Hydraulic dredges target bivalves, such as surf clams and ocean quahogs, by penetrating up to 25 cm into seafloor sediments (Stevenson et al. 2004; Carter et al. 2009). Clammers use high-pressure streams of water to liquefy the seabed in the immediate area into a slurry of sediment and exposed target species, which are then captured in the dredge. Such hydraulic dredges may remove a layer of sediment with each pass and vessels may often make multiple passes over productive grounds, digging deeply into the sediment and possibly exposing buried cables in some instances (Drew and Hopper 2009).

It is common practice for a fishing vessel to tow a homemade grapnel, sometimes a hook-like length of chain with several prongs, across the seabed to find and retrieve lost or snagged gear (Vize et al. 2008). Fishermen are encouraged to contact the Coast Guard or cable company regarding fouled gear rather than attempting to recover it themselves, and in many cases developers have included clauses in their fisheries mitigation plans to reimburse vessels for sacrificed gear to avoid cable damage (Drew and Hopper 2009; Ecology and Environment 2014; Equinor Wind 2019; Ørsted 2020).

Despite gear interactions with the seabed, most fishing vessels never interact with cables, and approximately 90 percent of active crossings over exposed cables do not result in cable damage or gear damage; fishermen may not even be aware of the occurrence (Wilson 2006). However, to ensure the lowest likelihood of faulting, there are several mitigation measures employed by cable operators, including cable armoring and burial for cable installed on the continental shelf (CSRIC 2014). Prior to project mobilization, cable routes are selected to avoid charted anchorages and dredge areas; fishing and merchant marine associations are consulted directly, and maritime authorities and permitting processes aid in selecting appropriate routes (Carter et al. 2009). These routes are then communicated to relevant stakeholders though Local Notices to Mariners, fishing news publications, project bulletins or emails, and navigational charts (Vize et al. 2008). Target burial depth is informed by engagement with stakeholders and assessment of seabed conditions and activity. While burial depths of 2 to 3 ft (0.6 to 0.9 m) have been shown to interact with hydraulic clam dredges, cables buried at target depths of 5 to 6 ft (1.5 to 1.8 m) have experienced little to no interactions with fisheries (NASCA 2019). Finally, in some industries (e.g., telecommunication cables) programs are in place to compensate fishermen for fouled fishing gear so they do not damage cables during attempted retrievals (CSRIC 2014).

5.0 Risk from Cables

5.1 Potential Environmental Impacts

Impacts resulting from subsea cable activities may be realized during cable installation, maintenance, and decommissioning phases and include physical seabed disturbances, sediment resuspension, chemical pollution, underwater noise emission, and habitat disturbances (Meissner et al. 2006; Vize et al. 2008; Carter et al. 2009; OSPAR Commission 2012; NIRAS 2015; Taormina et al. 2018). Longer term impacts may occur during cable operational phases, including changes in electromagnetic fields, heat emission, and reef effects. Generally, the spatial extent of these impacts is limited to the cable corridor and immediately surrounding environment. As of 2011, the footprint of subsea cables off the United Kingdom coast was estimated to be 0.3 km^2, less than 0.01 percent of the area between the coastline and the Exclusive Economic Zone (Foden et al. 2011). Similarly, the footprint of cables and pipelines off the Basque Country coast of Northern Spain was estimated to be 2.3 km^2, or 0.02 percent of the coastal zone (Borja et al. 2011). With respect to other anthropogenic marine activities, including bottom trawling, ship anchoring, or large-scale dredging, physical disturbance to the seabed caused by subsea cables is considered temporally and spatially limited (Carter et al. 2009; OSPAR Commission 2012; NIRAS 2015; Taormina et al. 2018).

5.1.1 Seabed/Substrate

Seabed alterations are primarily caused by the equipment used for route preparation (grapnels) and cable installation (plows, jetting systems, and mechanical cutting wheels); decommissioning and maintenance to a lesser extent may yield similar seabed alterations, but their magnitude will depend on the duration and scale of the work (Dernie et al. 2003; OSPAR Commission 2012; NIRAS 2015; Taormina et al. 2018). The total area of disturbance is expanded when installation techniques require large ships with several anchoring stabilizers (Taormina et al. 2018). Benthic substrates and habitats most likely impacted by such cable routes include bedrock and boulders, reefs, gravel beds, silt and clay banks, shellfish beds, and seagrass beds (Vize et al. 2008). For buried cables, plowing and jetting methods favor seabed recovery by infilling trenches with displaced material immediately after digging and cable laying (Vize et al. 2008; Taormina et al. 2018); plowing methods are believed to cause the least amount of disturbance, while jetting systems and mechanical cutting wheels may not allow layers of sediment to be reinstated in the same sequence as their natural state (Vize et al. 2008; Taormina et al. 2018).

