Shared Landfall and Cable Route Infrastructure

Feasibility Study Final Report

Revision B

December 13, 2023

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National OSW Research and Development Consortium

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Acronyms and Abbreviations

AC	Alternating Current
BOEM	Bureau of Ocean Energy Management
CAPEX	Capital Expenditures
CFD	Computational Fluid Dynamics
CLB	Cable Lay Barge
CLV	Cable Lay Vessel
CPS	Cable Protection System
DAS	Distributed Acoustic Sensing
DECEX	Decommissioning Expenditures
DEVEX	Development Expenditures
DP	Dynamic Positioning
DTS	Distributed Temperature Sensing
EMF	Electromagnetic Fields
FEED	Front-End Engineering Design
HDPE	High Density Polyethylene
IP	Individual Permit
GW	Gigawatt
HDD	Horizontal Directional Drill
HSE	Health, Safety, and Environment
HVDC	High Voltage Direct Current
kWh	kilowatt hours
LCoE	Levelized Cost of Energy
m/s	meters per second
MHHW	Mean Higher High Water
MW	megawatts
MWh	Megawatt hours
MVDC	Medium Voltage Direct Current
NPV	Net Present Value
NWP	Nationalwide Permit
NY	New York
NYISO	New York Independent System Operator
NYPA	New York Power Authority
NYS	New York State
NYSERDA	New York State Energy Research and Development Authority
OPEX	Operational Expenditures
OSW	Offshore Wind
POI	Point of Interconnection
PSC	Public Service Commission
RTO	Regional Transmission Organization
USACE	US Army Corp of Engineers
USCG	US Coast Guard
XLPE	Cross-linked Polyethylene

1 Introduction

1.1 Aims

The aim of this study and the report to follow is to quantify and assess the benefits and risks of a shared landfall and onshore infrastructure concept to co-locate transmission cables from multiple offshore wind (OSW) developments. This report coordinates industry stakeholders' challenges and insights; creates a well-supported basis for design concept based on stakeholder input and industry standards; and executes a design concept with possible next steps forward to addressing many of the key problems associated in coordinated transmission.

1.2 Context

The concept design is to be based around an example reference location. The study team has selected the New York (NY) area for the reference location. This is for the following reasons:

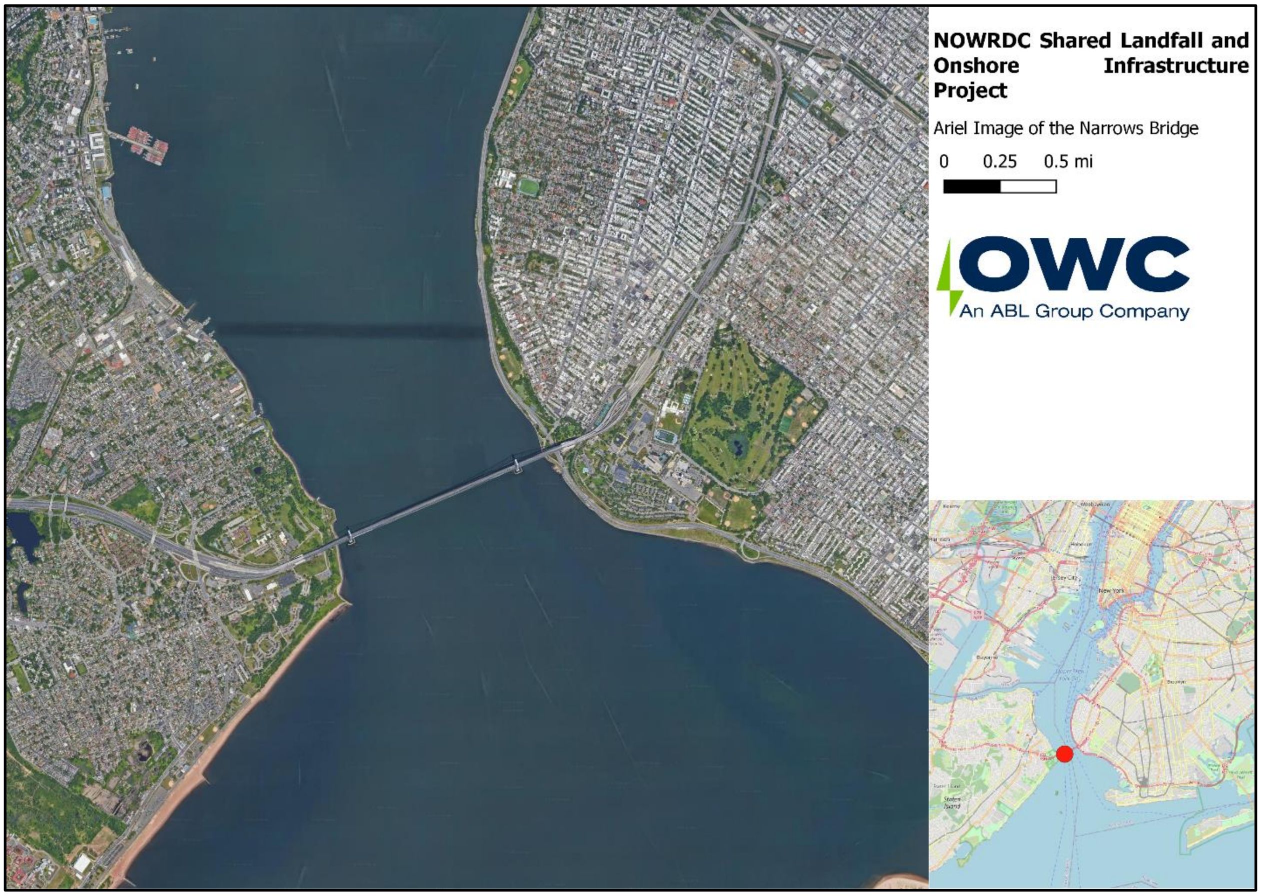
- NY State is holding solicitations for OSW energy delivery to the state. NY state has already procured 4,300 MW of offshore energy of a target 9,000 MW.
- BOEM recently auctioned six new sites in the NY Bight in February 2022.
- In NY, space is a premium and the general area is congested in terms of space for cable routing.
- The study team has considerable experience with the NY area in terms of grid connection, regulatory, permitting, and the existing infrastructure in the harbor.

A quotation from [1] puts the issue in perspective:

> *"Integrating 9,000 MW of OSW generation by 2035 is projected to be achievable without major onshore bulk transmission upgrades beyond expanding Long Island bulk transmission links and likely local upgrades in New York City, as previously noted. Interconnecting a maximum amount of OSW in the New York City area would be advantageous given the large load and strong bulk transmission system. However, overcoming cable routing limitations in New York Harbor, space constraints in substations on Manhattan, and permitting complexities in both the Harbor and along the Long Island coastline (including approaches to New York City through the Long Island Sound) will require careful planning of OSW transmission cable routes and points of interconnection."*

A reference location has been selected to facilitate cable routing through the Narrows, a tidal straight which connects Upper NY Bay with Lower NY Bay and the Atlantic Ocean. The Narrows has a width of about 1,500 meters and is spanned by the Verrazzano-Narrows Bridge. The bridge foundations leave an underpass width of about 1,300 meters to pass through. This is shown in Figure 1-1.

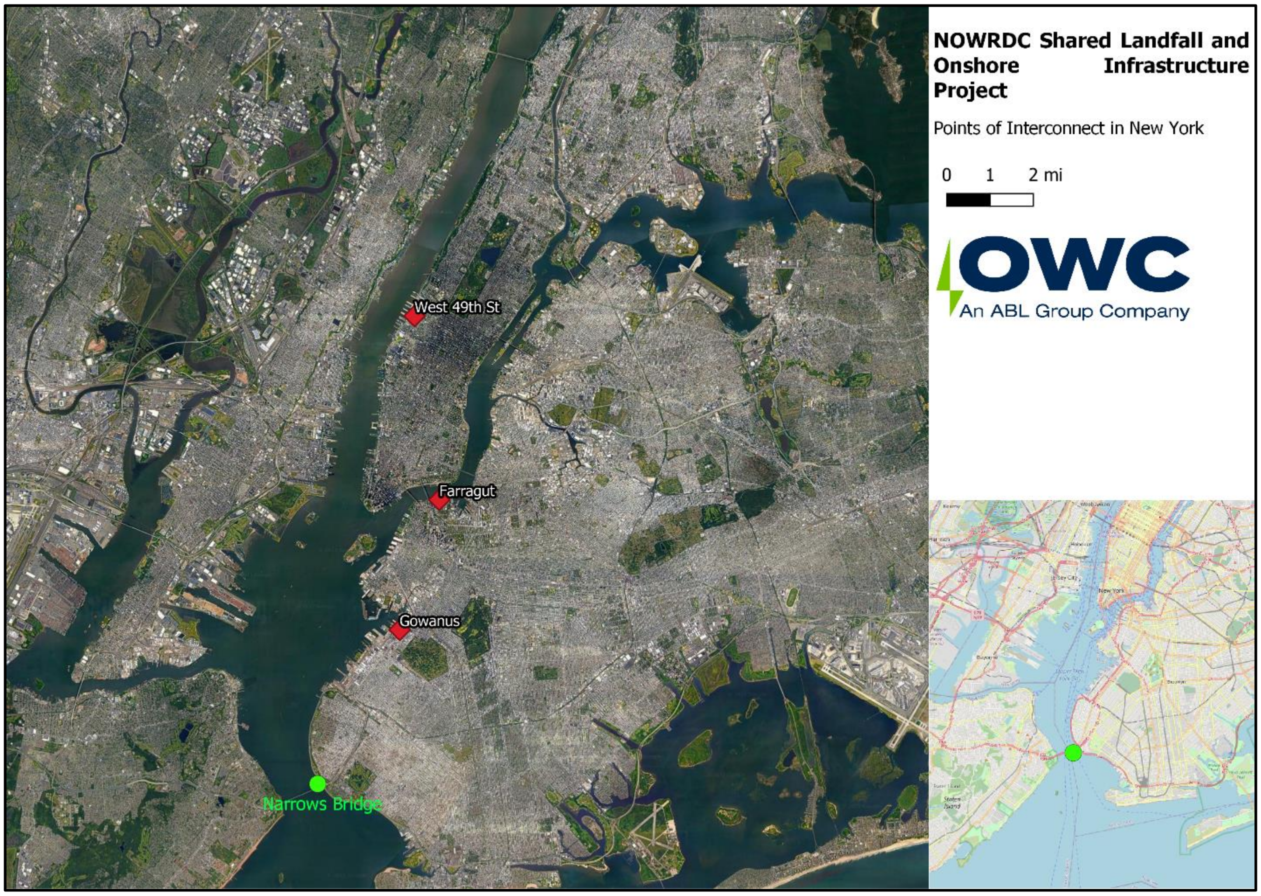
Figure 1-1. Aerial image of the Narrows



The Narrows is believed to be challenging from an offshore cable installation perspective, due to the narrow width and commercial activity of the port of New York City, with heavy vessel traffic and anchoring through this area. This will make cable installation expensive. It will be even more challenging for multiple independent OSW developments to install cables through this same corridor.

The concept being studied will feature infrastructure to allow multiple OSW developments' cables to be installed through this constrained offshore environment to reach Points of Interconnection (POI) in Brooklyn, Queens, Staten Island, and Manhattan, as outlined in Figure 1-2.

Figure 1-2: Points of Interconnection in the NY area



The study team has decided to design a concept which will enable cables to pass through this constrained offshore area and continue back offshore, such as into the rest of the harbor, the East River, or the Hudson River, depending on where each development's POI would be. The concept will also feature a transition to an onshore corridor, to enable many cables to be routed to a major onshore POI hub such as Farragut or Gowanus. This will allow concepts to be developed for several scenarios, covering offshore to onshore landfall transition, an onshore corridor, and an offshore corridor.

1.3 Scope of Work

This study focuses on developing a concept design for shared landfall and cable route infrastructure and evaluating the feasibility of it.

The work has been broken down into five tasks which are listed below and covered in this final report.

- Task 1: Stakeholder Engagement
  Coordinate and organize meetings with key stakeholders relative to the proposed design of a cable landing infrastructure such as NYSERDA, BOEM, NYISO, and several offshore wind developers.

- Task 2: Basis of Design
  Design infrastructure in accordance with a traditional OSW developments' cable landings to build a traditional "Base Case".

- Task 3: Concept Design
  Develop a solution for the Concept Case shared landfall infrastructure, delivering engineering calculations and drawings for the structure.

- Task 4: Cost Assessment
  A cost-benefit analysis to compare DEVEX, CAPEX, OPEX, and DECEX costs associated with the Concept Case against that of the Base Case.

- Task 5: Concept Evaluation
  Provide a qualitative evaluation of the Concept Case, the associated technical and commercial attributes, risks, challenges, opportunities, advantages, and disadvantages.

1.4 Study Team

The study team is comprised of five consultancies working in renewable energy. OWC is the principle investigator for this study. OWC (an ABL Group company) is a specialist and service-focused engineering consultancy that helps develop and deliver bespoke offshore and onshore renewable energy projects and investments for developers and investors in all global markets.

Support to OWC for this study is provided by ITPEnergised, Power Advisory, Continuum Associates, and Prospect Hill Consulting LLC. ITPEnergised Group is a world-leading consultancy offering energy, environmental, engineering, technical advisory and renewables asset management services. Power Advisory LLC (Power Advisory) is a consulting firm that focuses on the electricity sector, specializing in energy market analysis and strategy, power procurement, policy development, regulatory and litigation support, market design and project feasibility assessment. Continuum Associates (CA) is a leading renewable energy project development consulting and advisory firm with extensive focus on grid technical and analytical studies. Prospect Hill is a small, NYS Certified Minority and Women-owned Business Enterprise (M/WBE) LLC providing consultancy services for community planning, environmental planning, permitting, and geospatial & data visualization.

The division of scope of work amongst the study team is illustrated below.

OWC

- Electrical and cable feed into concept design
- Civil lead for concept design
- Stakeholder engagement lead
- Cost assessment support

OWC An ABL Group Company

ITPEnergised

- Cost assessment lead
- Electrical / cable calculation activities

ITPENERGISED

Power Advisory

- Power systems regulatory framework
- Ownership and funding models
- Support for stakeholder engagement

POWER ADVISORY

Continuum Associates

- Development of Reference Area for Design
- Advice for Points of Interconnection

ca continuum associates

Prospect Hill Consultants

- Permitting framework, issues and constraints
- Support for stakeholder engagement

PROSPECT HILL CONSULTING LLC

2 Method

2.1 Overview

Each phase of this study required a unique methodology to achieve optimal results. Each methodology was carefully thought out before completing the work of the phase to ensure that all requirements stated in the proposal were met. Described below is the methodology that was used to complete each individual phase.

2.2 Basis of Design

This report describes the basis of design for the shared landfall and cable route infrastructure study.

An approach for shared infrastructure to accommodate and co-locate cables at landfall and key onshore transmission corridors is proposed to increase cost efficiency and de-risk this element for OSW and offshore transmission developments.

The aim of the proposed research is to:

- Develop a conceptual design for landfall and onshore cable infrastructure that could be shared by two or more different OSW developments.
- Evaluate the feasibility in terms of costs, installation, and from industry stakeholders' perspectives.
- Identify the framework from a contractual interface, permitting, and regulatory perspective.
- Quantify and assess the benefits and risks / issues.

2.3 Stakeholder Engagement

This report describes the stakeholder feedback OWC collected for the shared landfall and cable route infrastructure study. The input from stakeholders helps develop consensus, constraints, and the framework for the design basis. The aim of the stakeholder engagement was to:

- Gain feedback from key stakeholders
- Highlight potential constraints or conflicts to take into consideration
- Help inform and advance the study design basis
- Outline key factors of concern for each stakeholder
- Understand potential benefits to stakeholders including OSW developers

2.4 Concept Design

For the concept study for this study, the team used the following method.

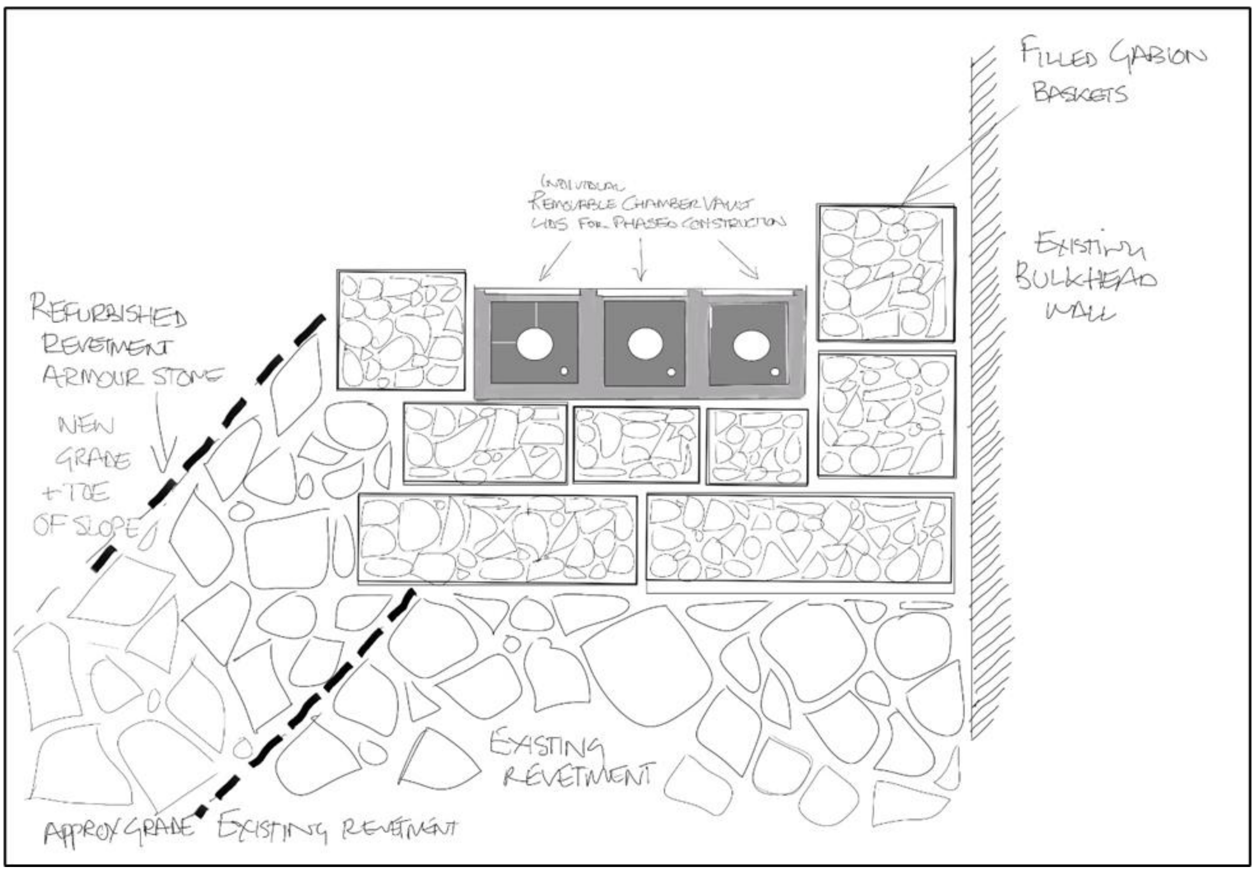
First, the Basis of Design was determined to set out the boundary conditions for the concept. This also included a definition of the Reference Location to design for. Refer to [2] for the Basis of Design.

The Reference Location required several connected designs. The concept designs needed to cover:

- The seabed to offshore infrastructure transition
- The offshore infrastructure
- The offshore to onshore transition
- The onshore infrastructure

In determining the offshore infrastructure concept, several initial concepts were constructed. Figure 2-1 shows an initial cross-section of the concept design along the offshore infrastructure hugging the existing bulkhead wall.

Figure 2-1: Initial cross-section of the concept design for three cable / circuits.



As inputs from the Stakeholder Engagement task were considered in finalizing the Basis of Design, the number of circuits increased from three to six. The concept design was adapted for this change. The design of the revetment and armoring along the infrastructure was developed by OWC's marine civil engineering team based on its history of experience in similar structured and high familiarity with the Reference Location along the Narrows. The requirements for the cables in terms of sizing, security, O&M, and installation were discussed between the electrical and civil engineering teams, and the concept of the cable chambers was developed.

An initial set of cable thermal calculations was undertaken using steady-state principles outlined in the IEC 60287 standard, and it was agreed the offshore infrastructure was likely to be feasible and more complex thermal analysis using computational fluid dynamic (CFD) was unnecessary. The seabed to offshore infrastructure transition was then developed by the marine civil engineering team.