Debris clearance from a path proposed for cable burial is usually followed within days to weeks by installation and burial, which itself only demands several hours to days per mile of cable (Rees et al. 2006; Carter et al. 2009; Taormina et al. 2018). Unless a cable fault demands maintenance, the seabed might not be disturbed again within the system's design life, which spans several decades on average (Carter et al. 2009). The degree of physical impact will depend both on sediment type and hydrodynamic conditions. Rock, stiff clay, and other consolidated substrates may exhibit scarring, while unconsolidated soft clay, sand, and certain types of gravel may recover naturally within six months to three years (Vize et al. 2008; RPS 2019). Hydrodynamic conditions associated with depth zone may predict the speed of recovery. The mobile sands of the inner continental shelf (0 to 100 ft [0 to 30 m] depth) are exposed to frequent wave and current action, and physical recovery commonly occurs within weeks to months (Carter et al. 2009). Middle continental shelf substrate (100 to 225 ft [30 to 70 m] depth) is less frequently disturbed, with storms primarily facilitating sediment erosion and transport; infilling of cable trenches is slower than on the inner shelf (Carter et al. 2009). Finally, outer continental shelf and upper continental slope substrate (225 to 425 ft [70 to 130 m] and deeper) experienced reduced sediment supply and infrequent wave and current action; trench scars are likely to last longer here than on middle shelf substrate (Carter et al. 2009). Still, disturbance is restricted to a narrow strip of seabed roughly 2 to 3 m on either side of the cable (Vize et al. 2008; Carter et al. 2009), and installation tools typically have footprints no greater than 10 m wide depending on the burial method used (Merck and Wasserthal 2009; NIRAS 2015).

5.1.2 Sediment Resuspension, Turbidity, and Burial

Seabed alterations, such as cable installation, may result in sediment mobility in the water column (Dernie et al. 2003; NIRAS 2015; Taormina et al. 2018). Suspended particulate matter causes turbid plumes whose extent depend on sediment type, installation technique, and hydrodynamic conditions and whose impacts must be assessed against the background of natural turbidity induced by tides, waves, and currents (Meissner et al. 2006). At any given location on a cable route, turbidity may persist from a few hours to days depending on the duration of the cable laying process, sediment type, and currents (Taormina et al. 2018). Coarser sediments such as sand and gravel settle relatively close to the origin of disturbance, while finer sediments such as clay and silt remain in suspension longer, creating a larger impact footprint. Most sediment deposition occurs within tens of meters of the cable route (Vize et al. 2008; NIRAS 2015). Cable installation activities for the Block Island Wind Farm yielded suspended sediments well below predictions of the project-specific turbidity model (Elliot et al. 2017).

Photosynthesizing species, such as plankton and seagrasses, may temporarily experience limited light due to decreased water transparency from the sediment plume and benthic animals and plants may experience stress, reduced rates of growth or reproduction, or mortality (Vize et al. 2008; Merck and Wasserthal 2009). Eggs of bottom laying species may be damaged by settling sediments, while young fish larvae, such as cod recruits, may experience temporary gill damage from suspended sediments (Au et al. 2004, Wong et al. 2012, Hammar et al. 2014, Taormina et al. 2018). However, mobile species are expected to be able to move away from areas of turbidity (OSPAR Commission 2012; NIRAS 2015). Typically, sediment plumes caused by subsea cable activities are of smaller magnitude than those associated with other marine activities, such as aggregate extraction, and both turbidity and burial constitute short-term effects resulting in negligible impacts on marine ecosystems (Vize et al. 2008; NIRAS 2015; Taormina et al. 2018).

5.1.3 Chemical Pollutants

The main chemical risk of subsea cable activities is not from the cable itself, but rather the potential release of sediment-buried pollutants (e.g., heavy metals and hydrocarbons) during installation, maintenance, or decommissioning, and should only be of concern near densely-populated and industrialized coasts (Meissner et al. 2006; Vize et al. 2008; NIRAS 2015; Taormina et al. 2018). Contaminants are generally attached to fine sediments, though certain chemicals may persist in coarser sediments, and are rapidly diluted beyond the immediate area of release (Meissner et al. 2006; Vize et al. 2008; Merck and Wasserthal 2009; NIRAS 2015).

Modern cables are encased in steel wire armor and bitumen-infused polypropylene materials (Carter et al. 2009). As the cables are armored and buried, the effects of ultraviolet light (UV-B), the main cause of degradation in most plastics, are therefore not of any great concern. Any physical breakdown of the cabling is also minimized by the armoring and through burial, which eliminates cable movement and accompanying fatigue (Carter et al. 2009). Furthermore, modern power cables do not contain any fluids and therefore do not pose any contamination threats during their operational lifespan.

5.1.4 Anthropogenic Noise

Anthropogenic noise may be produced during subsea cable route clearance, trenching and backfilling, and by the vessels and tools used during operations. Another, lesser noise emission may be caused during operation of HVAC cables because of the Coulomb force occurring between conductors; compared to cable installation, this noise is low but continuous (Taormina et al. 2018). The intensity and propagation of underwater noise varies according to bathymetry, seafloor characteristics (e.g., sediment type and topography), vessels and machines used, and water column properties (Taormina et al. 2018). There is no clear evidence that underwater noises emitted during cable activities adversely affect marine animals, though it is accepted that many marine animals detect and emit sounds for different purposes, such as communication, orientation, and feeding (Taormina et al. 2018). Sound sensitive marine animals include mammals, fishes, sea turtles, decapods (i.e., shrimp and lobster), cephalopods (squid), and some cnidarian corals (O'Hara and Wilcox 1990; Popper et al. 2001; André et al. 2011, Solé et al. 2016). Possible effects include attraction towards or avoidance of the source, feeding disruption, changes in migratory behavior, or masked communication (Meissner et al. 2006; NIRAS 2015).

The effect of underwater noise on marine animals may be categorized into primary effects (immediate or delayed injury), secondary effects (injury or deafness that may have long-term implications for survival), and tertiary effects (avoidance of the area) (Nedwell et al. 2003). Fishes hear at lower frequencies than marine mammals do and it is generally accepted that most marine fish species have high thresholds or are relatively insensitive to sound (Meissner et al. 2006). As the maximum sound pressure levels from subsea cable activities are considered to be low—below sensitivity thresholds (OSPAR Commission 2012; NIRAS 2015), effects most likely to occur with cable activities are tertiary effects and significant avoidance reactions are not expected to occur (Vize et al. 2008). Vessel activity associated with cable installation or decommissioning occurs over a relatively short time and is a singular event that may not occur again unless maintenance work is required (NIRAS 2015). Any marine animal displacement from the vicinity of operations is expected to be highly localized and temporary (Vize et al. 2008; NIRAS 2015). Therefore, compared with other anthropogenic sources of noise, such as sonar, drilling, pile driving, seismic surveys, vessel activities, and military activities, noise generation related to subsea cable projects is not considered to have large potential for harming marine fauna (Meissner et al. 2006; OSPAR Commission 2012; NIRAS 2015; Taormina et al. 2018).

5.1.5 EMF—Alternating Current versus Direct Current

The two components of electric and magnetic fields (EMF) are electric fields (E-fields) and magnetic fields (B-fields). Naturally occurring EMF are identified by their oscillation frequency, or the number of times the strength and direction of the field alternates per second. Direct current fields are static (i.e., they have a constant direction with no oscillations) and have a frequency of 0 Hz, while AC fields change direction many times per second and mostly occur at frequencies less than 10 Hz in the natural marine environment (Snyder et al. 2019).

There are three primary, natural sources of EMF in the marine environment: earth's geomagnetic field (GMF), electric fields induced by the movement of charged objects (e.g., marine currents and organisms) through this GMF, and bioelectric fields produced by organisms (Normandeau et al. 2011). Earth's GMF is a direct current (DC) magnetic field that originates from the flow of liquid metal in the earth's core and from local anomalies in earth's crust (Normandeau et al. 2011; Snyder et al. 2019). The intensity of this field varies with latitude: equatorial GMF measures roughly 30 microTesla (μT) while polar GMF can reach up to approximately 70 μT (Normandeau et al. 2011; Snyder et al. 2019). Along the southern New England coast, earth's GMF has a magnitude of approximately 51.6 μT (Snyder et al. 2019). Natural electric fields are produced by the interaction between the earth's GMF, the conductivity of the water, and the motion of tides and currents, which creates localized motion-induced fields (Normandeau et al. 2011; Gill and Desender 2020). As ocean currents and organisms move through earth's static magnetic field, they produce a weak static electric field, the intensity of which depends on the velocity and direction of movement but generally does not exceed 0.075 millivolt per meter (mV/m) (Normandeau et al. 2011; Snyder et al. 2019). Finally, all marine organisms produce AC and DC bioelectric fields through heartbeats, gill movements, nerve impulses, and uneven distributions of electric charge along their bodies (Normandeau et al. 2011; Snyder et al. 2019). These electric fields may reach values of 500 mV/m at the organism's body but quickly drop to much lower levels within 4 to 8 in (10 to 20 cm) of the source (Snyder et al. 2019). Some marine organisms use these fields to find each other and locate prey.

Any anthropogenic activity that uses electrical cables in the marine environment adds an additional source of EMF. High-voltage alternating currents are used to connect all types of offshore devices among units in an array and to export power to shore (Gill and Desender 2020). High-voltage direct currents are used exclusively to export power to shore (Gill and Desender 2020). As in natural systems, the EMF emitted by HVDC cables is static, while that emitted by HVAC cables is a low-frequency sinusoidal field (Gill and Desender 2020). The intensity of EMF depends on the type of current (AC or DC), cable characteristics, power transmitted, local GMF, and surrounding environment (Gill and Desender 2020). While the intensity of the field increases in rough proportion to the current flow on the cables, it is also influenced by the separation and burial depth of the cables, which serves to increase the distance between the field source and the marine environment (Normandeau et al. 2011).

As described in section 3.3, AC cables consist of an inner electrical conductor surrounded by layers of insulating material within conductive and non-conductive sheathing (Normandeau et al. 2011). Typically, three cables are bundled together to carry three-phase currents. The direct electric field produced by the voltage on the inner, current-carrying conductor is shielded from the marine environment by the outer grounded metallic sheath encircling the conductors (Normandeau et al. 2011; Snyder et al. 2019; Gill and Desender 2020). However, these metal sheaths do not shield the environment from the magnetic field produced by the cables. For each cable, the out-of-phase magnetic field emitted by each core of the cable causes a rotation in the magnetic emission; this oscillating magnetic field generates a secondary induced electric field (iE-field) in the surrounding marine environment that is unrelated to the voltage of the cable (Snyder et al. 2019; Gill and Desender 2020).