Finally, the team discussed the construction, cable installation and O&M philosophy and made modifications to the offshore concept design as appropriate.

Initially, the focus of the study was on the landfall infrastructure only. The study team decided to also address onshore to see if a more thermally efficient solution could be identified despite all cables being in proximity and in a common corridor. It was important to reduce the width of the infrastructure as far as possible and to fit all six circuits within a two-lane road as a minimum with the possibility of using one lane plus the sidewalk.

The Basis of Design identified a desire for separation of circuits, from a physical perspective for installation and maintenance, but also in terms of operation. We aimed to identify concepts that would enable the installation conditions to be predictable and for each circuit to be unaffected by operation of adjacent circuits. Initial thermal modeling was performed using steady-state principles of IEC 60287 for guidance in the early-stage design.

The Basis of Design also prescribed avoidance of active cooling systems if possible. To accomplish this, we explored the concept of thermal isolation using passive flow of air or water between circuits. We decided to focus on air isolation since it is simpler from an operation and maintenance perspective. OWC’s onshore civil engineering team put together a concept that utilizes buoyancy-driven airflow for managing cable temperatures and minimizing thermal interactions between cable circuits of different Cable Operators.

Due to the use of buoyancy-driven airflow, thermal calculations using IEC 60287 methods were not adequate to model this. Computation Fluid Dynamics (CFD) was utilized, using 2D models initially, followed by more sophisticated 3D models. The results of the CFD analysis were evaluated and further simulations undertaken as sensitivity analysis.

2.5 Cost Assessment

2.5.1 General

For the cost assessment for this study, the team used the following method.

The cost assessment of the shared landfall and cable route infrastructure closely follows the technical description in the Concept Design Report [3]. This report describes several connected designs around the Reference Location described in the Basis of Design [2]. The concept designs needed to cover:

- The seabed to offshore infrastructure transition
- The offshore infrastructure
- The offshore to onshore transition
- The onshore infrastructure

Using this information, two cost assessments were created, one for the Base Case and one for the Concept Case. Each of these cost assessments were broken down into four broad categories. These categories include:

- Development Expenditures (DEVEX)
- Capital Expenditures (CAPEX)
- Operation Expenditures (OPEX)
- Decommissioning Expenditures (DECEX)

2.5.2 Base case

From here, the Base Case and Concept Case begin to differ. After the Base Case was broken down in DEVEX, CAPEX, OPEX, and DECEX, smaller subcategories were formed based on the reference outlined in the basis of design (Task 2). A further breakdown for each category is shown in Table 2-1 below.

Table 2-1: Base case cost model breakdown

DEVEX	Feasibility Studies and Site Assessment	Geotechnical Investigations
		Oceanographic Studies
		Environmental Impact Assessment (EIA)
	Permitting and Approvals	Permit Applications and Regulatory Compliance
		Public Consultation and Stakeholder Engagement
		Legal and Professional Fees
	Land Acquisition and Rights-of-Way	Easements and Access Rights
		Land Surveys and Title Investigations
CAPEX	Cable Supply	HVDC Onshore cable supply
		HVDC Offshore cable supply
	Onshore Civil Works	-
	Offshore Civil Works	Offshore cable installation
		Landfall HDD
OPEX	Year 1 Operations	Onshore inspection
		Offshore inspection
	Annual operations (every year)	Onshore inspection

		Offshore inspection
	10 yearly operations	Onshore inspection & maintenance
		Offshore inspection & maintenance
	Cable Repair	Onshore cable repair
		Offshore cable repair
DECEX	Decommissioning Planning and Engineering Studies	Decommissioning Studies and Reports
		Engineering Design for Decommissioning

2.5.3 Concept Case

The Concept Case was also broken down according to DEVEX, CAPEX, OPEX, and DECEX, but these were broken down into different subcategories based on learnings from Task 1 and Task 2. A further breakdown for each category is shown in Table 2-2 below.

Table 2-2: Concept Case cost model breakdown

DEVEX	Feasibility Studies and Site Assessment	Geotechnical Investigations
		Oceanographic Studies
		Environmental Impact Assessment (EIA)
	Permitting and Approvals	Permit Applications and Regulatory Compliance
		Public Consultation and Stakeholder Engagement
		Legal and Professional Fees
	Land Acquisition and Rights-of-Way	Easements and Access Rights
		Land Surveys and Title Investigations
CAPEX	Cable Supply	HVDC Onshore cable supply
		HVDC Offshore cable supply
	Onshore Civil Works	Manufacturing
		Site Preparation
		Transportation
		Construction
		Cable installation
	Offshore Civil Works	Manufacturing
		Site Preparation
		Transportation
		Construction
		Cable installation
OPEX	Year 1 Operations	Onshore inspection
		Offshore inspection
	Annual operations (every year)	Onshore inspection
		Offshore inspection
	10 yearly operations	Onshore inspection & maintenance
		Offshore inspection & maintenance

	Cable Repair	Onshore cable repair
		Offshore cable repair
DECEX	Decommissioning Planning and Engineering Studies	Decommissioning Studies and Reports
		Engineering Design for Decommissioning

These categories were divided into individual components or services that are needed to complete each step of infrastructure construction and cable installation. As the Concept Case is for construction of novel infrastructure without existing examples to base off, this bottom-up approach was taken for costing. The method is to estimate dimensions and weights of materials, time of labor and equipment required, and unit rates of labor and equipment.

These items were all assigned a price based on various internal and public sources and a total price for each category was calculated. A list of assumptions for personnel rates, material costs, and plant costs can be found in Appendix B. Each category saw a combined project management and contingency price of 15% added on to the total.

2.5.4 NPV

Finally, an NPV calculation was performed on both the Base Case and the Concept Case using the lifetime costs of the infrastructure. A NPV is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. In the case of this study, the NPV was calculated over 32 total years, including Year 0 which contained CAPEX and OPEX costs, Year 31 which contained DECEX costs, and Years 1-30 which contained the lifetime of the OSW farm. The NPV calculation finds the current value of a future stream of payments, using the proper discount rate. In general, projects with a positive NPV are worth undertaking while those with a negative NPV are not. A discount rate of 3.5% was used to calculate the NPV for each year of the model (Year 0 – Year 31). The NPV was calculated using the following equation, where *i* equals the discount rate of 3.5%, *t* equals the number of time periods, and R_t equals the net cash inflow – outflow of a single period *t.*

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t}$$

2.5.5 LCOE

The levelized cost of energy (LCoE) of each case was calculated. There was a reference case used during the calculation to ensure an equal comparison of LCoE between the Base Case and Concept Case that used the following assumptions:

Table 2-3: LCOE Assumptions

Assumption	#	Unit
# of Wind Farms (WF)	6	number
WF Lifetime	30	years

Hours / year	8766	years
MW per WF	1200	MW
Capacity Factor (CF)	55%	%
Total MW / year with CF	660	MW

The following equation was used to calculate the LCoE, where C equals the total lifetime cost of the project, T equals the total lifetime of the project in years, h equals the total hours in a year (plus 6 hours to adjust for leap years), P equals the total number of wind farms, F equals the capacity factor, and M equals the total output in MW of each wind farm per year:

$$LCoE = \frac{C}{(P * T * M * F * h)}$$

Since this is just a reference case, the LCoE could increase or decrease depending on which variables change. If the number of wind farms increased, the total output of each wind farm increased, or the capacity factor increased, the LCoE would decrease.

2.5.6 Assumptions

To complete the cost model, several assumptions were made for the study. There are several reasons these assumptions must be made, including the fact that this is a feasibility study, and the topic is a new technology case that has not been done before. The assumptions were made by using information from previous projects that had similarities to this one including location, method, and size. Table 2-4 lists the assumptions that were used in the cost model.

Table 2-4: Cost Model Assumptions

Assumption	Description
2023 Prices	All prices were adjusted to be in 2023 USD prices.
NPV discount rate	The discount rate used for the NPV calculations was 3.5%, however this discount rate could change depending on financing of the capital required for the infrastructure and wind energy developments.
NPV years	The NPV was calculated over 34 years, including 3 years for development and construction, 30 years for the lifetime of the windfarms, and one year for decommissioning.
Length of infrastructure	The length of the infrastructure (i.e., length of offshore route, length of landfall, length of onshore route) were all assumed based on the example reference location of the infrastructure. It was assumed that the offshore section is 4 km, the landfall section is 1 km, and the onshore route is 10 km.
Timing of cash flow events	Each event was put into a certain year based on the order/timing of events for a typical windfarm. However, if this order of events is different, there could be either more or less of a discount factor applied to the event which would change the overall NPV value.

2.6 Concept Evaluation

The concept evaluation process began by reviewing each piece of the final report and considering the following categories that were decided upon to evaluate:

- Cost Efficiency
- Construction requirements
- Cable Installation
- Electrical Redundancy
- Planning and Development
- Ownership and funding models
- Risks and opportunities evaluation
- Environmental Impact
- Permitting Framework
- Power systems regulatory framework

After each category was reviewed, a section for each category was included to provide a qualitative evaluation of the concept case, the associated technical and commercial attributes, risks, challenges, opportunities, advantages, and disadvantages.

3 Reference for Concept Design

3.1 Reference Location

The study is to be based around a reference location. The New York (NY) area was selected as the reference. This is for the following reasons:

- NY State is holding solicitations for OSW energy delivery to the state. NY state has already procured 4,300 MW of offshore energy of a target 9,000 MW.
- BOEM recently auctioned six new sites in the NY Bight in February 2022.
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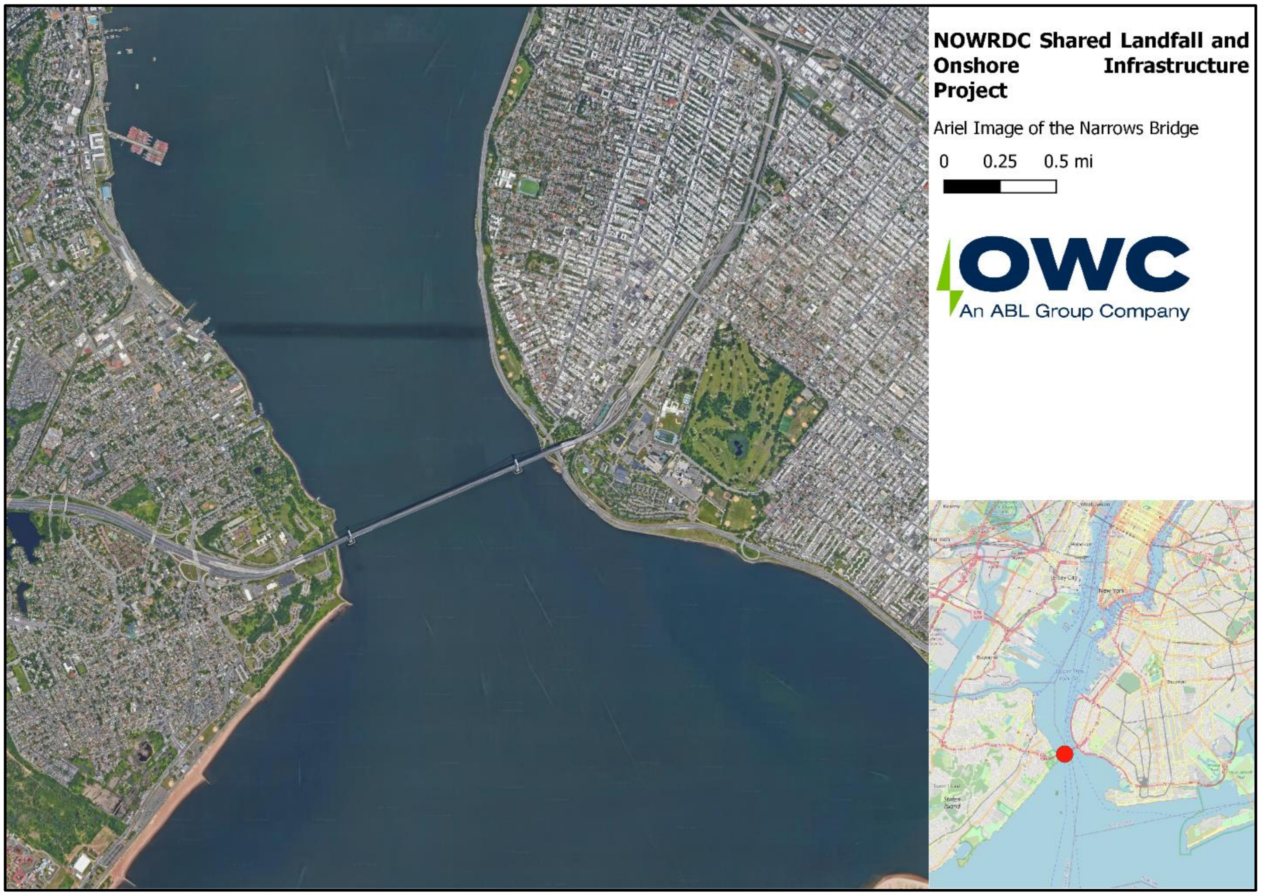

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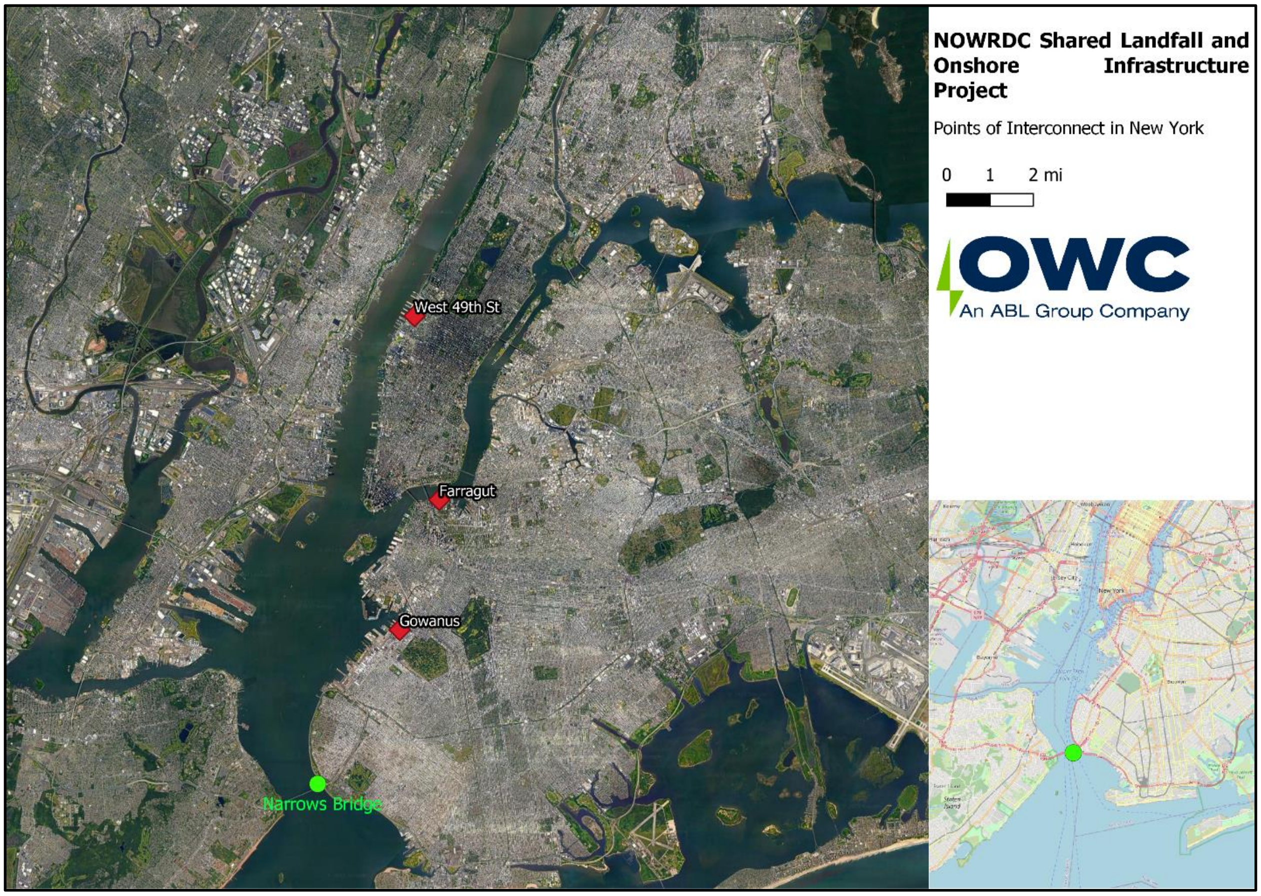
The concept being studied will feature infrastructure to allow multiple OSW developments to be installed through this constrained offshore environment to reach Points of Interconnection (POI) in Brooklyn, Queens, Staten Island, and Manhattan, as outlined in Figure 3-2.

Figure 3-2: Points of Interconnection in the NY area



The study team has decided to design a concept which will enable cables to pass through this constrained offshore area and continue back offshore, such as into the rest of the harbor, the East River, or the Hudson River, depending on where the OSW developments' POIs would be. The concept will also feature a transition to an onshore corridor, to enable many cables to be routed to a major onshore POI hub such as Farragut or Gowanus. This will allow concepts to be developed for several scenarios, covering offshore to onshore landfall transition, an onshore corridor, and an offshore corridor.

3.2 POI Locations

An indication of potential Points of Interconnection in the NY area are shown in Figure 3-3.

Figure 3-3: Points of Interconnection locations

4 Basis of Design

In the text below, “Concept” refers to the reference for the concept design.

4.1 Introduction

A Basis of Design technical note was prepared as a common understanding of the input design parameters, stakeholder requirements, and technical constraints. It includes sufficient definition of the reference location to allow a meaningful comparison with the Concept Case. The Basis of Design technical note includes:

- Environmental constraints and challenges (natural and cultural resources)
- State / federal regulatory jurisdictions
- Design codes
- Onshore impact considerations (shared use, congestion, existing infrastructure)
- Grid interconnection (availability, locations, distance of onshore cables to POI)
- OSW assumptions (number of developments, technology type, number of cables)
- Wind farm parameters

4.2 Electrical

1. Concept will facilitate cables for at least six circuits. This is based on OSW farm developments of approximately 1.2 GW each connected with ±320 kV HVDC single-circuit systems as is a plausible case for the NY Bight developments. This will be used for the **Base Case** (i.e. status quo) and **Concept Case**.

   If these six circuits were AC they could connect in the range of 400-600 MW each depending on the operating voltage and overall offshore transmission distance.

2. Each set of cable conduits (one for each development) will allow for individual protection and pull-in of three power cables and one fiber optic cable. This arrangement could therefore accommodate:

   a. Two (2) HVDC single-core power cables, operated as HVDC symmetric monopole, with one (1) separate fiber optic cable

   b. Two (2) HVDC single-core power cables, plus one (1) MVDC single-core power cable, operated as HVDC bipole, with one (1) separate fiber optic cable

   c. Up to three (3) HVAC three-core power cables with embedded fiber optic cables

3. Concept will facilitate cable installation only. It will not include cables, conductors, terminations, or terminals for connection of export cables and transmission of electricity.

4. Concept will account for cable ampacity, including the thermal environment and mutual heating between cables. **For this study, only HVDC will be considered in terms of electrical calculations.** The following assumptions will be used for cable rating:
    a. Symmetric monopole HVDC system, with each of two (2) HVDC power cables carrying a maximum of about 2,000 A
    b. Ambient summer sea water temperature: 20 °C
    c. Seabed thermal resistivity 0.9 K.m/W
    d. Summer ground temperature: 25°C
    e. Onshore thermal resistivity 1.2 K.m/W
5. Comparative ratings shall be carried out on a suitable three-core (3C) AC system to ensure that infrastructure is future proof for potential AC export systems connecting near shore wind farms.
6. Concept will account for cable physical dimensions. **Both HVAC and HVDC cables will be considered for physical dimensions.** The following assumptions will be used:
    a. HVDC cable maximum diameter of 150 mm. A pair of these is required for one circuit and the pair are typically bundled together.
    b. HVAC cable maximum diameter of 320 mm.
    c. Straight joint diameter of approximately 2.5 m length and 500 mm diameter.
    d. Conduit inner diameter of 2.5x cable diameter
    e. Minimum bending radius for installation of 20x largest (HVAC) cable diameter

   Cable designs utilized for the electrical and construction elements of the concept design will be based on industry tested and approved (pre-qualified) cables for both HVAC and HVDC applications taken from the study team's internal database.
7. The concept will include considerations to increase thermal efficiency and thermal conditions for cables. These measures shall include passive cooling and selection of materials. Active cooling will be excluded from the design on the basis that it will increase complexity, CAPEX and OPEX, and decrease reliability.
8. Thermal ratings will be conducted on identified thermal pinch points within the installation design. Typically, these would be at the 'neck' of the landfall as cables enter the infrastructure, at the deepest installation point of the circuits and at the point of closest proximity of circuits.
9. Assumptions for thermal properties of construction materials used in the infrastructure design will be based on industry norms.
10. Concept will allow reasonable space between pairs of HVDC cables to minimize magnetic field interaction. Consideration will be given to the design for magnetic field strength limitations imposed on HVDC systems and reduction of fields where possible. Ultimately,

however, magnetic field measures will depend on the user cable designs and therefore user will bear responsibility for magnetic field compliance.