Direct current cables consist of a rectifier (or converter) station to convert AC power to DC power, a cable to transmit the DC power, and an inverter (or converter) station to convert DC power back to AC power (Normandeau et al. 2011). In a monopolar system, power is transmitted on a single HVDC conductor at one voltage with respect to ground. In a bipolar system, two HVDC conductors operate at opposite polarity and a third conductor serves as a return path for any current imbalance between the two poles; power is transmitted at two voltages with respect to ground (Normandeau et al. 2011). Magnetic fields emitted from HVDC cables can influence the intensity of earth's GMF as well as its inclination and declination, where inclination is the angle between the horizontal plane and the magnetic field vector and declination is the angle between the magnetic field and geomagnetic north (Normandeau et al. 2011). HVDC cable fields alter the apparent intensity and direction of magnetic north, and the influence of the cable field depends on the orientation of the cable relative to earth's field (Normandeau et al. 2011).

Elasmobranchs (rays, sharks, and skates), fishes, invertebrates (e.g., crustaceans and mollusks), mammals, and turtles have all been shown to exhibit varying degrees of sensitivity to EMF (Taormina et al. 2018). Sensitive taxa exhibit varying degrees of magnetosensitivity, electrosensitivity, or a combination of the two; therefore, potential impacts of anthropogenically-introduced magnetic fields and electric fields should be considered separately. Magnetosensitive species use earth's GMF for migration, foraging, and discovery of appropriate habitat and spawning grounds. Some studies have shown that magnetosensitive species may respond to anthropogenic magnetic fields at or below the intensity of local GMF and ambient conditions (approximately 30 to 60 µT); however, cable EMF is currently considered unlikely to generate ecologically significant impacts at these low frequencies (Gill and Desender 2014). Electrosensitive species have specialized sensory organs called ampullae of Lorenzini (Figure 92); these organs, arranged in clusters, use naturally occurring electric fields to locate prey or detect the presence of predators, though the range over which these species can detect electric fields is limited to centimeters (Snyder et al. 2019). Strengths of electric fields associated with subsea cables are in the 1 to 100 µV/cm range, which is similar to the bioelectric fields emitted by prey species and may act as an attractant for electrosensitive ocean predators (Gill and Desender 2020).

Laboratory and field studies and reviews have illustrated the potential for anthropogenic EMF to interfere with ambient EMF and impact adult and juvenile fishes (e.g., Chinook salmon, little skates, elasmobranchs, European eels) and invertebrates (e.g., American lobster, Baltic clam, brown shrimp, common ragworm, edible crab) via predator/prey interactions, avoidance/orientation Capabilities, and physiology/development (Soetaert et al. 2014; Siegenthaler et al. 2016; Anderson et al. 2017; Bellono et al. 2018; Hutchison et al. 2018; Richards et al. 2018; Scott et al. 2018; Wyman et al. 2018; Formicki et al. 2019; Newton et al. 2019; Stankeviciute et al. 2019; Nyqvist et al. 2020). Certain commercially important species in southern New England and the New York Bight may exhibit similar sensitivities to anthropogenic EMF. All rays, skates, and sharks native to the southern New England waters and New York Bight are both magneto- and electro-sensitive and may experience some combination of these effects. However, in all cases, these effects are minor enough to be considered negligible both at the individual and population level (Snyder et al. 2019).

While the potential impacts of EMF to marine life are considered minor, cable selection and careful design may be used to further reduce potential impacts. Studies have shown the magnetic fields surrounding all types of subsea power cables (except monopolar, HVDC cables) to be negligible (Sharples 2011). In monopolar HVDC cables, EMF is generated along the single cable and electrolysis occurs at the anode and cathode of the return conductor (sea water). In contrast, the forward and return conductors in bipolar HVDC cables are installed parallel to each other and subsequently neutralize each field (Sharples 2011). Therefore, three-phase AC systems and bipolar DC systems are favored in the marine environment. Cable armor design, sheath design, and burial depth may also influence the strength and spatial extent of EMF emissions. For example, as the permeability of cable armor increases, the resultant EMF strength outside of the cable has been shown to decrease; similarly, as the conductivity of cable sheath and armor increases, the resultant EMF strength outside of the cable decreases (CMACS 2003). Finally, burying cables to a depth of at least 3.3 ft (1 m) may mitigate impacts of the strongest magnetic and induced electrical fields simply by employing sediment as a physical barrier to sensitive species (CMACS 2003; Taormina et al. 2018). Selecting highly permeable armor material, highly conductive armor and sheath material, proximity/bundling of conductors, and appropriate burial depths may effectively mitigate the described impacts of EMF to local marine life.

Figure 92. Porbeagle Shark *(Courtesy; Fisheries and Oceans Canada). Visible ampullae of Lorenzini visible as black dots along the snout of the porbeagle shark.*

5.1.6 Thermal Gradients

The process by which subsea cables generate heat is termed resistive heating. When electric current flows through a cable, some energy is lost as thermal radiation (known as the Joule effect), leading to increased temperatures at the cable surface and subsequent warming of the immediate surrounding environment (Viking Link 2017; Taormina et al. 2018). Because of the high-heat capacity of water, unburied cables have a limited ability to heat the water column and constant water flow dissipates any generated heat (Viking Link 2017). However, heat emissions from buried cables can warm surrounding sediments, creating a thermal gradient that may extend up to tens of inches away from the cable (Taormina et al. 2018). The use of high voltages minimizes such heat loss and HVDC cables exhibit lower heat emissions than do HVAC cables at equal transmission rates (Viking Link 2017; Taormina et al. 2017). Presently, the maximum operating temperature of high-voltage cable conductors is 194° F (90˚C), which can translate to cable surface temperatures of up to 158°F (70˚C) (Emeana et al. 2016). Most subsea cables have average loads much lower than these maximum rated loads (Worzyk 2009).

Factors determining the degree and distance of the thermal gradient surrounding a cable include cable characteristics, transmission rate, and sediment characteristics (e.g., ambient temperatures, thermal conductivity, thermal resistance) (OSPAR Commission 2012). For fully saturated marine sediments, heat transfer can occur both by conduction (transfer of thermal energy through direct contact) and convection (transfer of thermal energy through the movement of a liquid) (Emeana et al. 2016). In continental shelf settings, fine-grained sediments are expected to exhibit conductive heat transport, while coarse-grained sediments are expected to exhibit convective transport (Emeana et al. 2016). Convective transport allows for increased heat loss through interstitial water, and coarser sediments are expected to have a shorter heat gradient surrounding the cable than finer sands and muds (Merck and Wasserthal 2009). Few field studies have been conducted to confirm predicted heat emissions from operational cables. However, in a study of the Nysted wind farm in Denmark, the maximum temperature increase at the sediment surface yielded by buried cables was 2.5°C and the average increase was 0.8°C (Meissner et al. 2006). Therefore, the overlying sediment provides insulating properties to the benthic habitat and surrounding water column from thermal impacts of the buried cable.

Because cables have a negligible capacity to heat the water column, demersal and epibenthic (seafloor surface) organisms in direct contact with water are not at risk of experiencing thermal impacts from buried cables. However, by heating seafloor sediments, buried cables do have the potential to modify chemical and physical properties of substratum, such as altering the oxygen concentration profile, apparent redox potential discontinuity depth, ammonium profile, sulfide profile, and nutrient profile (Meissner et al. 2006; Merck and Wasserthal 2009; Taormina et al. 2018). This may subsequently increase bacterial activity and alter distributions of faunal and floral elements; cryophilic (cold-affiliated) organisms may be limited within the thermal gradient surrounding the cable, while thermophilic (warm-affiliated) organisms may be attracted to the area (Worzyk 2009). Certain organisms may be more impacted than others. Laboratory experiments have demonstrated avoidance behaviors in deep-burying polychaete worms to heat sources, but no behavioral changes in mud shrimp were observed (Meissner et al. 2006).

While permanent temperature increases in seafloor sediments may yield changes in physiology, reproduction, or benthic community structure, burial depth may mitigate thermal impacts. The majority of infaunal communities are within the top 8 inches (20 cm) of the sediment (Viking Link 2017; Vize et al. 2008). The German Federal Agency of Nature Conservation has pioneered thermal guidelines for buried cables by recommending no more than a 2°C temperature elevation in seafloor sediments located 0.2 m below the surface to protect benthic organisms (Worzyk 2009). This limit may be met by increasing cable burial depth according to cable design. Bundled cables typically require between 2.3 ft (0.7 m) and 3.75 ft (1.15 m) of sediment cover, while single cables emit less heat and only require between 1 and 2 ft (0.35 m and 0.55 m) of sediment cover to meet the 2°C (2K) rule (Viking Link 2017). Alternately, increasing conductor diameter may also reduce thermal radiation in instances when adequate cable burial is infeasible (Meissner et al. 2006). Ultimately, the limited width of cable burial corridors and predicted surrounding thermal gradients are expected to yield negligible impacts to the benthic environment.

5.2 Potential Impacts to Habitat/Potential Impacts to Fishing

The New York Bight is home to more than 300 fish species that move between the region’s estuarine, inshore, and offshore habitats daily, seasonally, or throughout their life cycle. Essential Fish Habitat (EFH) has been identified in these waters for 52 species and NOAA Fisheries’ Greater Atlantic Regional Field Office (GARFO) considers 10 species common to these waters as species of special concern (NYSERDA 2017).