11. Concept will facilitate each pair of HVDC cables to be installed adjacent to one another to minimize magnetic fields.

4.3 Physical Extent

12. Concept will extend offshore to onshore and provide a possible solution for dealing with constrained corridors for multiple development cables offshore, landfall, and onshore.
13. Depth of infrastructure to be determined.

4.4 Reliability

14. Concept will ensure that one of the following N-1 events does not disrupt operation of more than one OSW development's cable system:
    a. Cable fire
    b. Cable joint short circuit / explosion
15. No active systems (e.g., air conditioning, lighting) to minimize need for maintenance and maximize reliability.
16. Protection and security measures consistent with other important national infrastructure to limit theft, vandalism, terrorism, e.g., how security for port infrastructure is implemented, will be considered.
17. Active and passive monitoring systems for security, protection, and thermal performance will be considered.

4.5 Maintainability

18. Concept shall allow maintenance and repair works to be performed safely on the concept infrastructure itself and/or one OSW development's cable system at a time.
19. Repair works shall not require outages on any cables other than the circuit under service.
20. Space for repairs including requirement for a repair joint shall be considered.

4.6 Constructability

21. Concept shall make best use of balance of pre-made / pre-cast and on-site casting to minimize construction schedule.
22. Concrete reinforcement utilized for in-situ and pre-cast concrete applications shall be synthetic structural fiber reinforcement and/or glass fiber reinforcement bars for all structural elements within 1m of transmission line paths.
23. Concrete mix design for all on-shore transition in-situ and pre-castings shall be designed for submerged marine applications.

24. Alternative recycled / renewable / sustainable structural materials, when feasible, shall be considered for use within the concept design.
25. Concept shall be feasible for construction within 18-24 months from inception (i.e. shovel ready) to completion (i.e. ready for cable installation) including stakeholder and permitting restrictions.
26. Concept shall make use of best practices for cable burial in the near shore environment approach to the onshore transition with submerged embedment of the transmission cabling (and infill of trench) to 2m below existing mudline.

4.7 Cable Installation

27. Concept will consider space for offshore to onshore cable transition joint (or similar).
28. Concept will allow normal installation procedures widely used in the offshore industry to be used, such as a Landfall Pull-in Operation. This means that the infrastructure and the nearshore approach must allow enough space for a floating bight to be deployed to transfer the cable end from the Cable Lay Vessel (CLV) to any transition joint for connection to the onshore section of the cable.
29. Considering that each conduit must carry one set of cables for each OSW development (could include up to three cables (see Point 2)), a bundle configuration will be considered for the floating bights. Alternatively, if each conduit is divided into different sub-conduits, separate pull-in operations will be considered for each cable through to each sub-conduit.
30. Concept will also allow a CLV to approach sufficiently close to the concept to allow for the operation. The main restrictions to consider are water depth, shipping/ferry transit lanes and other infrastructure/assets in the vicinity (such as bridges, buoys, wharfs, anchorages, etc.).
31. The offshore cable end will be accessible to any one cable installation vessel at a time for cable pull-in.
32. The spacing of the subsea section of multiple development’s cables will have adequate separation between themselves to allow station keeping of the cable installation vessel without risk of damaging nearby cables, especially during the pull-in operations. This may be performed either through the deployment of anchors/mooring lines, the vessel’s dynamic positioning (DP) or spud cans.
33. The concept landfall point will be designed to accommodate the requirements for a landfall winch with enough capacity to perform pull-in operations. The main requirements include providing enough space to facilitate offshore to onshore cable transition and for any temporary works for the landfall pull-in operation (e.g., foundations of the pull-in winch, the winch itself, trackways pulleys).
34. Any cable transition areas will be designed to remain accessible to plant and service workers for any maintenance and/or temporary works.
35. Concept will consider typical mechanical limitations of cables including tension, sidewall pressure, compression, and bend radius.

36. Considerations in the event of cable repair/replacement at the infrastructure will be made. The concept should allow for the removal of the existing cable without interfering with the operations of the other cables at the landfall infrastructure. This could include either be performed through a 'cut and drag' method or through the recovery of the damaged cable.
37. Concept will protect cables throughout the wind farm's lifetime. Common industry practices will be considered including burial and/or external protections such as rock berm covering, Cable Protection Systems (CPS), concrete mattresses or sleeves. Additionally, to avoid the risk of a free-spanning cable, a j-tube or ramp up to the entrance of the conduits may be prescribed to ensure cable stability and reduce the risk of fatigue damage. The main risks considered are the following:
    a. Anchor drags/strikes
    b. Dredging
    c. Fishing
    d. Abrasion
    e. Fatigue
    f. Theft / Vandalism
    g. Terrorist acts
38. As part of this concept, the onshore section of the cable (running along the conduits) is assumed to be pre-installed and not included in this concept. The concept will only focus on cable installation from the point of onshore to offshore transition and seawards.

4.8 Onshore Impacts

39. Onshore impacts will be determined as Concept develops.
40. Concept to follow public roads and right of way where possible.
41. Concept to avoid environmentally sensitive and socially sensitive areas such as parks.
42. Concept width and depth to be mindful of potential existing presence of utilities.

4.9 Grid Interconnection

43. Concept to be designed to facilitate cable installation to POIs in the NY City area such as Gowanas, Farragut, East 13th Street, and those further afield in Queens and Manhattan.

4.10 Permitting Impacts and Limitations

44. Although design requirements and associated permitting implications are project-specific and can only be fully known following informal consultation with the agencies involved, the proposed design is expected to have some permitting impact. These could include the following:

- **Mitigation** – Mitigation for expanding the existing revetment footprint and/or adding to or improving rip rap along the shoreline segment of the line within waters of the U.S.

will likely be required by USACE. Mitigation could be substantial given the length of the proposed design and spatial area impacted. Mitigation is typically required in the same watershed as the impact and could include eelgrass restoration, removal of derelict structures (e.g., piers), "softening" of the shoreline (e.g., seawall removal, beach restoration), in-lieu fees, or permanent land preservation (e.g., land transfer, conservation easement).

- **Alternatives** – In addition, USACE will likely require an explanation of alternative designs. This analysis will require a justification for choosing the expanded revetment design over other potential alternatives, both from a landfall perspective and the proposed cable route to proposed POIs. Alternatives such as HDD of the landfall location and/or burying the cable in the upland area (i.e., in the adjacent bike/walking path) between the shoreline and road or burying the cable in the nearshore area until closer to the POI will need to be addressed in follow on permitting and environmental analyses.
- **Near shore cable permitting** – There are also permitting implications for the near shore portions of the cable. Design requirements for submarine power cables would include limiting crossings of existing cables and burial and/or armoring to account for potential EMF impact. State requirements regarding burial depth, as well as cable spacing, vary from state to state. Per New York State Energy Research and Development Authority's (NYSERDA) 2021 OSW Submarine Cabling Overview Study, New Jersey has a minimum burial depth requirement in waters of 5 ft, while New York does not have an explicit minimum burial depth requirement. Agencies in New York, however, are charged with "protecting water dependent uses like commercial and recreation fishing and maritime commerce" and will assess the project accordingly. Additionally, coordination would need to take place with other agencies, such as the US Coast Guard who manages navigation corridors and vessel routes.

45. NYSDEC advised on potential timing restrictions for in-water construction in the New York Bight/Brooklyn area with respect to marine species. The DEC advised that generally for NY Bight/Brooklyn area, these are the species timing restrictions:

    - Atlantic Sturgeon – no work from March 1 – June 30 and from October 1 – November 30.
    - Winter Flounder – no work from December 15 – May 31 in waters less than 20 feet.

    The application of these restrictions depends on the activity type, duration of work, etc.

    Concept will consider these potential limitations in the design.

A permitting matrix is provided in Appendix A.

5 Stakeholder Engagement

5.1 Introduction

The objective of this phase was to kick-off the work, ensure the study team is aligned with NYSERDA as to expectations and underlying assumptions, set the Reference Location which feeds into the basis of design, and to canvas stakeholders including NYSERDA, relevant New York transmission owners (e.g., NYPA, ConEd, and LIPA), BOEM, offshore developers, and others with interest in OSW development and offshore wind leases in the NY Bight. The input from stakeholders assisted with developing consensus, constraints, and the framework for the design basis.

5.2 Stakeholders

The study team identified OSW stakeholders with experience and purview over cable routing, onshoring transmission infrastructure, electricity regulation, and permitting aspects related to OSW development. We identified individuals in utilities, the New York Public Service Commission, OSW developers, and NYSERDA to participate in our initial discussions. A list of key stakeholders who could provide critical input were decided upon with input from the study's Advisory Board. We contacted priority stakeholders including:

Table 5-1: US OSW Stakeholders

Name of Stakeholder	Role in US OSW
Bureau of Ocean Energy Management (BOEM)	Federal Agency
United States Coast Guard (USCG)	Federal Agency
Army Corp of Engineers (USACE)	Federal Agency
Con Edison	Transmission Owner
New York Power Authority (NYPA)	Transmission Owner
Pennsylvania Services Enterprise Group (PSEG)	Transmission Owner
New York Independent System Operator (NYISO)	RTO
PJM Interconnection (PJM)	RTO
CIP / Mid-Atlantic OSW LLC	OSW Developer/Lease Holder

OW Ocean Winds East LLC	OSW Developer/Lease Holder
Attentive Energy LLC	OSW Developer/Lease Holder
Atlantic Shores OSW Bight LLC -	OSW Developer/Lease Holder
Invenergy OSW LLC	OSW Developer/Lease Holder
Community OSW Energy	OSW Developer/Lease Holder
Anbaric	Merchant Transmission Developer
New York State Energy Research and Development Authority (NYSERDA)	Policymaker
The New York State Reliability Council, LLC (NYSRC)	Non-profit organization

5.3 Information Gathering Approach

Qualitative information from stakeholders was gathered by two main methods, an online survey with a list of open-ended or multiple-choice questions, or telephone interviews (virtual calls). The online surveys were designed with separate sets of questions for wind developers, permitting agencies, and regulatory authorities. These questions sought to obtain useful feedback from each group of stakeholders. The stakeholder engagement portion of the study lasted from March through July 2022. An extract of 5 key questions provided to each set of stakeholders are listed below.

5.3.1 Wind Developers (commercial)

1. How should development rights for shared landfall and route infrastructure be established?
2. What would you require from the asset to meet your cable installation requirements?
3. Could shared landfall and route infrastructure ease the burden of permitting for OSW projects that are able to utilize this available shared landfall?
4. Before what stage in a project’s development timeline would shared landfall and route infrastructures need to be constructed in order to ease the development process?
5. Would a shared landfall and route infrastructure system be of potential benefit to your project development timeline?

5.3.2 Regulatory

1. How many cables and projects should be included at one location?’

2. If a local transmission utility (e.g., NYPA) owned the asset, would cost recovery be from its wholesale transmission tariff?
3. What could be the criteria for granting access to the shared landfall and cable route infrastructure?
4. Should there be a competitive process to determine who will be awarded development and ownership rights or should these rights be assigned to an incumbent utility (e.g., NYPA) where development of this infrastructure is generally consistent with its charter?
5. What links between cost recovery and access are appropriate? For example, if the costs of shared landfall and route infrastructure were included as part of the RTO transmission tariff, what access rights would be provided for a transmission customer that sought to deliver the power to another RTO?

5.3.3 Permitting and Environmental

1. What do you anticipate is the greatest environmental and permitting barriers or risks to connecting OSW developments to landfall and POI locations?
2. What is your understanding of which federal agencies have independent sources of jurisdiction over resources related to a cable landfall project?
3. What is your understanding of what the highest priority state permitting requirements are for projects of this type?
4. How would you characterize the differences between federal vs. state permitting processes – is one more straight forward than the other?
5. Are there any permits required for projects of this type that applicants typically find problematic in obtaining?

5.4 Results

Following the identification of key stakeholders, the study team contacted individuals from specified entities who provided detailed feedback for this study. Individuals provided feedback through questionnaire response as well as interviews. Table 1 provides the status of feedback, broken down into questionnaire responses and interview feedback. The table is further broken down by color coding: red indicates their feedback was not collected and green indicates a successful retrieval of feedback for method.

Table 5-2: Stakeholder Feedback Status Summary

Stakeholders	**Questionnaire**	**Interview**
New York State Energy Research and Development Authority (NYSERDA)	No	Yes
Bureau of Ocean Energy Management (BOEM)	No	Yes
New York Power Authority (NYPA)	Yes	No
New York Independent System Operator (NYISO)	Yes	Yes
PJM Interconnection (PJM)	No	No
Army Corp of Engineers (USACE)	No	Yes
Pennsylvania Services Enterprise Group (PSEG)	No	No
United States Coast Guard (USCG)	No	Yes
Con Edison (ConEd)	No	Yes
The New York State Reliability Council, LLC (NYSRC)	No	No
Developers and Lease Holders		
Anbaric	No	No
CIP	Yes	Yes
Invenergy OSW LLC	Yes	Yes
Community OSW	Yes	Yes
Atlantic Shores OSW	Yes	Yes
Ocean Winds East LLC	Yes	Yes
Attentive Energy LLC	Pending	Yes
Equinor	No	No

Table 5-3: Interview Summaries

Feedback Themes: BOEM	Key Points
Further Research	Look into energy "backbone" approach (New Jersey process dovetails with backbone approach and process) New Jersey is currently looking into interconnection issues New Jersey State Agreement Approach: look at proposals from industry (that asked developers to propose the mix of onshore and offshore transmission facilities that provide efficient and reliable way of getting power from offshore to NJ customers) to provide pathway for the State to advance an OSW transmission solution
Feedback Themes: NYSERDA	Key Points
Potential Constraints	There are potential challenges getting the cable back to the river because Gowanus is mostly full Project will be running through stone on east side of the revetment so the project could be constrained by the size of the stone Equinor and ConEd cable projects are being proposed in the same area, project may become an obstacle. Likely only four cables could be squeezed into the current project site with the proposed Equinor project already in this location
Project Value	Differentiate project as a highly valuable solution and clarify the problem that it is a solution to Project should demonstrate and justify solution while emphasizing its high value Project analysis could culminate in a type of policy that could be parlayed into a regional approach that includes other New England states Maintain market value-approach rather than for-profit approach
Project Design	Include "hub concept" --uses converter station as a hub; requires a third-party which could be done through PSC or NYPA Construction could be completed all in one season to avoid habitat and maritime destruction ("the island approach" done in Europe – brought together on a flooring stage and then brought on shore from there) Identify how many MW and circuits the project includes

Further Considerations	Consider expanding project to address the challenge of getting cables from the converter station to the points of interconnect (considering a 5 acre site is needed for 1200 MW coming out of 3 AC cables from HVDC converter stations to points of interconnection) Demonstrate ways of building support for best interconnection location and identifying the cost effectiveness of the approach Identify how this will align with 9MW goal and how will they measure many MW are coming into substations or points of interconnection Review NYSERDA's draft cable assessment and potential cable project constraints Clint Plummer (Ravenswood POC) worked closely with this concept and could provide some insights
Feedback Themes: NYPA	Key Points
Regulation	Development and ownership rights for the shared landfall and route infrastructure should be competitively bid and awarded If a local transmission utility owned the asset, whether the cost recovery would be from its wholesale transmission utility would/should depend on how the solicitation is structured Costs would be recovered through the systems operator/RTO wholesale transmission service charges with cost recover approved by FERC if the asset Granting access for the shared landfall and cable route infrastructure should be based on first come, first served basis and/or part of an auction
Project Design	Ideally 2 projects should be included at one location—2 HVDC projects of 1310 MW each
Feedback Themes: NYISO	Key Points
Regulation	Future development should remain compliant with FERC Order #1000 and Order #890 transparency and open access and competition principles, and with New York State Public Service Commission requirements for providing access to and leasing of utility rights of way—aka development rights should be dependent on developers land use rights or how they plan to obtain land use rights Development rights should be open to all transmission developers, not just an incumbent utility Incumbent utilities should provide access to their rights of way for planning projects and for construction at fair market value For transmission projects selected through a competitive transmission solicitation process, rate recovery is through NYISO OATT Rate Schedule 10. There are also individual rate schedules for certain approved transmission tariffs in other rate schedules in OATT Article 6. The criteria would be established in transmission planning tariffs with discussion with NYISO stakeholders. Preliminarily, applicable metrics may be similar to evaluating competitive transmission projects, such as operability and expandability and the metrics suggested in FERC NOPR in Docket

	No. RM21-17-000 Building for the Future Through Electric Regional Transmission Planning and Cost Allocation and Generator Interconnection If a project is selected through a competitive process as the more efficient or cost effective transmission project to fulfill a transmission need, the real estate costs of that project may be recovered through an appropriate NYISO rate schedule, such as OATT Rate Schedule 10. Interregional transmission projects located in two or more regions are eligible for cost allocation and cost recovery if they are selected in the regional transmission plans of each region. Market and operation rules should be designed for this type of project
Project Design	Multiple projects may be built in the same location due to the lack of availability of new cable routes
Feedback Themes: USCG	Key Points
Project Value	This project provides a resolution to a constrained area of the harbor. If something is not done to control/organize all the cables that will be on the bottom of the harbor, there will eventually be so many wires that they will interfere with anchorage.
Project Design	A 30 ft embedment should be deep enough that if ships drop their anchors, it shouldn't be an issue.
Further Considerations	This project does not solve any issues north of Owls head.
Feedback Themes: USACE	Key Points
Project Value	Maritime users are voicing concern about cable projects in the harbor, focused on the hazards of cable lines in federal channels. Main communication concerning OSW is the subsea utilities, said critics call it a "bowl of spaghetti" and pushing for one pathway for utilities into the city. This is good timing for this type of approach.
Project Design	Because of proposed dredging activities, cables crossing the federal harbor channel or within side slopes will require 15 feet burial for safety cover. This burial is measured from the top of the cable armament to channel depth.
Further Considerations	Engaging with Harbor Operations and Safety committee and tug and barge operations. This committee could be a potential partner for routing the cable corridor. Consideration should be given to a proposed construction approach that provides some flood protection. Out-of-kind mitigations projects are possible - provide more acreage per acre of impact for mitigation. Staten Island has mitigation credits that can be purchased in the service area. NYC is also pursuing other mitigation project opportunities. Aesthetics are important - if project can be aesthetically pleasing - that goes a long way.