5.2.1 Fisheries Habitat

Potential biological impacts associated with physical disturbance to the seabed include damage, displacement and removal of flora and fauna (Dernie et al. 2003; OSPAR Commission 2012; NIRAS 2015). Such disturbance is most obvious in biogenic habitats like mussel beds, seagrass beds, and slow-growing marl beds (calcified red algae) (Meissner et al. 2006). Habitat or community resilience is characterized by the capacity to return to initial ecological state after perturbation and depends upon the nature and stability of the seabed (Foden et al. 2010), habitat depth (Foden et al. 2011; Clark et al. 2014), and the abundance, diversity, and life cycles of the disturbed species (Erftemeijer and Lewis 2006). Studies have demonstrated that cables typically result in minimal damage to resident biota (Andrulewicz et al. 2003; Kogan et al. 2003, 2006; Carter et al. 2009). At the Block Island Wind Farm, flounder abundance did not appear to be influenced by the installation or operation of the cable (Wilber et al. 2018). Due to the localized nature of cabling activity, the overall biological impact is likely to be negligible particularly if the habitat distribution throughout the wider area is homogenous (Vize et al. 2008).

Sessile species, such as bivalves and tubeworms, may experience damage or mortality during excavation via direct contact with the installation device, burial, or dislodgement (Vize et al. 2008; OSPAR Commission 2012). The majority of infaunal communities are within the top 8 inches (20 cm) of the sediment, indicating that disturbances below these depths may not drastically impact recovery time (Vize et al. 2008). Species inhabiting sand and gravel substrates are typically adapted to frequent natural disturbances and are expected to recover quickly; long-term disturbance is only likely to occur in sensitive habitats, which include slower-growing sessile species (Meissner et al. 2006; Vize et al. 2008). Mobile benthic species, such as crustacean species, in the vicinity of the cable route are generally able to avoid the footprint of the impact.

Certain shellfish species, such as scallops, exhibit avoidance behavior only over short distances and are more likely to be impacted by seabed disturbances (Vize et al. 2008). Furthermore, areas important for certain shellfish life stages associated with limited mobility, such as crustacean overwintering areas and settlement areas for juvenile fish, may experience greater impacts (Vize et al. 2008). Initial recolonization takes place rapidly following cable burial, with certain species returning almost immediately to the disturbed site (Vize et al. 2008). Andrulewicz et al. (2003) found no difference in benthic diversity, abundance, or biomass on a cable route buried in soft-bottom substrate in the Baltic Sea one year after installation. Kogan et al. (2003, 2006) found no difference in abundance and distribution of 17 benthic animal groups within 100 m of a surface-laid coaxial cable and no infaunal difference (polychaete worms, nematodes, and amphipods) in 138 sediment cores of varying distances from the cable.

Fisheries habitat types potentially affected by subsea cable activities include spawning grounds, nursery grounds, feeding grounds, and migration routes (Vize et al. 2008). Most species of marine fish spawn in the water column where reproduction is not severely impacted by the placement of cable (Vize et al. 2008). The reproduction of certain fishes may be linked to sediment types and annual cycles. Sediment spawning fishes, like Atlantic herring and sand lance, may be affected by direct loss or injury to eggs and larvae (NIRAS 2015). While nursery habitats are important, such habitats are widespread and juveniles are unlikely to be heavily impacted by narrow cable routes. Finally, as most fish species are relatively opportunistic feeders, temporary cable laying activities are unlikely to hinder feeding activities, though cable activities should attempt to avoid regions and times of year identified as critical to certain species feeding or spawning behaviors (Vize et al. 2008). The presence of installation vessels and equipment is expected to result in only temporary displacement of fishes (Vize et al. 2008). Monitoring of the two earliest offshore wind farms in Denmark, Horns Rev and Nysted, have found no substantial impacts of cables on fish stock displacement (Vize et al. 2008).

In shallow, nearshore environments, various techniques to meet different environmental conditions have been employed to help reduce disturbance in wetlands and intertidal zones. Seagrasses have been reseeded and replanted in Puget Sound, Washington and regions of Australia to assist in the recovery of beds impacted by cable burial (Carter et al. 2009). In one instance, a low-impact vibrating plough was used to bury a cable through salt marshes along the Frisian coast in Germany, which exhibited re-establishment of vegetation within one to two years and full recovery within five years (Carter et al. 2009). In turn, intertidal regions such as sand and mudflats display a high resilience to temporary sediment displacement likely to occur from trenching, plowing, or jetting, and burrowing species are likely to rapidly re-establish themselves in the sediment (NIRAS 2015).

5.2.2 Reef Effects

Like other immersed hard-structured objects (e.g., shipwrecks, oil/gas platforms, and marine renewable energy devices), unburied submarine cables and associated protection can create artificial reefs (Tyrell and Byers 2007; Kerckhof et al. 2010; Langhamer 2012; OSPAR Commission 2012). Lengths of exposed unburied cable often utilize over-covering concrete mattresses, frond mattresses, rock dumping, or cast-iron split-pipe shells (Meissner et al. 2006; Vize et al. 2008). These structures are colonized by sessile encrusting organisms (barnacles, mussels, sponges, anemones, corals) and mobile macrofauna, and may also attract mobile megafauna, such as decapods or fishes (Taormina et al. 2018). Such artificial structures are expected to have limited reef effects when located within a naturally hard seabed environment (Langhamer 2012; Sherwood et al. 2016) and investigations have shown no substantial differences between communities on cables and nearby rock outcrops (Dunham et al. 2015, Kuhnz et al. 2015; Love et al. 2017). However, on soft sediments, where cables and associated hard protection represent novel features in a seafloor otherwise devoid of such features, a stronger reef effect may occur (Meissner et al. 2006). Encrusting species may either be native or non-native to the region. There is no documented spread of invasive species linked to subsea cables, as cable routes are narrow and typically buried in areas of soft sediment (Taormina et al. 2018).

Large recreationally and commercially valuable species, such as black sea bass, summer flounder, and tautog, may be attracted to the higher densities of forage fishes and decapod crustaceans present on cable protection measures (Vize et al. 2008; Carter et al. 2009; Taormina et al. 2018). This may benefit recreational anglers and private charter boats, both of which have notably capitalized on reef-associated assemblages attracted to the larger structures of the turbine foundations, such as the Block Island Wind Farm and associated cable protections (Prevost 2019). These reef effect benefits, however, may not extend to commercial fishermen who may not be willing to risk losing gear to snags on cable protection measures (Carter et al. 2009).

5.2.3 Fishing Gear

In 2019, the New York Bight yielded approximately 23.0 million pounds in total commercial landings, valued at $39.2 million (NOAA Fisheries 2020a). Of these landings, scup, longfin squid, monkfish, northern quahog, silver hake, golden tilefish, and Atlantic surfclam each totaled over one million pounds. Longfin squid and northern quahog were valued at more than $6 million each. Landings through the State's largest ports, Montauk and Hampton Bay-Shinnecock, totaled 15.5 million pounds at $23.5 million (NOAA Fisheries 2020b). Similarly, the New York Bight yielded approximately 29.2 million pounds in total recreational landings, with the most highly targeted species including striped bass, scup (porgy), bluefish, black sea bass, tautog, summer flounder, and Atlantic herring (NOAA Fisheries 2020c). In addition, states outside NY Bight fish these waters and land their catch in their home ports throughout New England and the mid-Atlantic states.

Most saltwater recreational fishing involves the use of hook and line (rod and reel) methods, which are unlikely to have substantial interactions with subsea cables. As described in section 4.3, commercial fishing activity can broadly be divided into methods involving mobile gear, where nets or lines are towed by vessels, and fixed gear, where nets, lines or pots are left in the environment for a period of time (see section 4.3 for gear descriptions). Both mobile and fixed gear vessels may be impacted by temporary activity exclusion, temporary fish stock displacement, and snagging of fish gear, which can result in reduced catch or increased costs (Vize et al. 2008; NIRAS 2015).

Cable installation and maintenance activities and associated vessel activity have the potential to increase the risk of collision with existing navigational users. For safety purposes, fishing vessels are often prevented from fishing within the work area designated by dynamic safety zones around vessels during the limited timeframe of cable installation and maintenance. This may lead to increased steaming times to fishing grounds, increased fuel costs, and reduced fishing time for fishermen (Vize et al. 2008). However, due to the short duration of construction activity and the small width of habitat affected by cable laying, likely impacts of restricted access are considered short-term and minimal (Vize et al. 2008; NIRAS 2015). Once installation is complete, commercial fishing activities may continue as usual, bound by existing navigational regulations.

Fisheries may also be impacted by physical damage to bottom fishing gear. Otter trawls, beam trawls, scallop dredges, gill nets, and demersal longlines all involve weighted nets, chain bags, or lines that may snag on exposed cables or cable armor. If such gear interacts with an exposed cable, it may be damaged or lost completely, along with any catch contained in the gear at the time. However, most cables are buried to depths deeper than those penetrated by bottom fishing gear to avoid such problems; where burial is impractical, other cable protection may be used (Carter et al. 2009). Modifications to bottom gear used in areas where structure is common (e.g., rollers, cookies, rockhoppers, etc.) are designed specifically to pass over natural and artificial seabed obstacles to reduce the probability of gear damage or loss. Therefore, as mentioned in section 4.3, the vast majority of active trawl crossings over buried cables often go entirely unnoticed by the fisherman. In the limited areas of the seafloor with exposed cables or cable protection, gear interactions may occur, but the risk of damage to either cable or fishing gear remains low.

In the unlikely situation where fishing gear may snag on a cable to the point that the cable is damaged, this may result in an electrical short. The resulting electrical short can lead to equipment overload and shut-down of power at the offshore substation. This is not likely to result in electrical safety impacts to a vessel or its crew due to the high conductivity of seawater, resulting in a complete earthing, or grounding, of the damaged cable upon shorting (Sharples 2011).

6.0 Mitigation Measures

Sections 4 and 5 described various risks and impacts to cables (seabed conditions, navigation, fishing, etc.) and from cables (environmental, EMF, thermal, and fishing). This section summarizes the various mitigation measures aimed to reduce those risks and impacts, where feasible.

The main areas where mitigation measures are adopted are during selection of cable route and cable burial method (Vize et al. 2008). During these periods, mitigation in the form of re-routing or micro-siting is considered to avoid significant environmental impacts. Routes with the lowest environmental impacts and highest resource efficiency are selected by comparing alternatives based on existing literature and survey data; selection is carried out with formal approval procedures and integrated survey assessments. Low-impact routes are selected based on avoidance of protected areas, environmentally sensitive areas, and/or valuable areas as well as; avoidance of route lengths longer than necessary, and avoidance of crossings with existing cables and pipelines (OSPAR Commission 2012).