Potential Constraints	Concern about the risk associated with avoidance of channel (where possible), proper cable burial, depth, anchor, snags, and the liability associated with this. Maritime users feel this is where they work – their “office”. Energy companies placing cables in the center of their “office” leads to concern surrounding how the maritime users are liable if cable damaged during emergency operations when they have been using the space for a long time. Concern over timing - what if the project proposed happens over the same 18 months as other projects (e.g., dredging, other marine infrastructure builds) - timing is a major concern. Endangered Species (i.e., sturgeon) and Essential Fish Habitat are concerns as well.
Regulation	Getting ahead of what NOAA Fisheries will require regarding ESA-listed species will be crucial. With respect to permit type generally project like this would be an Individual Permit (IP) not a Nationwide Permit (NWP). Generally, only IPs are issued within the harbor region due to the larger number of maritime users. You can try an NWP but most likely will be an IP.
	Developers and Leaseholders
Feedback Themes: Community Winds	Key Points
Regulation	The establishment of development rights should be coordinated with government support, either state or local. NYSERDA would be well positioned to coordinate. There should be a competitive process for ownership and development rights Would be comfortable using shared infrastructure they do not own One ownership model would be to set up a co-op like structure. In the case of NY, perhaps NYSERDA could create a condition in the OREC contract that winning projects participate in a shared ownership consortium. Each owner could have equity membership and representation on the management committee
Influencing Factors	OREC 3 timeline may have moved back – backend of June, 150 day window, late November for submission
Project Value	Shared landfall and route infrastructure would ease the burden of permitting Unsure of the asset would help the timeline of development projects It could be difficult to manage the volume of crossings funneling into the asset, particularly if all project locations are not known ahead of time.
Project Design	Consider having the design placed deeper Underground cables are lower risk to acts of sabotage

	For physical security, design should be secure from vandals and terrorist. Encourage leaving cable access under the water surface to deter access to the cables. Asset shouldn't create thermal pinch point Asset would need to be constructed pre-FEED of the development process The infrastructure would ideally extend far enough in either direction to mitigate the most severe route constraints. This would include consideration of where installation vessel would operate in relation to established anchorages.
Feedback Themes: ASOW	Key Points
Regulation	Development rights for shared landfall and route infrastructure should be established by state setting up initial ROWs and assigning them to projects they select Issue with the actual construction of conduits/duct banks, along with onshore vaults There should be a competitive process to determine who will be awarded development and ownership rights
Project Design	In order to meet ASOW cable installment requirements, the asset would need to meet technical standards as well as schedule, management and other aspects of project on project risk CPs would be needed to meet ASOW O&M requirements The asset should be built in the early planning stage of a project's development timeline The infrastructure should ideally extend to the POI substation/1km onshore and offshore it should come to the lease area/5km
Project Value	Shared landfall and route infrastructure would ease the burden of permitting for OSW projects using this asset Would be of benefit to ASOW's project development timeline If built in a correct way and with an appropriate timeline, it would reduce risk project on project risk
Potential Concerns	Project on project risk is a major concern, along with ensuring the design, construction, and operations of any shared facilities since this is often the only way a project can sell power into this market. A timing issue is how this ties to permitting and the overall COP. Projects must submit key details and conduct surveys. To change that up or mandate that an alternate route must be selected will put the entire project schedule at risk
Feedback Themes: Ocean Winds (OW)	Key Points
Regulation	• Development rights should be treated as a FERC-approved NYISO tariff-based transmission entity, using the previously established transmission interconnection protocols

	• There should be a competitive process for awarding development and ownership rights
Project Design	• Support the design and would use a shared infrastructure • Design performance guarantees for on-time & on-budget for COD with punitive clauses to minimize project-on-project risk (capturing all the permitting requirements through Construction and Delivery) • Deliverability/reliability guarantees (minimum reliability metrics inclusive of scheduled maintenance and contingency events) during operational lifetime with no-caps on liquidated damages attached to lost revenues, damage to generator-owned equipment, and generator third-party damage/liability indemnification for export route without a force-majeure exclusion for these requirements • Alignment of scheduled maintenance windows of the shared transmission assets with the scheduled maintenance window of generation equipment. (Note: Given the supply chain constraints of maintenance resources, it is highly unlikely a shared transmission assets can be scheduled effectively among multiple generators and the Tx asset.) • There should be a fire wall and locked access to any transmission vault. HDD separation during installation. Cable separation should be maintained at all times to ensure proper access for O&M activities without disruption to other projects' cables and minimize cascading electrical events (i.e., fault on one project's cables arcing over and causing a fault on another project's cables). • Would need to be constructed during the early planning phase of project development • The infrastructure would ideally extend 1,000 m from any conduit exit pit
Project Value	• The shared infrastructure would not ease the burden of permitting for the projects utilizing it • Unsure if it would reduce project on project risk • Would not be a benefit to their project
Feedback Themes: Attentive	Key Points
Project Value	• Design is extremely valuable and much needed for connecting more power to the grid
Further Considerations	• Review Section 408 with the Army Corps of Engineers regarding permitting

Takeaways:

The information gathered during the stakeholder engagement helped inform concept requirements and design. Ownership models, permitting requirements, other operational and maintenance requirements. The input contained in this report was then considered when formulating the basis of design - deliverable D2.

6 Concept Design

6.1 Introduction

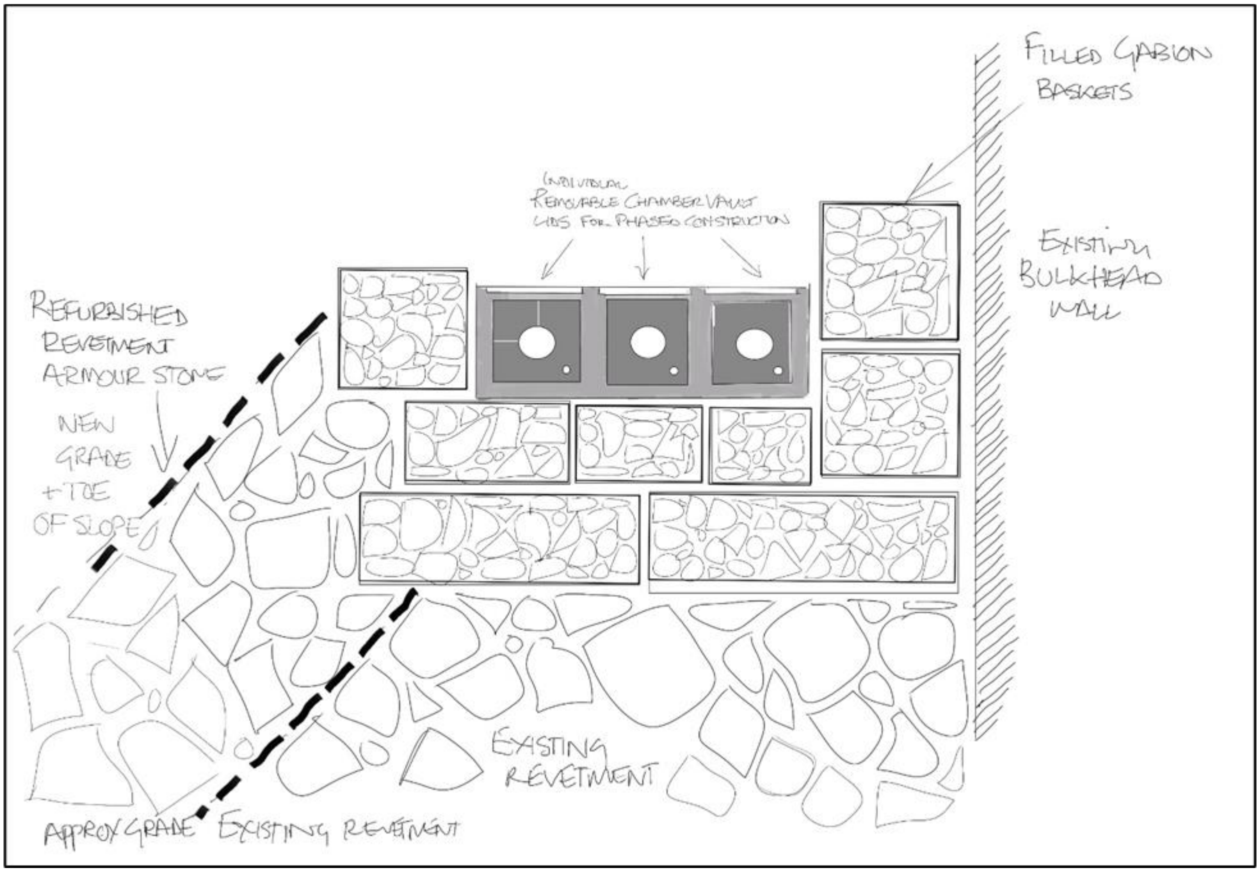
This section shows the initial conceptual work which was used to develop the Basis of Design.

Figure 6-1 shows one end of the concept infrastructure. The infrastructure then continues along the Brooklyn coast.

Figure 6-1. Overhead of reception point for offshore cables at Gravesend Bay (shown for three cables / circuits).

Figure 6-2. Overview of Owls Head to South Brooklyn Marine Terminal where the concept splits to allow cables to continue offshore (north) further into NY Harbor, or to continue onshore into Brooklyn (shown for three cables / circuits).

Figure 6-3. Initial cross-section of the concept design for three cable / circuits.



6.2 Offshore Section

6.2.1 Description

The Narrows, as a tidal straight that connects the Upper NY Bay and Lower NY Bay to the Atlantic Ocean, was selected in the Basis of Design. It is acknowledged that the area is a busy harbor which introduces constraints from an offshore routing perspective.

The current concept focuses on a Reference Location, heading north to Gravesend Bay and suggests a corridor route of six circuits running along the shoreline of the Shore Parkway up to the Owl's Head Park. Figure 6-4, Figure 6-5 and Figure 6-6 outline this concept, providing further details of the design developed in Sections 6.2.2.2 and 6.2.2.3.

At the boundary of this route, a novel landfall transition structure is proposed to facilitate the passage from the offshore to the nearshore cable installation. The northern cable routes (offshore and onshore), beyond the Owl's Head Park, are indicatively shown to demonstrate the potential Point of Interconnections (POI), Gowanus and Farragut.

Figure 6-4: Overview map of the cable route. Southern location at Gravesend Bay, Layout 1/3.

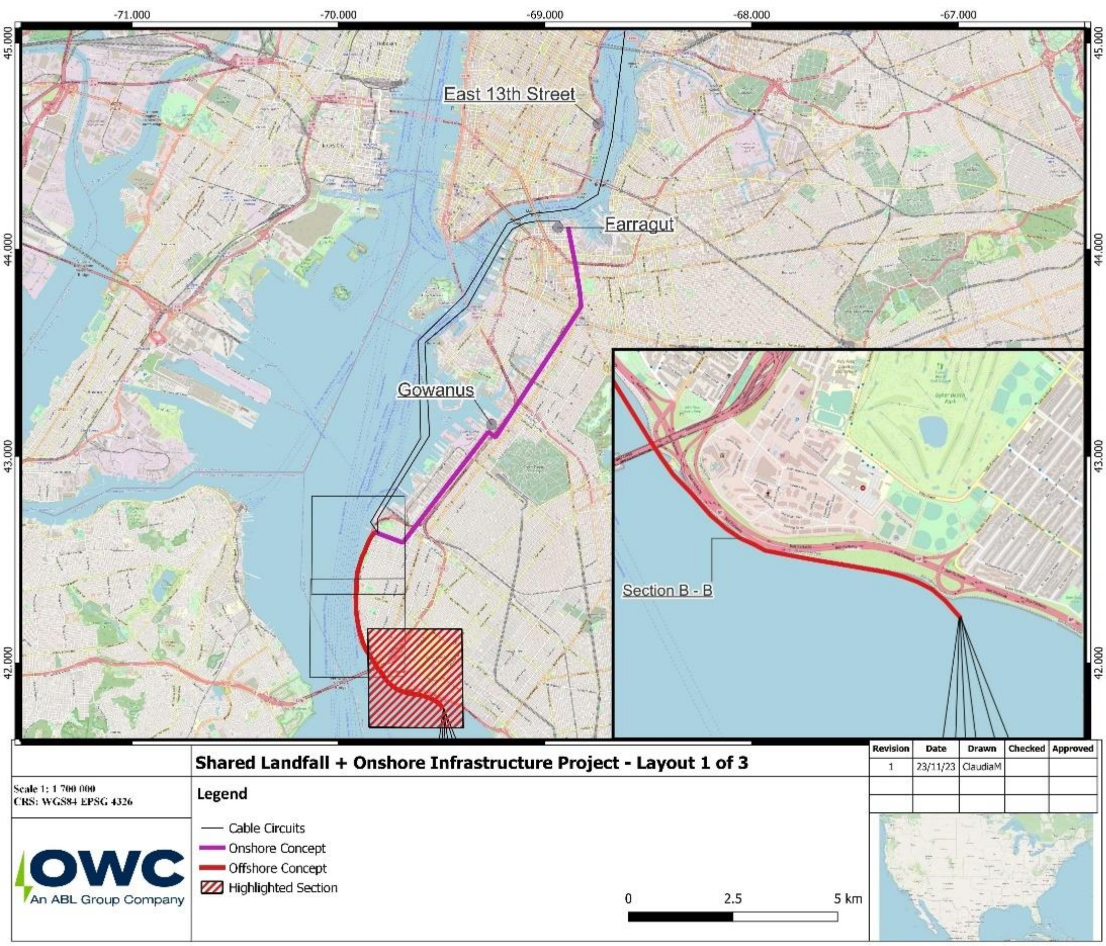


Figure 6-5: Overview map of the cable route. Verrazzano – Narrows bridge, Layout 2/3.

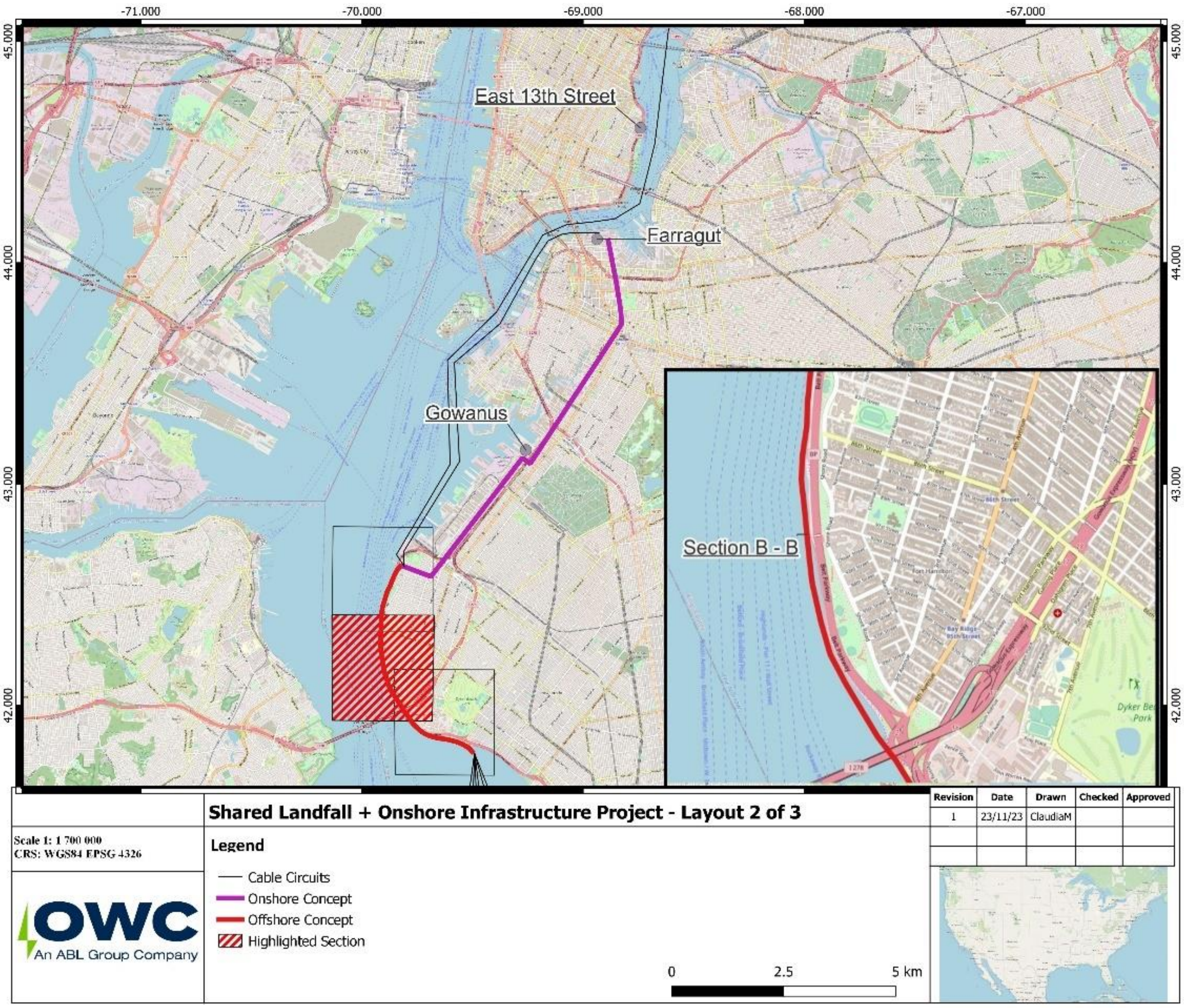
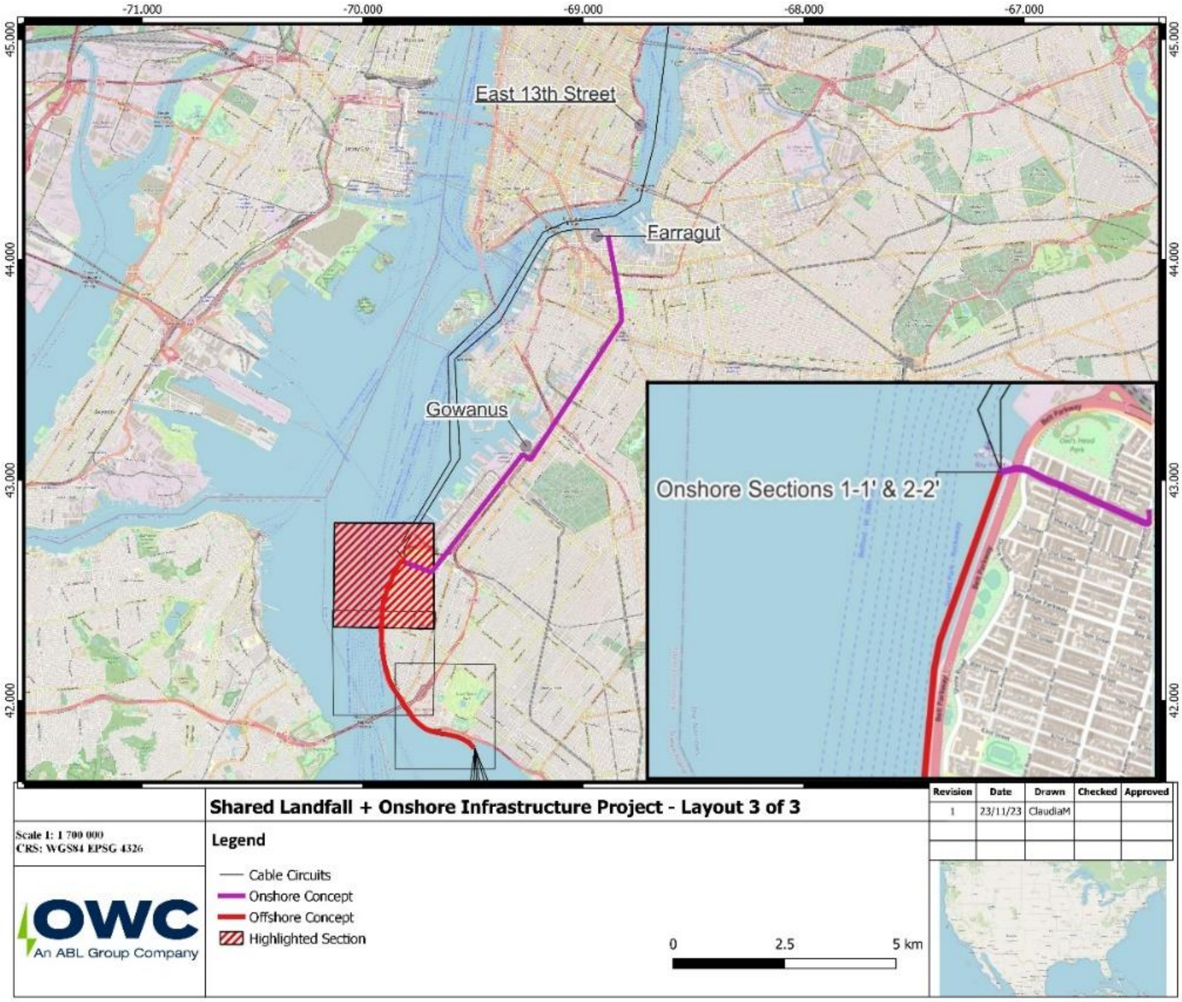


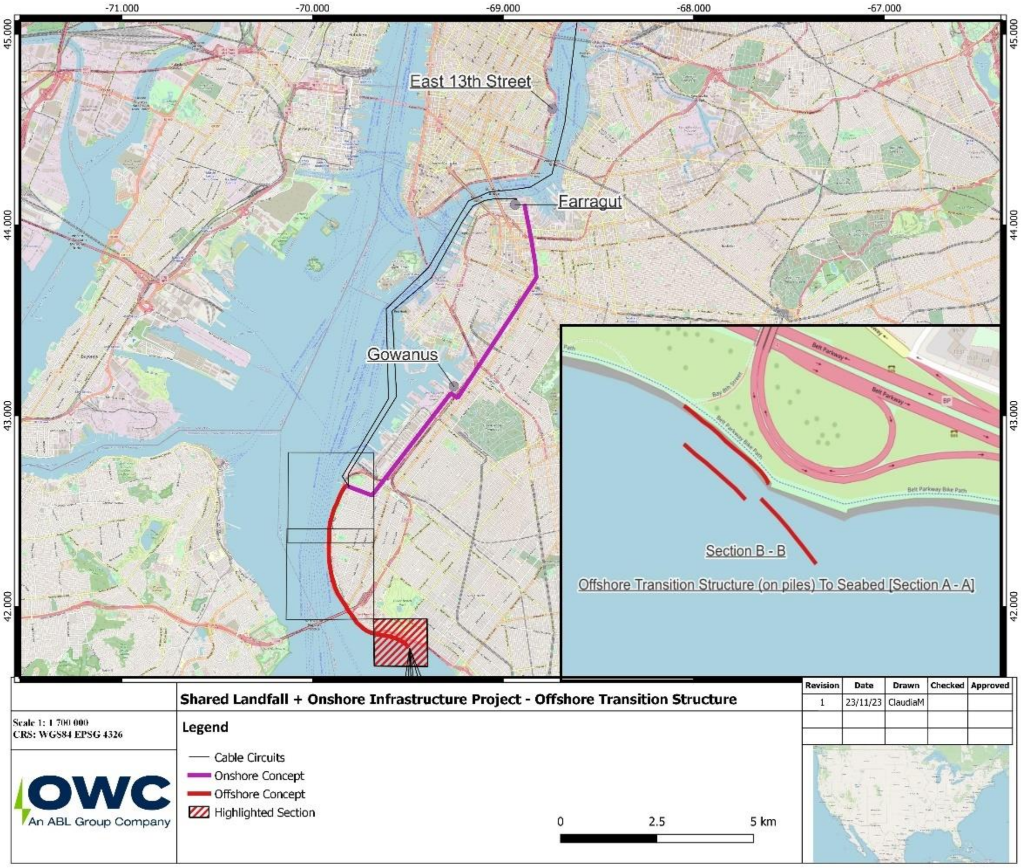
Figure 6-6: Overview map of the cable route. Owl's Head Park, Layout 3/3.