Once cable routes are selected and the cable is installed, the burial of the cable itself may function as a mitigation measure to minimize interaction with the cable once installed. Techniques may also be selected to ensure a berm is not left along the cable route following backfilling activities, leaving the seabed as close to its natural "pre-installation" state as possible. Installation devices that possess depressors, designed to infill plow furrows, may effectively mitigate berm impacts and reduce the need for manual backfilling (Vize et al. 2008). Where there are species that are sensitive to suspended sediment, techniques are selected to ensure the lowest resuspension of sediment where possible. While jetting fluidizes the seabed using high-power jets and may subsequently resuspend sediments for hours, plowing usually entails lifting a wedge of seabed and allowing it to slump back over the laid cable within minutes or hours of the installation (OSPAR Commission 2012). The level of sediment disturbance is therefore lower using plowing methods. This also prevents remobilizing potential contaminants present in coastal sediments, that is, if there is a concern that disturbing sediments could be an issue, this would be considered (avoided if possible) during the planning phase and mitigated by the selection of installation and burial techniques that reduce turbidity.

Baseline information on the distribution of sensitive habitats and species in the construction area is collected prior to project mobilization. Cable routes are selected to avoid fish spawning, nursery, and feeding habitats, and appropriate scheduling is selected to avoid sensitive times of year (e.g., winter dormancy, migration, mating, spawning) to mitigate noise impacts. Particular consideration is given to habitats and benthic species that are most sensitive to disturbance (e.g., slow-growing long-lived species). In the North Atlantic, this might include mussel beds, algae beds, and eelgrass (*Zostera* sp.) beds (Taormina et al. 2018). Exclusion zones for anchoring are established if necessary, and anchor disturbance is further reduced by using tenders to lift anchors rather than dragging them across the seabed (Vize et al. 2008).

Horizontal directional drilling has been shown to be an appropriate form of mitigation to avoid damage in intertidal areas; in tidal flats where large laying vessels cannot operate, laying barges and vibration plows have been used to bury cables (Carter et al. 2009). In soft substrates not characterized by sensitive habitats, cables are buried where possible to avoid generating morphological changes favorable to non-native species. Cable burial depth is informed by engagement with stakeholders in the commercial fishery industry and an assessment of seabed conditions and activity. While depths of 2 to 3 ft (0.6 to 0.9 m) have been shown to interact with hydraulic clam dredges, cables buried at target depths of 5 to 6 ft (1.5 to 1.8 m) have experienced little to no interactions with fisheries (NASCA 2019).

In planning around commercial fishing industries, charted anchorages and dredged areas are avoided as well. Maritime authorities and permitting processes aid in selecting appropriate routes, and fishing and merchant marine associations are consulted directly (Carter et al. 2009). Organizations focused on the fisheries have worked successfully with cable owners with a mutual interest of minimizing gear interactions and damage to the cable and fishing gear (Oregon Fishermen's Cable Committee 2017). Cable laying activities are communicated prior to project mobilization through Notices to Mariners, fishing news publications, project emails and bulletins, and navigational charts (Vize et al. 2008). Cables are further monitored in situ to identify and address physical risks to fisheries as explained above. Finally, using suitable, local fishing vessels as guard vessels for cable laying operations may provide useful alternative supplemental income to temporarily displaced vessels (Vize et al. 2008).

7.0 Conclusion

The northeast U.S. is a densely populated area, with large population centers on the Atlantic Ocean. In particular, New York Bight's densely populated coastline is generally conducive to OSW as an efficient source of electricity proximate to load centers.

This high population results in a high number of stakeholders competing for resources in the ocean, particularly:

- Commercial maritime vessel traffic
- Commercial and recreational fishing
- Recreation
- Military/homeland security
- Energy
- Communications

The individual states surrounding the New York Bight have all set goals for renewable energy generation, and offshore wind as well as offshore electrical power transmission will play a large role in attaining those goals. This means that the demand for submarine cables in the region will continue to grow. It is important that the installation and operation of submarine cables avoid, minimize, or mitigate impacts to the environment as well as to existing ocean users. This is entirely possible and can be achieved by proper and diligent project planning and execution.

Proper and diligent planning can reduce the impacts of submarine cable installation and operation through the following steps:

1. The gathering and understanding of all **relevant data for the region and specific** project cable routes, including:
   a. Geotechnical and geophysical data
   b. A fishing industry study
   c. A commercial traffic study
2. The creation of an in-depth Cable Burial Risk Assessment to identify risks and create a set of burial recommendations designed to mitigate those risks.
3. Due diligence when selecting cable installation and burial contractors, methods, and equipment.
4. Oversight during installation and burial operations to ensure the cable is laid and buried in accordance with the plan.
5. An effective operations and maintenance strategy to ensure the cable burial depth is monitored and any trends (such as reduction of burial depths) can be remedied before becoming problematic.
6. A decommissioning plan that weighs the pros and cons of abandonment versus recovery of the cabling after the operational life is complete.

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