At the Reference Location, up to six circuits of offshore export cables will route from the seabed to the near shore along a novel marine structure. From that point, they will run parallel to the shoreline bulkhead for more than 3.5 km (two-and-a-half miles) up to the place (nearby Owl's Head Park) where the circuits could be either split into two groups – one following an offshore route (transitioning to a seabed lay & protect) and the other an onshore one – or all transit to the onshore section via a shared landfall.

As shown in Figure 6-7, the proposed transition scheme, further described in Section 6.2.2.2, includes six concrete structures (one per circuit) that will be laid on a piling system to effectively secure the stable transition from the seabed to the new revetment along the shoreline. A new bulkhead is suggested, vertically designed to the existing one, allowing for nearly straight-line routing. From that point, a re-nourished – marginally expanded from the existing shoreline – revetment is proposed along the existing coastline bulkhead (see section 6.2.2.3).

Figure 6-7: Southern offshore transition structure for six circuits at Gravesend Bay.



6.2.2 Construction

6.2.2.1 General

The Infrastructure Operator will be responsible for the construction of the offshore infrastructure. This would include the construction of the nearshore transition structures and the revetment along the bulkhead.

A work method statement will need to be produced primarily at the FEED stage and further developed after the final design. This shall include, at the minimum, all the equipment and means to be employed, an access plan, a proposed method of dewatering, a full description of the activities and their sequence, the construction quality plan, and the risk assessment related to specific works (as part of the HSE plan). O&M aspects shall be considered as well, foreseeing potential risks and suggesting mitigation measures.

Before any construction activity, a full site investigation of the near shore areas will be conducted to confirm the feasibility of the design and compliance with the studies.

All third parties must be timely informed of the schedule and agree or approve work method statements.

This type of nearshore revetment work is typically only undertaken in autumn and winter due to fish and wildlife moratoriums in place for spring and summer months in NY harbor to protect juvenile striped bass, Atlantic sturgeon, etc. Grading work above the high water line can continue in the summer months. The Army Corp would identify working windows following feedback with National Marine Fisheries Service and the Environmental Protection Agency.

6.2.2.2 Offshore Transition Structure on Micropiles

As mentioned above, a novel marine structure is proposed for the landfall transition points at Gravesend Bay and Owl's Head.

A generic concept design was originally developed in Figure 6-8 and Figure 6-9, suggesting six concrete chambers equally separated from one another. They will route from the seabed level to an elevation of approx. 2.1 m (7 ft) below the top of the shoreline level (see Figure 6-9).

One or two new bulkheads are foreseen to support the perpendicular entrance (plan view reception) of each cable chamber/circuit to the new revetment along the shoreline. The type and the arrangement of the bulkheads will rely on the exact landfall point and be subject to the final design.

Each concrete chamber will be pre-cast and founded on an indicative scheme of four sets of pile-cap system of different depths.

Coffer dams are expected to be needed when installing the pile bents to resist the uplift in the sand from -30 ft near shore into the first beachhead landing.

At the first stage, all the piles will be drilled out and reinforced with steel cages and bars. As the drilling/reinforcement placing is ongoing, cast in place concrete or grout will be used to complete their construction. Once each set of piles is ready, a bench cap will be installed for the stability of the structure. The cap will be made of recycled plastic and contain stainless steel turnbuckles laterally placed on top of each pile to allow for the installation of a frame of stainless-steel band straps. This will ensure the proper placement of the chambers along the pile-cap system.

Figure 6-8: Generic Plan view of the Offshore Transition Structure.

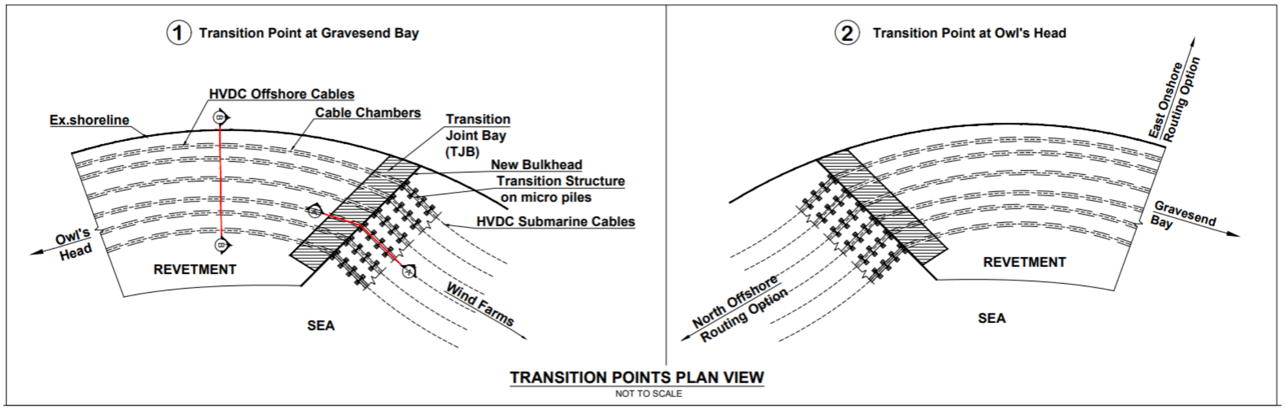
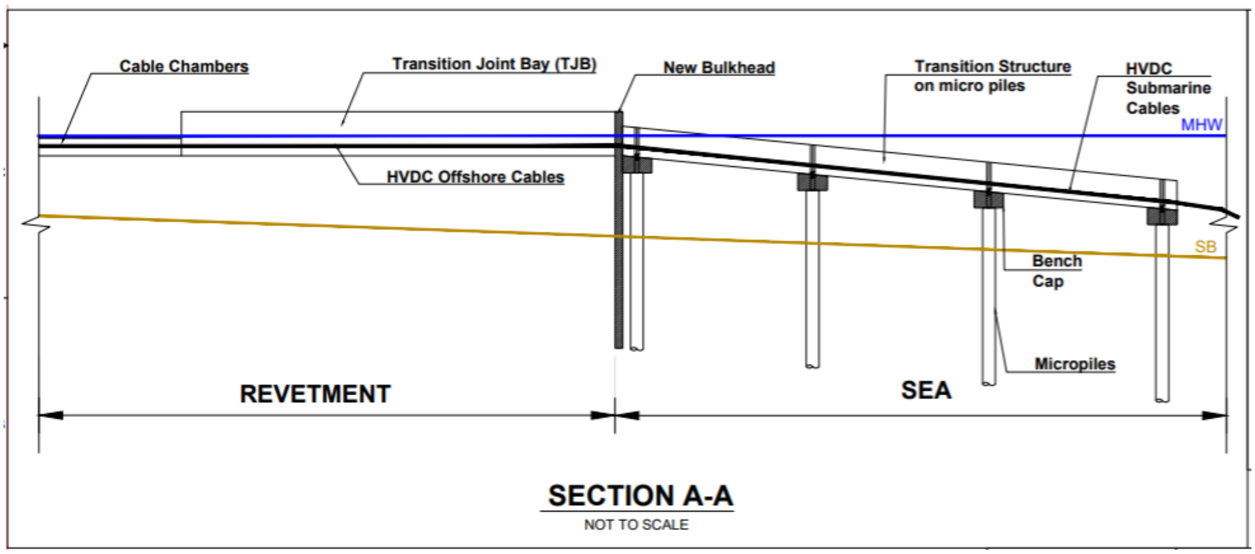


Figure 6-9: Generic Cross-Section of the Offshore Transition Structure/Section A-A.



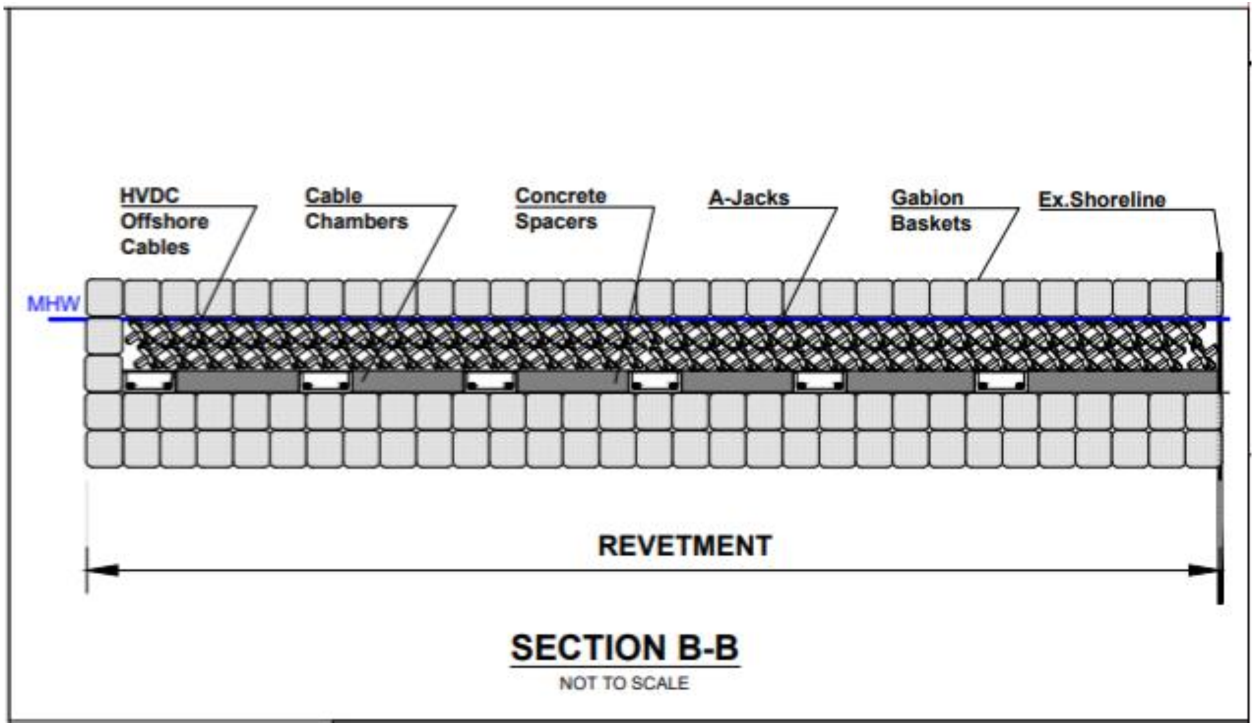
6.2.2.3 Nearshore Section Along the Bulkhead

A conceptual design is proposed for the cable route between the two landfall transition locations based on the initial approach for the three circuits (shown in Figure 14).

A new revetment will be expanded from the existing bulkhead to the seaside, along the Shore Parkway, to avoid disturbing the slope stability of the current infrastructure.

Figure 6-10 presents a typical structure of one course of filled gabion baskets on the existing revetment. On top of them, six pre-cast concrete chambers will be placed, sufficiently separated to allow for a feasible and technically proper cable installation. Depending on the method selected for cable installation (see Section 2.3), the concept design will be amended and aligned with this.

Figure 6-10: Section View of the New Revetment Along Bulkhead/Section B-B.



The cable chamber would be constructed of precast sections, each approximately with a width of 0.75-1.10 m (2.5-3.6 ft), height of 0.55-1.10 m (1.8-3.6 ft), and length of 1.0-2.0 m (3.3-6.6 ft). The chambers would present an innovative design using grooves at each end to allow each pre-cast section to be easily slotted and connected to the next one. Each unit will contain pre-installed lugs to allow for easier lifting into place, and for the chamber lid to be removed. The final design is subject to more detailed evaluation as fabrication, transportation and installation aspects shall be considered. The pre-cast concrete chambers shall be fitted at the fabrication site with a foam insert to prevent marine life growth until the cables are installed later.

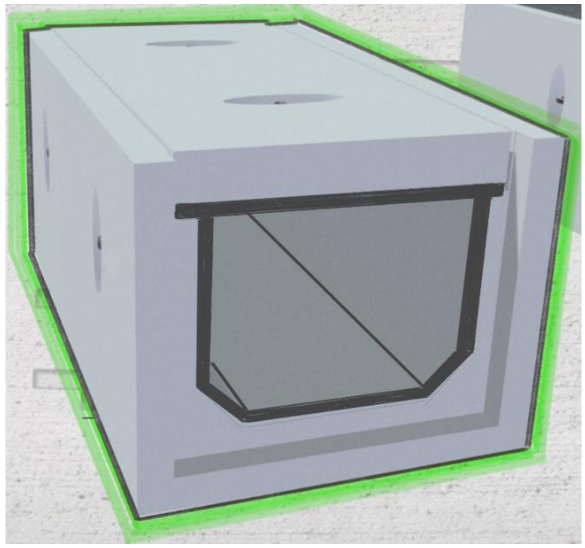
No cofferdams are expected to be needed for this part of the cable route.

The revetment would be installed with a crane barge and scow barge with rock armament stone moving up the line taking the top dressing stone and resetting at the new toe slope. This would be followed by land-based mobile crane setting the gabion baskets and pre-cast cable chambers. A floating crane barge would be used to complete the route infrastructure to the north at Owl Point. Land-based cranes can be used for re-nourishing the new revetment slope.

The stability of the revetment slope will be dependent on the development of an appropriately designed “toe” for the newly placed rock armor protection. The slope stability and therefore its robustness for the duration of the project lifetime will be developed during detailed design together with the appropriate slope angles, toe foundation and rock type / sizing for the revetement slope.

Once the cable chambers are laid, the infrastructure will be topped with a layer of A-jacks and left in a temporary condition until the cables are pulled through and installed.

Figure 6-11: Concept drawing for pre-cast chamber section.



After cable installation is completed by Cable Operators, the infrastructure will be fully topped with A-Jacks and an extra course of filled gabion baskets. The A-Jacks are an ideal option, as they are much lighter, and their delivery can be done in less transportation cycles than other materials used for civil marine works.

The infrastructure will be inspected to ensure the sea defense and protection are adequate and meet the specification identified during the detailed design stage.

6.2.3 Cable Installation

6.2.3.1 General

Cable installation will be coordinated separately with each Cable Operator, as it is assumed that no two OSW developments will reach the cable installation stage at the same time. This is also necessary to ensure there is space for the OSW development to pull cables through at the offshore entrance.

Most landfall cable installations begin by performing a landfall pull-in which is, essentially, the transfer of one of the subsea cable ends from the vessel to the shore. We expect a similar procedure in this scenario where the cable laying vessel (or barge) will approach the bulkhead and then float the cable towards it using messenger wires, winches, floats and support vessels (such as RIBS). The cable will then be pulled through the chambers and up into the offshore transition structures. This is applicable to both the North and South entrance.

Figure 6-12: Landfall Pull-in with cable floated from the CLV towards shore.

Generally, the maximum distance a cable can run through ducts/throughs/chambers is driven by the maximum pulling length of the cable which itself depends on the cable properties (mass, maximum allowable tension…), and the friction that the ducts/seabed apply on the cable. For this reason, cable installation generally relies on the ducts/throughs/chambers being designed with large bending radii. Other possible solutions include cable manufacturers providing well armored cables with high maximum allowable tension limits; and/or, during installation, mitigations to reduce the friction would also be beneficial (e.g. lubrication of the cable or the deployment of rollers).

From then, two potential cable installation approaches are envisaged, covered in the following Section 6.2.3.3 and Section 6.2.3.4.

Offshore cable installation is normally undertaken only during summer months due to whether windows. Due to the nearshore nature of this site, it should be reasonably protected from significant swells which would allow for longer working windows.

6.2.3.2 Preparation

To commence cable installation after the initial construction phase of the infrastructure, first the infrastructure will be prepared for cable installation. The temporary top layer of A-jacks will be removed as required, depending on the installation option to be utilized. For Method 1, the A-jacks will be removed from cable joint locations only and these areas prepared for jointing using the methods described in Section 6.2.4.2. For Method 2, the entire infrastructure will need to be cleared of A-jacks to allow for vessel access. A temporary laydown location for the A-jacks just inland of the infrastructure or via separate barge with crane will be necessary.

6.2.3.3 Method 1 – Cable Lay Using Shallow Draught Vessels

With Method 1, the cables will be installed by deploying a shallow-water Cable Laying Barge (CLB). The construction of the bulkhead (prior to the A-jacks/top layer being built) will need to be designed to allow for the CLB’s draught (i.e. 2-3 m / 6.5-10 ft). The CLB should then be able to position the cable chute right above the chambers to carefully deploy the cable directly into it whilst following the coastline. The CLB’s motion will either need to be performed using a pull anchor arrangement or using pre-installed onshore bollard whereby the CLB can pull itself along as it will not be able to do so under normal thrust due to the shallowness of the installation. This is common industry practice in shallow conditions although the cable-installing precision and vessel motion will be complex tasks that will require careful installation planning and a considerable constraint on barge/vessel selection.

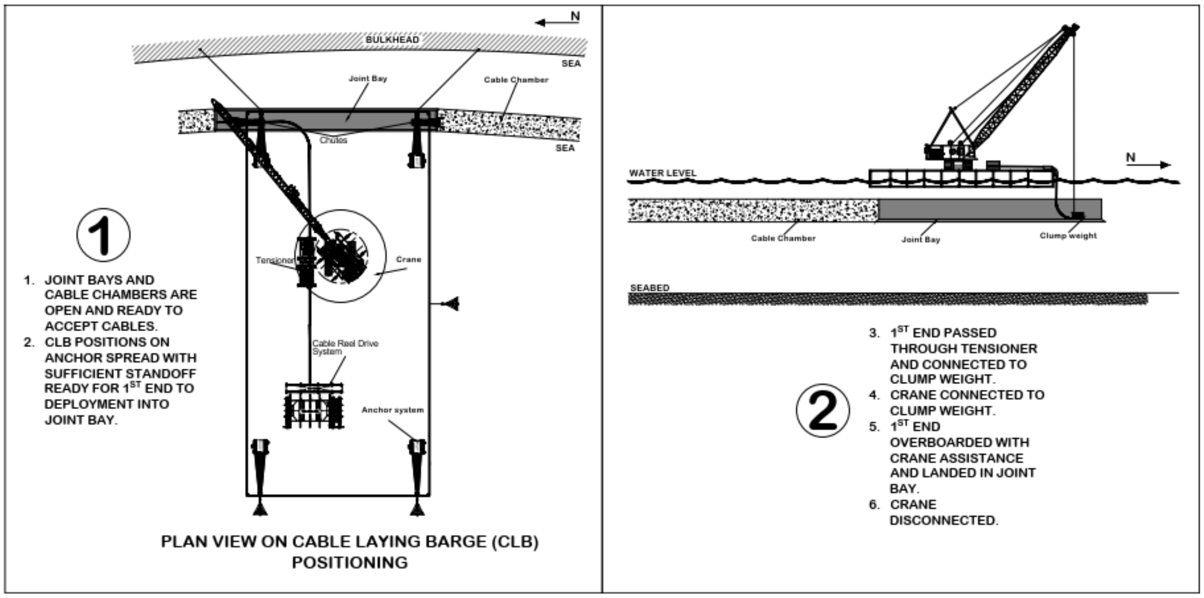
Once the cables have been installed within the chambers, the bulkhead construction will be finalized by laying the A-jacks and gabion baskets on top of the associated cable chamber.

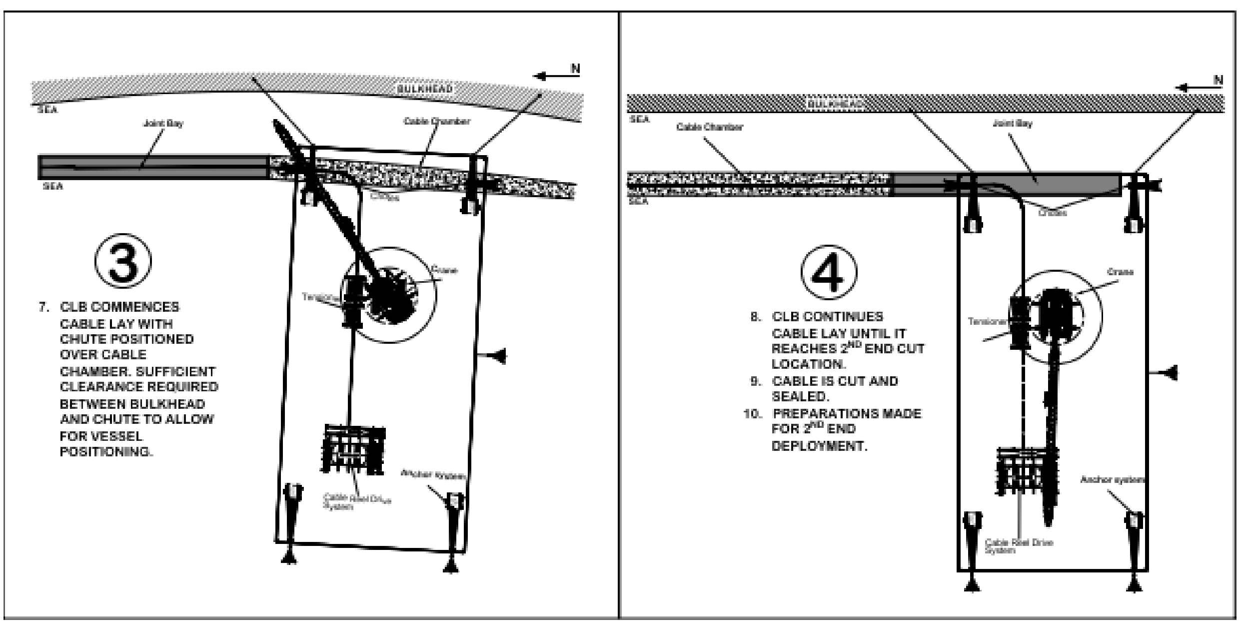
The benefit of this cable installation method is that it would avoid time-consuming and sensitive pulling joint works in a wet environment, requiring coffer damming and dewatering.

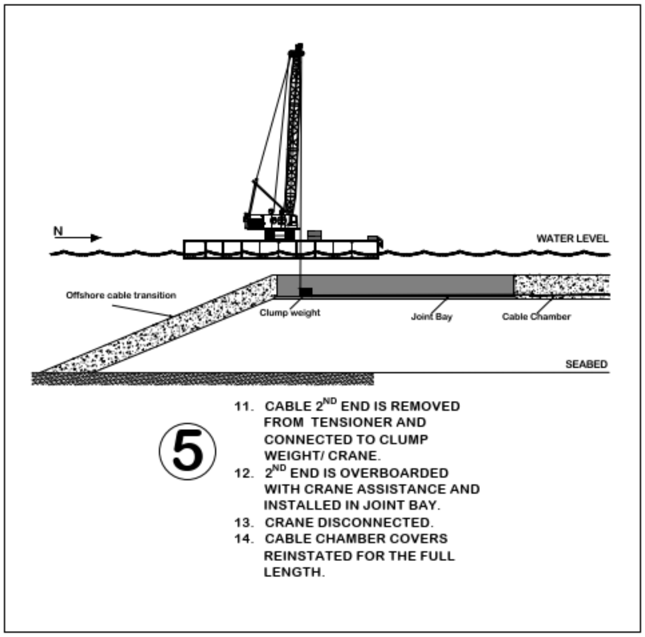
The limit of this approach is that once the bulkhead is fully constructed, vessels will no longer be able to approach it which would mean that any future repair will have to be performed using an onshore approach and by removing a significant section of the A-jacks and gabions to gain access to the damaged cable.

Also, it will be necessary to install the cable circuits starting from inside (closest to land) to outside (closest to offshore) if the chambers are to be covered with A-jacks and gabion baskets as each circuit is completed. Alternatively, the entire infrastructure would be left essentially uncovered until all Cable Operator circuits have been installed, then all A-jacks and gabion baskets installed to cover the entire infrastructure in one operation.

Figure 6-13: Examples of CLBs (draught less than 3m) – Nostag 10 (right) and NP289 (Left)


N
BULKHEAD
SEA
Joint Bay
Cable Chamber
Chutes
SEA
1
Tensioner
Crane
1. JOINT BAYS AND CABLE CHAMBERS ARE OPEN AND READY TO ACCEPT CABLES.
2. CLB POSITIONS ON ANCHOR SPREAD WITH SUFFICIENT STANDOFF READY FOR 1ST END TO DEPLOYMENT INTO JOINT BAY.
Cable Reel Drive System
Anchor system
PLAN VIEW ON CABLE LAYING BARGE (CLB) POSITIONING
N
WATER LEVEL
Cable Chamber
Joint Bay
Clump weight
SEABED
2
3. 1ST END PASSED THROUGH TENSIONER AND CONNECTED TO CLUMP WEIGHT.
4. CRANE CONNECTED TO CLUMP WEIGHT.
5. 1ST END OVERBOARDED WITH CRANE ASSISTANCE AND LANDED IN JOINT BAY.
6. CRANE DISCONNECTED.


N
BULKHEAD
SEA
Joint Bay
Cable Chamber
SEA
Chutes
3
Crane
7. CLB COMMENCES CABLE LAY WITH CHUTE POSITIONED OVER CABLE CHAMBER. SUFFICIENT CLEARANCE REQUIRED BETWEEN BULKHEAD AND CHUTE TO ALLOW FOR VESSEL POSITIONING.
Anchor system
Cable Reel Drive System
N
BULKHEAD
SEA
Cable Chamber
Joint Bay
SEA
Chutes
4
Crane
Tensioner
8. CLB CONTINUES CABLE LAY UNTIL IT REACHES 2ND END CUT LOCATION.
9. CABLE IS CUT AND SEALED.
10. PREPARATIONS MADE FOR 2ND END DEPLOYMENT.
Anchor system
Cable Reel Drive System



6.2.3.4 Method 2 – Cable Pull Using Onshore Installation Techniques

With Method 2, the cables within the bulkhead will be installed separately to, and either before or after, the landfall pull-in operation. This requires the cable to be installed using an ‘onshore’ approach and using reels/drums brought to the site with HGVs and a system of pulleys, cranes, winches to place the cable within the cable chambers. When finalized, the bulkhead-installed cable can be jointed together with the offshore section of the cable to complete the circuit. This is expected to happen within the offshore transition structure itself (or shortly after) due to limits on the maximum tension that can be endured by a cable. This is mainly due to the small bending radii expected as the cable comes up from the seabed and turns to align with the bulkhead structure.

The bulkhead construction can then be finalized by laying the A-jacks and gabions on top of the associated cable chamber.

This method will lead to several joints per cable due to the maximum length of cable that each cable drum can support (~500-800 m). The process of jointing can be complex as it requires a dry and sterile environment that may be difficult to achieve on the bulkhead. It is likely that at the location of each joint, the bulkhead will need to allow for other accessories (e.g. a plinth to place the cable reel or a winch, or access chambers) to manage the jointing operation. Coffer dams will likely be required to pump out the water from these locations (refer to the coffer dam description in Section 6.2.4.2).

The joint locations will need to be identified and these short sections will be set up with coffer dams. The cable chambers in these sections will be removed (approximate length of 12 m / 40 ft to be removed) and replaced with wider precast joint bay sections of approximate width 3 m (10 ft) each. The joint bay sections will be brought to site and slotted in and retrofitted to align with the existing array of cable chambers. It would be possible to pre-install the cable joint sections during the initial construction if this method of cable installation is decided and agreed with Cable Operators at detailed design.

These additional joint bays with access chambers will make it easier to perform any future maintenance or repair operation as the infrastructure to replace/install cables onshore would already be in place.

Once the cables have been pulled through and the joints executed, the cable joint chamber lids would be refitted, and A-jacks and gabion baskets laid on top of the associated cable chamber.

6.2.4 O&M

6.2.4.1 Maintenance

It is anticipated that the Infrastructure Operator would likely establish an O&M facility within a reasonable proximity of the infrastructure to support maintenance and repair operations for both the onshore and offshore infrastructure sections. The O&M facility may require spare A-jacks, gabion baskets, and concrete chamber sections to facilitate maintenance and repair operations.

We expect visual inspection will normally be performed at twelve-month intervals. These inspections will take place at more frequent intervals, every few weeks or months, during the first year, to ensure robustness of the installation and identify problems associated with construction.

The revetment structure should be inspected on a minimum period of between 3-5 years post-construction for any indication of distress to the revetment slope/ grade and armor stone such as scour, breakage or displacement of rock armor stone due to wave/ wake, settlement of revetment slope.

Scheduled maintenance will be performed on the bulkhead structure at ten-year intervals, along with a more comprehensive inspection of the landfall transition structure.

Visual inspections of the bulkhead structure will identify structural concerns, such as damaged gabion baskets, bulkhead erosion, general degradation, encroachments, and other potential issues. A visual inspection of the landfall transition structure will be performed every twelve months to identify structural concerns, such as damaged concrete, condition of armor stone, encroachments, general degradation, and any other potential issues. Remotely Operated Vehicles (ROVs), Unmanned Aerial Vehicles (UAVs – also known as drones), and underwater drones can be used for visual inspection at the discretion of the Infrastructure Operator. Otherwise, it may require specially trained labor to perform the inspections in the flooded environment.

Scheduled maintenance of the bulkhead structure will consist of an in-depth assessment of the gabion baskets above waterline, along with a removal of the baskets overtopping the A-jacks and cable chambers for visual inspection. Damaged or degraded baskets and A-jacks will be refurbished or replaced, and any degradation of the cable chambers will be assessed for potential repair. Scheduled maintenance of the landfall transition structure will comprise a more detailed inspection of the exterior structure, along with removal of access hatches for a visual inspection of the interior and cable system. Any degradation will be assessed for potential repair.

6.2.4.2 Repairs

Over the life of a typical OSW farm (25-30 years), most export cable systems will see at least one failure. Hence, there is a particular importance to ensure that any O&M or repair operation is swift to minimize the length of time that the offshore generator is unable to use the cable circuits.

Emergent issues, such as a cable fault or immediate structural concern, will be coordinated with the Cable Operators to ensure prompt and acceptable action can be taken to resolve the situation. Repairs of the landfall or bulkhead structures will be coordinated through the established O&M facility.

The Cable Operator will need to detect the location of the fault, expected using industry standard Distributed Acoustic Sensing (DAS) and Distributed Temperature Sensing (DTS) systems. This will be communicated to the Infrastructure Operator who will deploy an O&M team to the faulted cable location. Guided by as-built drawings, the gabion baskets and A-jacks will be removed and set aside on a temporary lay down area using a land-based crane, such as an adjacent part of the infrastructure that does not need to be uncovered. Alternatively, a separate barge with crane can be used for laydown. The chamber lid(s) will be opened for the faulted section. At this point, the Infrastructure Operator will ensure the site is safe for the Cable Operator to perform the cable repair. The faulted section of the cable will be cut and removed, and a new cable section will be jointed in its place.

Any joint work will require either a temporary coffer dam or a temporary elevated platform. With the coffer dam method, a combination of sandbags and braced walls can be used for damming, or a system similar to Portadam using fabric wraps with bracing equipment would be possible. A dewater pump powered by a small generator will be used to remove water within the coffer dam. Then the jointing tent can be set up and the area prepared for jointing. Once the repair joints are completed, the chamber lids will be reinstated, the coffer dam will be deconstructed, and the A-jacks and gabion baskets will be reinstated.

For the elevated platform method, a platform will be erected, extending from the shore above the water line to the top of the infrastructure just before the chamber of the faulted cable, using scaffolding. Wooden planks or metal sheets will be secured to the scaffold to provide floor and walls. The scaffold will be secured on top of the infrastructure using sandbags. A winch and pulley system located on the platform will be used to lift the cable onto the platform. The jointing tent will be erected on the scaffolding platform around the cable. Once the repair joints are completed, the cable will be lowered into the chamber with the winch, and the chamber lids will be reinstated. Then the A-jacks and gabion baskets will be reinstated.

6.2.4.3 Monitoring

It is not unreasonable to expect that each Cable Operator would utilize DAS and DTS systems to monitor cable system health and locate faults, as it standard industry practice now.

This study has not specified additional active monitoring systems to be built into the shared infrastructure by the Infrastructure Operator. The Basis of Design assumed no active systems to reduce maintenance of such systems and reduce complexity in requiring an electricity supply. Hence the concept as developed in this study does not envisage fire detection / suppression, fault monitoring, condition monitoring, etc. However, this does not mean it is unfeasible or out of the question. We suggest the advantages, disadvantages and cost-benefit would need to be examined in further detail at the next stage of engineering.

6.2.5 Electrical

Cable rating calculations were undertaken to evaluate the thermal performance of the proposed share landfall and cable route infrastructure. This section outlines the method used to carry out these calculations, the cable models used, the installation conditions modelled and the rating results.

6.2.5.1 Approach

The cable rating calculations were performed according to International Electrotechnical Commission (IEC) standard 60287 parts 1.1 [4] and 2.1 [5] for steady-state conditions. Part 1-1 [4] models the electrical losses within the cable and Part 2-1 [5] models the thermal resistances of the cable elements and surrounding medium and the mutual heating between groups of cables.

The methods in the standard calculate a factor $\Delta\theta$, which is the difference between the maximum permitted operating temperature of the conductor and that of the surrounding environment. The maximum conductor temperature is determined by the insulation type and the cross-linked polyethylene (XLPE) insulation used in HVDC cables is presently in a state of ongoing development. For many presently available 320 kV HVDC cables, 70°C is the maximum operating temperature and this has been used to calculate the ratings in this study. Some manufacturers offer cables with higher operating temperatures (80°C and in rare cases 90°C).

For presently available HVDC XLPE insulation, the electrical field strength in the insulation must be kept below a design limit of around 30 kV/mm [6]. The electrical field strength in XLPE insulation is highly temperature dependent and so the 30 kV/mm electrical field strength limit leads to a limit on the temperature rise across the insulation. For this study a value of 9°C has been used for the design temperature limit across the 320 kV HVDC XLPE insulation.

HVDC cable rating can be determined by the conductor temperature or by the temperature rise across the insulation.

6.2.5.2 Cable Models and Required Current

The steady state rating calculations were undertaken for 320 kV HVDC cables as defined in report 'Shared Landfall and Cable Route Infrastructure Basis of Design' [2]. These are single core cables with copper (Cu) conductors with cross-sectional areas of 2000, 2500 or 3000 mm2, with aluminum sheaths and galvanized steel armor. An outline of the cable models is provided in Appendix C.

The basis of design required steady state current is 2000 A, which gives a ±320 kV HVDC circuit capacity of about 1.2 GW [2].

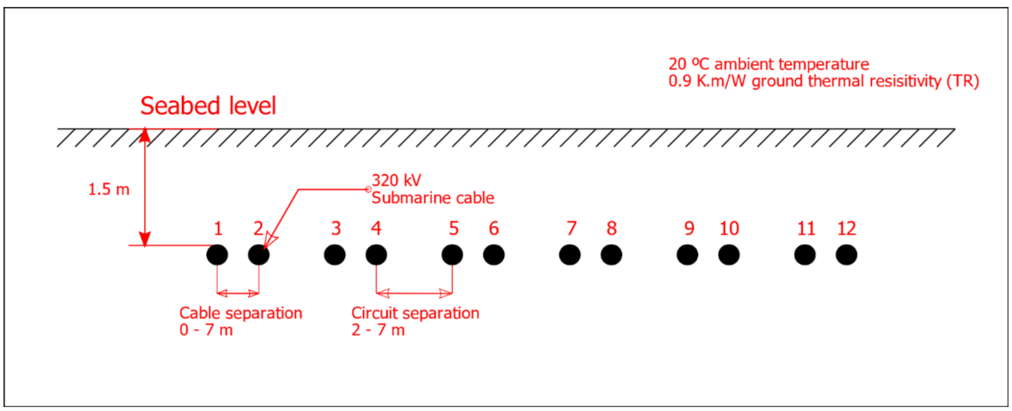
6.2.5.3 Installation Conditions

Two main offshore installation conditions were considered for six ±320 kV HVDC circuits, each comprising two cables:

1. Directly buried in the seabed in the nearshore area
2. In shallow troughs at landfall

The seabed installation conditions are illustrated in Figure 6-14.

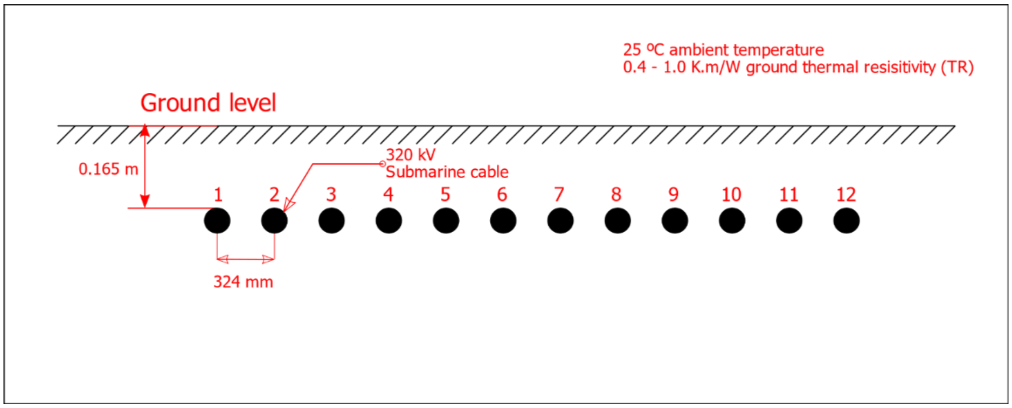
Figure 6-14: Seabed installation conditions in the nearshore area.



A representative burial depth of 1.5 m is assumed for all cases and the separation distances between each pair of cables and between the six circuits are varied in the range 0 – 7 m and 2 – 7 m respectively. A seabed temperature of 20°C and a seabed soil thermal resistivity (TR) of 0.9 K.m/W are assumed [2].

The landfall trough condition is illustrated in Figure 6-15.

Figure 6-15: Landfall trough installation conditions.



The landfall troughs were modelled very simply as cables directly buried at a very shallow depth of 0.165 m with a cable center-to-center separation distance of 0.324 m and a ground ambient temperature of 25°C. The TR of the ground is varied in the range 0.4 to 1.0 K.m/W, which is intended to represent concrete surrounding the cables. This is a simple conceptual analysis to determine how close twelve large 320 kV HVDC cables, each carrying 2000 A, can be placed from a thermal rating perspective.

6.2.5.4 Results

Table 6-2 shows the calculation results for cables directly buried in the seabed in the nearshore area and in troughs at landfall. The color coding of the results is shown in Table 6-1.

Table 6-1: Color coding of results.

Color	Description
Green	The rating is above the required current.
Amber	The rating is within 10 A of the required current.
Red	The rating is below the required current by more than 10 A.

Table 6-2: Steady-state cable rating calculations for the offshore section.

Parameter		Seabed			Landfall trough			
Variable	Unit	Case 1.1	Case 1.2	Case 1.3	Case 2.1	Case 2.2	Case 2.3	Case 2.4
System	N/A	HVDC	HVDC	HVDC	HVDC	HVDC	HVDC	HVDC
Cable Voltage	kV	320	320	320	320	320	320	320

Formation	N/A	Flat	Flat	Flat	Flat	Flat	Flat	Flat
Depth of cover over cable / duct	mm	1.5	1.5	1.5	0.165	0.165	0.165	0.165
Circuit separation	mm	2000	7000	2000	324	324	324	324
Cable separation	mm	500	7000	touching	324	324	324	324
Ground temp at cable depth	°C	20	20	20	25	25	25	25
Ground thermal resistivity	K.m/W	0.9	0.9	0.9	0.4	0.6	0.8	1.0
3000 mm^2 Cu XLPE galvanized steel armor – current rating	A	2,024	2,170*	2,028	2,170*	2,170*	2,170*	2,170*
2500 mm^2 Cu XLPE galvanized steel armor – current rating	A	1,872	1,990*	-	1,990*	1,990*	1,990*	1,990*
2000 mm^2 Cu XLPE galvanized steel armor – current rating	A	1,651	1,696*	-	1,696*	1,696*	1,696*	1,696*

Results in Table 6-2 denoted with an asterisk (*) are ratings that are determined by the temperature rise across the insulation and those without an asterisk are determined by the conductor temperature.

For seabed cases 1.1 – 1.3, the 3000 mm2 conductor has an acceptable rating. Case 1.3 represents the two cables of each circuit bundled together in a single trench, with a 2 m separation distance between trenches. This is a very close spacing in the nearshore area from a construction perspective, so demonstrates the viability of six ±320 kV HVDC circuits, each carrying 2000 A, sharing a landfall location in terms of their thermal interaction in the nearshore area.

For landfall trough cases 2.1 – 2.4, the 3000 mm2 conductor has an acceptable rating. The 2500 mm2 conductor is also close to an acceptable rating. All the landfall trough results are limited by the temperature rise across the insulation. This is due to the shallow burial depth allowing effective heat transfer to the air above. The temperature rise across the insulation is a design limit, largely (but not entirely) independent of the installation conditions, so the 3000 mm2 conductor can comfortably carry the required current of 2000 A, while the 2500 mm2 conductor is at its design limit. However, as HVDC XLPE insulation continues to be developed, the 9°C temperature limit across 320 kV insulation may increase, so allowing higher currents to be carried by cables with these conductor sizes.

Cases 2.1 – 2.4 demonstrate the viability of six ±320 kV HVDC circuits, each carrying 2000 A, sharing a suitably designed piece of landfall infrastructure.

The condition of submerged troughs was not specifically studied. This is because the water around the troughs will be tidal or flowing and so will be effective in transferring heat away from the submerged troughs. As the landfall trough cases 2.1 – 2.4 are acceptable for the 3000 mm2 conductor, it is inferred that similar trough installation conditions submerged in flowing water would also be acceptable. Additionally, IEC 60287 part 2.1 [5] is only applicable to relatively simple installation conditions, such as directly buried cables. It would be appropriate to study the submerged trough condition using a method such as computational fluid dynamics at detailed design stage.

6.2.6 Civil/Structural

The conceptual infrastructure design is based on fitting six HVDC circuits through the Narrows along Shore Park in Brooklyn. The plan includes the installation of circuits in six cable chambers. This section describes the civil engineering aspects of each part of this section of infrastructure.

6.2.6.1 Micropiles

The following narrative accounts for the nearshore engagement of marine civil structures with the export cables as they emerge from an assumed 3 to 6 m burial depth in the foreshore approach to the proposed landfall.

It is assumed the export cable will be picked up some 10-12 m away offshore, from the conceptual landfall bulkhead situated on the eastern shore of Gravesend Bay, at a depth of approximately 5-6 m. As the trench is pitched up toward, physical restraints will be required to prevent the buoyant heaving effects, structures can be exposed to in sand/shale conditions when exposed to prevailing winds, waves and wakes in the near shore. To such conditions, it is assumed that helical micropiles, in conjunction with a Mean Higher High Water (MHHW) plastic pile cap, spaced every 2 m, could withstand such forces acting upward on the pre-cast concrete chambers containing the export cables. The chambers would be tied down to the MHHW pile cap with stainless steel banding.

It is assumed, for the sake of this concept, that a length of penetrations through the landfall bulkhead of 3 m will be sufficient for the chambers and export cables.

6.2.6.2 Landfall New Bulkhead

This describes the landfall new bulkhead at the east shore of Gravesend Bay.

The landfall bulkhead (with up to 6 subsurface export cable chamber penetrations) could be constructed several different ways. However, understanding its end use and possibilities to make up the finished surface area as an extension of the existing Shore Park, it is assumed that the required vertical loading requirement would be for emergency vehicles, and therefore loading for HS-20 traffic rating would likely drive the bulkhead make-up. Therefore, it is proposed to comprise a steel sheet pile bulkhead with concrete cap and dead-man anchorage system.

The landfall bulkhead will provide for controlled jointing of export cables (for method 2 cable install) during its construction and will align the export cable chambers at an angle perpendicular to the cable approach at the point of bulkhead penetration. The penetrated bulkhead structure, following the placement of the cable chambers through the penetration will be secured through the forming and pouring of cast-in-place closures. Any structural reinforcement around or in any penetrations of bulkheads supporting this concept should utilize glass-fiber-reinforcement-rods to eliminate any stray water currents having an adverse effect on surrounding steel of the bulkhead or embedded steel normally found in concrete.

6.2.6.3 Shoreline Embedment and Protection Of Export Cable Structure

This section describes the shoreline embedment and protection of the export cable structure at the north side of the landfall bulkhead to Owl Point.

North of the landfall bulkhead, the export cables emerge at the same elevation, some -1m below the Mean Lower Low Water (MLLW) level atop the prepared armor stone revetment bedding stone identified in the section detail. The export cables would be protected within pre-cast tongue and groove linear chambers. Any chambers that will house the export cables will be lined internally on three sides with a refractory grout to prevent conduction of heat through the concrete units. The uppermost cover for cable chambers would be a MHHW high density concrete grate to allow the continuous flow of water to continually cool the export cables under load.

Each of the cable chambers containing an export cable will be structurally separated along its length, standing off from one another at least two chamber widths. The purpose for this would be two-fold. Firstly, to provide ample separation between cabling that electromagnetic field impacts and mutual heating potential of cable circuits on each other are eliminated, and secondly, A-Jacks can be set within each section between each stand-off to horizontally and longitudinally lock the chambers into one another.

6.2.6.4 Transition to Water or Land and Continuation to POIs

From the northernmost point of the Shore Park bulkhead revetment at Owl's Head, there are opportunities for the route to connect to Gowanus or Farragut substations in Brooklyn using onshore infrastructure. Alternatively, the cables could continue offshore to Manhattan and other areas.

Landward Routing from Owl Point

The landward detail for export cabling route (as identified in the onshore civils section, 3.6) would necessitate penetrating the existing mass concrete low-level relieving platform that provides for the upland Shore Park cycle way. The penetration of each cable chamber would be enacted with traditional bulkhead partial demolition practices and would not require a complete top-down removal and replacement of structure. Instead, rather precise 'windows' can be provided through the existing concrete through use of underwater demolition saws and Broco underwater burning rods. When the chamber is placed through the bulkhead, shuttering and glass fiber reinforced cast-in-situ concrete closures can be made.

Offshore Routing from Owl Point

Some Cable Operators may require continuing the route within NY harbor to other POIs. To accomplish this, the export cable chambers would transition downward within the east to west shoreline protection that forms the southern shore of the wastewater facility at Owl's Head. The downward transition of export cable detail should occur, avoiding using a micro pile structure in the east west revetment, such that when the toe of the revetment level is achieved, the cable chambers should be at an elevation of approximately -2 m. In achieving this level of burial within the revetment, the export cabling can be picked up directly by offshore installation tools such as tracked ROVs for precise placement at the eastern limit of the navigation channel that runs between Governor’s Island and Red Hook in Brooklyn. In taking this route, the expanded anchorages at Red Hook Flats would also be eliminated from potential impacts during installation.

6.2.7 Health and Safety

6.2.7.1 H&S Plan

A Health and Safety management system will need to be established and maintained for construction and O&M. The Infrastructure Operator will be responsible for the health and safety of the personnel, asset integrity, security, and the quality of work. A full HSE plan is required and shall include, at the minimum but without limitation, the following aspects:

- Provide safety and lifesaving equipment that follows the applicable Law.
- Provide all reasonable means to control and prevent fires and explosions, injury to personnel and damage to equipment and property.
- Ensure all the necessary scaffolding and work platforms are installed, tested, and certified by competent personnel, prior to use.
- Specific occupational health and safety issues relevant to marine operations:
    - Physical hazards.
    - Chemical hazards.
    - Confined spaces.
    - Exposure to organic and inorganic dust; and
    - Exposure to noise.
- A risk assessment that will be developed for each construction phase including O&M. The risks and Hazards will be identified, recorded, and updated systematically in a risk register throughout the Work. All equipment, material and processes shall be a criticality rating for safety, security, environmental impact, operational performance significance, availability for repair, complexity of construction/installation, cost and schedule.
- Precaution measures shall be established for the offshore cable installation specifically planned based on the method to be adopted.

It is anticipated that the Port Operator have certain key responsibilities for the safe operation of the vessels not involved in the Construction or O&M activities of the infrastructure., ranging from passengers’ safety to the safe access and maneuvering of chemicals and oil transporting ships inside the harbor and port areas. In accordance with applicable legal requirements, port security arrangements (e.g., access control) may be established through the completion of a Port Facility Security Assessment based on the outcome of the Project Risk Assessment. A Port Facility Security Plan may be required to be integrated within the Project HSE plan.

6.2.7.2 H&S Risks

Specific risk aspects pertaining to the offshore infrastructure include but are not limited to:

- Fabrication - the concept calls for bespoke fabrication (pre-cast) cable chambers. Any such work associated with these units will require vetting from a competent fabricator. There are established suppliers for A-jacks and gabion baskets, and this should be less of an issue.
- Transport and loading – the concept requires delivery of materials and equipment to site. This will require both road and barge transport as well as loading and unloading operations. Such loading / unloading operations with a barge will require a crane. These transport, loading and unloading operations will need to be carefully planned to mitigate the risks.
- Construction – the construction phase has several elements that carry risks:
  - Coffer dam and dewatering operations and similar work in a marine environment carry higher risks than in an onshore environment. This work must be carefully planned according to seasons and weather.
  - Some of the construction activities will require landside access including construction laydown and personnel compound. The space for these activities will need to be carefully thought out and measures such as security and traffic management put into place.
- Cable installation – two methods have been outlined for cable installation. One requires a complex cable lay operation using CLBs and the other requires coffer dam, dewatering and jointing on site. Both will have risks, and the methods involved will need much further elaboration at detailed design to mitigate risks. Two parties are involved for cable installation – the Infrastructure Operator and the Cable Operator – and their activities must be coordinated.
- Cable repair – similar to installation, repair will require coordination from both the Infrastructure Operator and the Cable Operator. Repair operation may be complex and planning operations will have to take account of the severity of the cable damage, its location, the condition of the infrastructure at time of repair, as well as weather and water conditions.

6.3 Onshore Section

6.3.8 Description

For the onshore export cables, up to six circuits would be expected to route through the same corridor, from the Owl's Head to the potential POI.

The infrastructure concept has been designed for installation in the road which is common for built-up urban areas.

The cables will run through concrete ducts banks and the pull in operation will be executed for each cable section, defined between two consecutive joint vaults. The location of the vaults will be determined once the corridor route is finalized. The footprint required will be subject to the detailed design.

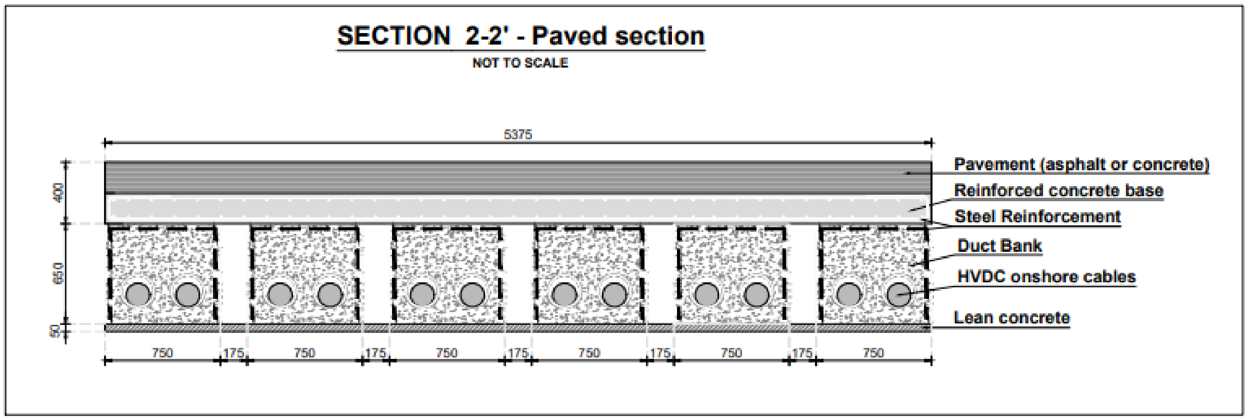
Concrete duct banks, whereby a matrix of cable ducts are encased in concrete, is a common existing method used for onshore utility cables. This method has decades of track record. However, these duct banks are not very thermally efficient, and it would not be possible to install six HVDC circuits within the same duct bank without the cables experiencing significant derating and reduction of current-carrying capacity. The concept uses a modified version of the duct bank, with the aim of increasing thermal independence and thermal efficiency of each cable circuit.

Figure 31 shows a typical cross-section of the concept in the road with indicative dimensions. It consists of a group of six individual duct banks, 750 mm (29.5 in) wide and 650 mm (25.6 in) deep each, installed in one excavation. The bottom of the excavation is formed of lean concrete. There are air gaps of approximately 175 mm (6.89 in) between each duct bank. A reinforced (with steel rebar) concrete base is laid on top of the duct bank group, covering the air gaps. The asphalt road surface is laid on top of the concrete base.

The overall width of the installation is 5,375 mm (17.6 ft). A single road lane is approximately 3,050 mm (10 ft) and a sidewalk is up to 1,829 mm (6 ft). This means the concept would fit within a two-lane road. Pending space in the road, it may be necessary to reduce the number of circuits, e.g., to 3, 4 or 5. Reduction to 5 circuits or less would allow the concept to fit within a single lane of road plus the sidewalk. Note that some areas have many utilities in the road, and it will be necessary to conduct a utility survey to truly understand the space to install the concept. Modifications may be required depending on the space available.

Should the infrastructure need to be deeper to cross utilities, a general approach to resolve this would be to locate the grates where the crossings are to be found in order to balance depth increase. However, each utility shall be handled in a different, unique way. So, any challenge related to utilities will be addressed at the detailed design stage.

Figure 6-16: Section View of Buried Onshore Section with Road Surface.



The cable ducts are made of HDPE and are aligned in a single shallow row instead of in multiple rows. This arrangement requires more corridor width but reduces thermal interaction between cable circuits. It is also more thermally efficient, as increased burial depth reduces cable rating.

Figure 6-17 shows a cross-section of a grated version of the concept. To make best use of the air gaps to increase thermal efficiency, the concept uses a short, grated section at regular intervals. This allows natural movement of air due to buoyancy force, as there will be a temperature difference between the ambient air at the surface, and the ambient air in the air gaps.

Figure 6-17: Section View of Buried Onshore Section with Grated Surface.

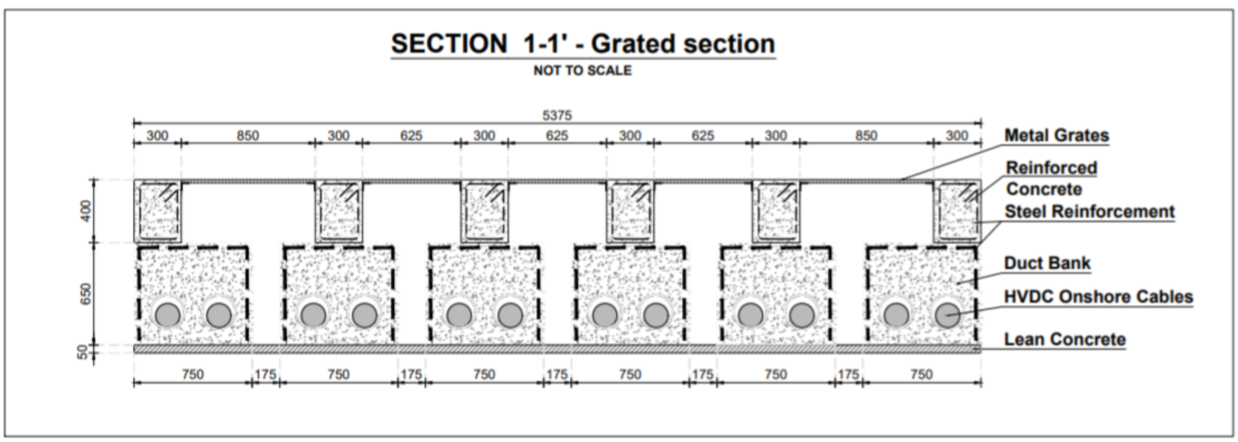


Figure 6-18 contains a plan view, which shows the grated version at regular sections.

Figure 6-18: Plan View of Typical Onshore Section.

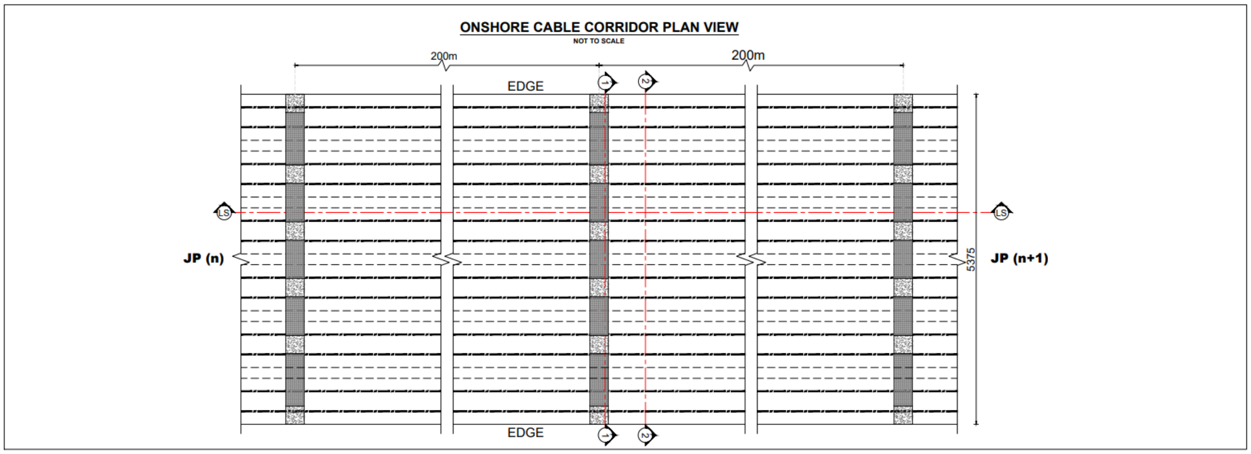
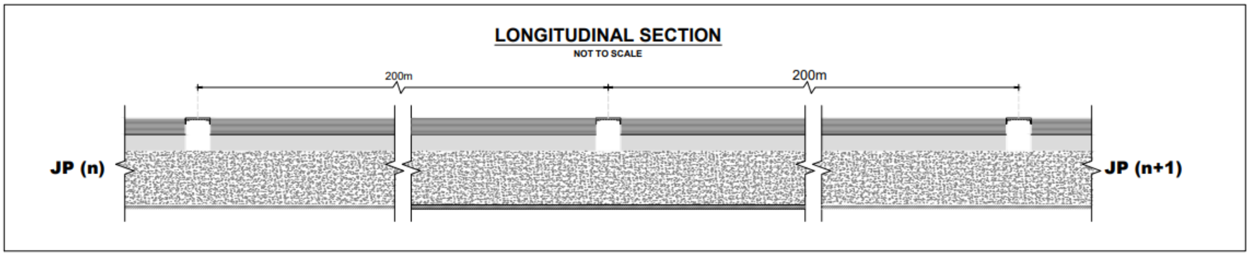


Figure 6-19 contains a longitudinal section view.

Figure 6-19: Longitudinal Section



6.3.9 Construction

The Infrastructure Operator will be responsible for the construction of the onshore infrastructure, the same as the offshore.

It is anticipated that the cable corridor will pass through a heavily developed urban area, and largely lie under roadways and sidewalks. At an early design stage, a site investigation with full utility mapping and the detection of major crossings shall be conducted to confirm the feasibility of the concept.

Once the cable route is defined based on a precise landfall and POI selection, further design considerations shall be determined such as the number, location, and the footprint of the join vaults, laydown areas, temporary compounds, and the need for imported materials. The number of circuits and the infrastructure footprint may need to be reduced depending on the available width of the road lane and other unforeseen risks. The final design shall include thorough cable route drawings, further engineering studies and the construction traffic management plan.

The construction will take place in stages due to traffic management, permitting, and manpower considerations. The contractor will be responsible for assessing the final design and the relative requirements and HSE aspects.

The construction of each stage will occur in three phases: Excavation, Duct Bank Install, and Re-Pavement. The contractor will be responsible for determining staging areas, spoil removal and disposal, permitting, all other necessary planning and the implementation of the traffic management plan.

Once excavation has been completed, duct bank install will follow with a ground layer of lean concrete to provide a firm and level foundation for the cable chambers. The foundation concrete must be level, or the duct segments will not join properly. The cable chambers themselves will be pre-cast in segments with two ducts each, and the segments will be limited to 10 m (32 ft 9.7in) long to allow transportation by a standard flatbed truck. The six duct segments will be aligned within the excavation, separated from each other by a 175 mm (6.89 in) air gap. The ducts themselves will be joined by appropriate couplings to allow cable pulling when construction is complete.

Joint vaults will be placed along the cable run at points determined during detailed engineering for cable pulling and splicing operations. These vaults will be placed at set intervals along the cable path, as well as at significant inflection points, to ensure the cables can be installed without damage.

The duct banks will be overtopped by a solid pavement of reinforced concrete, except for every 200 m (approx. 656 ft) where heavy-duty steel grates are to be placed on concrete in-cast supports. These supports are typically reinforced concrete beams of 400 mm height (15,75 in) x 300 (11,81) mm width structurally connected to the duct bunks. At those locations, short rebars and ties will be placed between the spans, tightened to post-installed rebars on the top of the duct banks. Then suitable formworks shall frame each support and prepare the section for concrete pouring. When the above stage is complete, steel sections will be used as a basis for the metal grates installation. As these grates are vital to the longevity of the installed cables, due to the passive air cooling they offer, it is expected that two layers of grating will be implemented to protect the infrastructure from debris, rodents etc.

Covered access ports will be installed for the joint vaults. When the paving and metal grates are placed, construction of the stage will be completed, and construction can move to the subsequent stage.

The cable chambers will be rodded and strung prior to cable installation, either during construction or at an agreed-upon interval prior to installation.

Seasonal restrictions for infrastructure construction would follow the same regulations as traditional transmission concrete duct banks. Typically, summer work is preferred as this makes the excavation work easier to complete, but busy tourist or recreational areas may require winter construction.

6.3.10 Cable Installation

Cable installation will be the responsibility of each Cable Operator and undertaken by its designated cable installation contractor. The Infrastructure Operator will provide access to the specific joint vaults assigned to the Cable Operator.

Traffic control, as part of the construction traffic management plan, will be required around staging and pulling locations, as they will likely be in the roadway. The pulling contractor will be responsible for determining the order in which cable sections will be installed and obtaining permits accordingly. The contractor will also be responsible for ensuring that the cable's mechanical ratings are not exceeded at any point during the pulling operation. The joint vaults will be placed such that no non-standard pulling equipment, such as rollers or protective coatings, will be required.

The first step will be for the contractor to perform checks on the conduits to ensure they have been properly proved and that there are no obstructions, and the conduit is satisfactory to commence the pulling operations.

Cable pulling and jointing work will largely follow standard practice for onshore utilities. However, as the Reference Location is an urban, heavily developed area, a short construction timeline would be an essential requirement. Cable pulling and jointing operations shall be planned to be executed in parallel, when and where is possible to done. This would be feasible as long as two groups of contractors are deployed and come to an agreement for a schedule alignment.

When each section of cable has been installed it will be capped and water sealed by the pulling crew. When two or more cable sections have been installed, the joining contractor will schedule the cable joining operation. Joints will be installed to factory specification, properly sealed, and protected from arc-flash prior to the joint vaults being closed.

Seasonal restrictions for cable pulling would follow the same regulations as cable pulling for traditional transmission concrete duct banks.

6.3.11 O&M

6.3.11.1 Maintenance

It is anticipated that the Infrastructure Operator would likely establish an O&M facility within a reasonable proximity to the infrastructure to support maintenance and repair operations for both the onshore and offshore infrastructure sections. The O&M facility may require spare metal grates, access covers for the joint vaults, and a small number of pre-cast concrete cable chamber sections to facilitate maintenance and repair operations.

Visual inspections will normally be performed at twelve-month intervals. These inspections will take place at more frequent intervals, such as every few weeks or months, during the first year to ensure the robustness of the installation and identify problems associated with construction. Due to the location of the onshore cable system, and the nature of concrete duct emplacements, it is anticipated that little scheduled maintenance will be required, however there is a risk of encroachment or damage from utility work and road construction and maintenance. The Infrastructure Operator will maintain records and contact with the local 811 office to ensure the cable system is properly marked prior to construction and will liaise with the local departments of transportation and public works to prevent accidental damage from planned construction.

Visual inspections of the cable system will be conducted on clearly visible portions of the system, such as metal gratings and joint vault access covers. These inspections will identify structural concerns, such as damaged grates and vault covers, general degradation, new or altered utility encroachments, and any other potential issues. The inspection will also determine whether detritus has fallen through the gratings in sufficient quantities to degrade the thermal capacity of the system, in which case a cleaning operation will be scheduled. Based on feedback from a utility, such cleaning is estimated to be required every 6 months. It is unlikely that regular inspections inside the joint vaults or under roadway grates would provide useful information, but if desired these inspections should take place at five-year intervals.

6.3.11.2 Repair

Over the life of a typical OSW farm (25-30 years), most export cable systems will see at least one failure. Hence, there is a particular importance to ensure that any O&M or repair operation is swift to minimize the length of time that windfarm is offline.

Emergent issues, such as a cable fault or immediate structural concern, will be coordinated with the Cable Operators to ensure prompt and acceptable action can be taken to resolve the situation. Repairs to the cable system will be coordinated through the established O&M facility.

The Cable Operator will need to detect the location of the fault, expected using industry standard Distributed Acoustic Sensing (DAS) and Distributed Temperature Sensing (DTS) systems. This will be communicated to the Infrastructure Operator who will obtain emergency work permits and deploy O&M teams to cordon off and prepare the joint vaults on either side of the located fault, along with an appropriate laydown yard and pulling set up for the new cable. The O&M crews will remove the access covers from the joint vaults and ensure the site is safe for the Cable Operator to perform the cable repair. The faulted section of the cable will be cut and rigged to pull out of the duct, while pulling the new section of cable in. The new cable will be properly jointed in its place, and the O&M crew will re-seal the joint vaults and remove traffic control measures to return the roadway to typical conditions.

In the event of a structural emergency, such as impact from a paving campaign, external utility installation, or other incident that has an immediate, serious impact on the cable system up to and including collapse of the concrete cable chambers, the Infrastructure Operator will immediately coordinate with the Cable Operators impacted as well as civil authorities and any other involved parties to assess damages and determine a best course of action. In general, the Infrastructure Operator will take responsibility for structural remediation, such as repair or replacement of a damaged cable chamber section, and the Cable Operator(s) will take responsibility for electrical repair, such as repair or replacement of damaged cable.

6.3.11.3 Monitoring

As highlighted in Section 6.3.11.3, active monitoring systems were not considered as part of this study but could be the subject of further engineering studies. The potential for monitoring systems for the onshore infrastructure is higher due to joint bays and grating.

6.3.12 Electrical

Cable rating calculations were undertaken to evaluate the thermal performance of the proposed onshore shared infrastructure. Initially, calculations were carried out using the same analytical methods as for the landfall infrastructure. These indicated the need to mitigate the ground TR values likely to be found onshore. A detailed study of the proposed onshore infrastructure incorporating passive air cooling was therefore carried out using computational fluid dynamics (CFD).

For the analytical calculations, this section outlines the method and cable models used, the installation conditions modelled and the rating results.

In the following section, a summary of the CFD study is provided.

6.3.12.1 Analytical Calculations

Method

Initial conceptual calculations were carried out, using the same analytical methods outlined in Section 6.2.5.4. These aimed to establish the viability or otherwise of installing six ±320kV HVDC circuits in close proximity in reasonably typical onshore installation conditions.

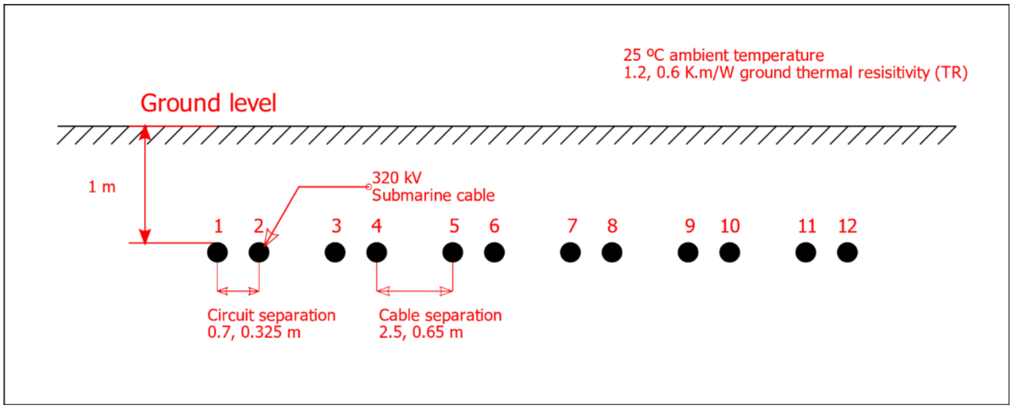
Cable models and required current

The cable models and required current are as outlined in Section 6.2.5.2.

Installation conditions

The installation conditions studied are shown in Figure 6-20.

Figure 6-20: Onshore cable installation conditions



The cables are modelled simply as directly buried, with a typical burial depth of 1 m and two ground TR values of 0.6 K.m/W and 1.2 K.m/W. The cable and circuit separation distances are different for the two TR values. The value of 1.2 K.m/W is typical for onshore installations in temperate climates [1, 5]. The value of 0.6 K.m/W is intended to represent some form of mitigation to reduce the effective ground TR, such as air-cooling channels or low TR backfill.

Results

The results for the initial analytical cable rating calculations for the onshore infrastructure are shown in Table 6-3. The color coding is as described in Table 6-1

Table 6-3: Steady-state Cable Rating Calculations for the Onshore Section.

Parameter		Onshore	
Variable	Unit	Case 3.1	Case 3.2
System	N/A	HVDC	HVDC
Cable Voltage	kV	320	320
Formation	N/A	Flat	Flat
Depth of cover over cable / duct	m	1	1
Circuit separation	m	2.5	0.65
Cable separation	m	0.7	0.325
Ground temp at cable depth	°C	25	25
Ground thermal resistivity	K.m/W	1.2	0.6
3000 mm^2 Cu XLPE galvanized steel armor – current rating	A	2,006	2,010

Both the cable rating results in Table 31 are determined by the conductor temperature.

Case 3.1 shows that for a typical ground TR of 1.2 K.m/W and burial depth of 1 m, the cable separation distance needs to be 0.7 m and the circuit separation distance needs to be 2.5 m for the cable rating to be above the required current of 2000 A. This gives a required total easement for the six circuits of about 17 m (55.8 ft), which is considered to be unrealistic unless in a rural location.

Case 3.2 shows that if the effective TR of the ground can be reduced to 0.6 K.m/W, the cable and circuit separation distances can be reduced to 0.325 m (1.1 ft) and 0.65 m (2.1 ft) respectively. This gives a required total easement of about 5.5 m (18.0 ft), which is considered to be realistic in terms of installation beneath a road carriageway or similar urban location.

Case 3.2 indicates the need for mitigating the ground TR and so a detailed CFD study was carried out on a passively air-cooled infrastructure design.

6.3.12.2 Computational Fluid Dynamics Study

The CFD study models the environment around each cable using the losses calculated by the analytical cable models. Each cable in the CFD study is represented as a 2D circle or a 3D cylinder with a diameter of 162 mm and cable losses of 31 W/m.

The installation conditions for the CFD study are shown in Figure 6-16 and Figure 6-17 in Section 3.1. Each cable is installed in an air-filled duct and the two ducts comprising one circuit are installed in a duct bank. Between adjacent duct banks there is an air-filled channel and there are grates opening each air-filled channel to the air above ground at regular spacings along the cable route. This arrangement is intended to provide passive cooling of the infrastructure by allowing warm air to escape through the grates.

Initially the ambient air temperature was taken as 25°C and the maximum allowable cable conductor temperature was 70°C, as for the analytical calculations.

The study of the arrangement outlined above progressed in stages, as described below.

Firstly, a 2D CFD model based on Figure 6-16 was built to assess the effect of the air channels between the duct banks, without taking into consideration longitudinal air flow in the channels parallel to the cables. This model found that the cable surface temperature would be above 55°C.

The analytical calculations outlined in Section 6.3.12.1 showed a 15°C temperature rise between the cable surface and conductor, so the conductor temperature would be above 70°C and therefore not acceptable.

Secondly, a 2D CFD model based on Figure 6-17 was built to assess the effect of the air channels between the duct banks, together with the grates open to the air above. This did not take into consideration longitudinal air flow in the air channels parallel to the cables. This model found that the cable surface temperature would be 50°C, giving an acceptable conductor temperature of 65°C.

Thirdly, a 3D CFD model based on both Figure 6-16 and Figure 6-17 was built to assess the effect of longitudinal flow in the air channels due to the grates. The findings of the model were as follows:

1. For 25°C ambient air temperature:
    a. For 70°C cable conductor temperature, 10 m (32.8 ft) grate spacing would be required.
    b. If cables utilizing XLPE insulation with a maximum temperature of 80°C are used, grates would not be necessary, or could be spaced more than 50 m apart.
2. A higher ambient air temperature of 33°C was considered:
    a. For 80°C cable conductor temperature, 15 m (49.2 ft) grate spacing would be required.

This model showed that the feasibility of a passive air-cooled system was highly sensitive to the ambient air temperature. The maximum permissible conductor temperature was also a significant factor in determining the required grate spacing.

Fourthly, a 3D CFD model based on Figure 6-17 was built to assess the effect of longitudinal flow in the air channels due to forced cooling without grates. This used a high ambient air temperature of 37°C and showed that with this air temperature even with forced air cooling the cable conductor temperature would be above 80°C.

The main conclusion of the CFD study is that the onshore infrastructure incorporating passive air cooling, outlined in Section 6.3.8 may be feasible, depending on the ambient air temperature and HVDC cable maximum allowable temperature.

For the case of 25°C ambient air temperature and 80°C maximum allowable conductor temperature, the pass air cool design was feasible, with little or no sensitivity to the grate spacing distance along the cable route. For this reason, the grate spacing is still shown with 200 m intervals in the drawings above.

Other possible infrastructures could be investigated, such as low TR construction and backfill materials or active water cooling.

6.3.13 Civil/Structural

The conceptual infrastructure design is based on fitting six HVDC circuits within one lane underground, most likely of an arterial road. The plan includes the installation of circuits in six duct banks equally separated by air gaps to increase thermal efficiency. The principle of the air gap concept relies on the narrow-grated pavement sections at regular intervals along the cable route that allow the air flow to circulate effectively. This section describes the civil engineering aspects of each part of this section of infrastructure.

As the approach is high-level and the onshore cable route is not defined yet, there has not been established a road classification or any specific design criteria. However, the NYSDOT Highway Design guidelines (Chapter 3 – Section 3.2.4 Pavement Sections – Conventional thickness guide) have been considered for the selection of a minimum – Rigid Pavement – depth of approx. 400 mm (8.85 in) applying to the development of the Interstates System. As the infrastructure matures and the cable route is determined, further details shall be investigated such as the condition of the existing road network, the classification of the functional route and other NYSDOT and AASHTO parameters.

The current design presents a rather conservative concept of the road infrastructure due to the air gaps underneath the road. It is recommended that once the cable route is determined, a Pavement Type Selection Analysis should be prepared and confirmed with an ESAL-Based pavement design according to the AASHTO or the Portland Cement Association methods.

A rigid pavement was selected as the most secure option, made either of Portland Cement Concrete (PCC) or a hybrid profile section of using the PCC as a subbase course and the Hot Mix Asphalt (HMA) as the base – binder – top courses.

The conventional thickness of the concrete slab is considered indicatively 400 mm (15.75 in)> 8.85 in (minimum requirement for PCC), which means approximately 1.78 times greater than least required according to NYSDOT.

The slab is suggested to be reinforced with tension and distribution steel bars which are only indicatively shown in Figure 3 1 since further calculations need to be done.

If HMA is decided to be used for cost-efficiency, further analysis shall be performed to ensure infrastructure's bearing capacity. Additionally, more criteria and requirements shall be met for the HMA mix design.

The depth of the cables infrastructure underneath the surface is indicatively selected to be at approx. 940 mm (37 in), as close as possible to the typical utilities' depth and shallow enough for thermal efficiency between circuits. An accurate decision on the depth could be possible after a full survey and mapping of the utilities once the cable route is selected.

As mentioned above, the overall width of the installation is 5,375 mm (17.6 ft). A highway single lane, providing enough space for bicyclists/motorists would be expected to be at the minimum between 13-15 ft.

As it is acknowledged that the cables depth could be at shallow depth depending on the implementation of the duct bank that is chosen. Pre-cast concrete has been considered for this concept. The concrete shall be reinforced with steel mesh and of high cement density to ensure thermal resistivity. The dimensions for each duct bank are 650 (25.6 in) mm x 750 mm (29.5 in).

Their depth is determined by the overall and the pavement depth and their width from the required clearance between the cables. It was assumed that a cover of 10 cm (3.9 in) between the ducts and the bottom and lateral edges of the bank is sufficient to protect each circuit.

Following the determination of the basic dimensions, the air gaps between circuits derived to be 175mm (6.89 in). On the bottom of the profile a lean cast in place concrete layer of 50 mm (1.97 in) will be laid to facilitate the whole installation.

At an interval 200 m along the onshore cable route (Figure 3 3) a grated section of 300 mm (118.11 in) width is proposed indicatively to allow the air flow to circulate among the circuits (Figure 3 2). The design distance between the grated sections can be modified according to the electrical/cable design needs.

The grates will be laid on reinforced concrete beams (supports), of indicatively 400 mm height (15.75 in) x 300 mm (11.81 in) width through steel section frames.

The grates are expected to be heavy duty products, made of carbon or stainless steel. The grate bars sizing and spacing will be determined as the road design gets finalized.

As the concept design suggests a rigid concrete pavement, expansion joints of 20 mm (0.79 in) at the minimum must be considered along the infrastructure at 25 m (82 ft) to 50 m (164 ft) intervals.

6.3.14 HSE

6.3.14.1 H&S Plan

A Health and Safety management system shall be established and maintained for the Construction and O&M.

The Infrastructure Operator will be responsible through the Contractors deployed, for maintaining a safe working environment, at all worksites whether of a temporary or permanent nature.

A full HSE plan is required and shall include -at the minimum but without limitation- the following aspects:

- Provide safety and lifesaving equipment that follows the applicable Law.
- Provide all reasonable means to control and prevent fires and explosions, injury to personnel and damage to equipment and property.
- Prescribe all personal protective equipment and ensure to be in place and personnel are trained properly.
- Ensure all the necessary scaffolding and work platforms are installed, tested, and certified by competent personnel, prior to use.
- A risk assessment that will be developed for each construction phase including O&M. The risks and Hazards will be identified, recorded, and updated systematically in a risk register throughout the works. All equipment, material and processes shall be a criticality rating for safety, security, environmental impact, operational performance significance, availability for repair, complexity of construction/installation, cost, and schedule.

Specific precautionary measures shall be taken for the onshore section according to each construction phase. A list of potential safety items could include the following:

- Develop construction traffic management plans for each phase of construction, along with traffic management plans for post-construction maintenance and repair at each joint vault access point and likely laydown yard.
- Implement general signage and barricades necessary for promoting safety in and around the construction site. Ensure safe access for pedestrians.
- Develop emergency procedures covering all likely scenarios, and ensure all personnel are trained in those procedures to prevent confusion or delay in an emergency situation.
- Ensure all lifting equipment is fully certified with suitable inspection procedures in place. Develop a lock out/tag out procedure for all work on equipment during excavation and future activities.
- Ensure open and clear communication with local utilities and civil authorities prior to and during all operations, to prevent unexpected conflict or hazard with activities in progress.
- Ensure personnel good communication during cable pulling operation.
- A particular Health and Safety plan shall be performed for the jointing operation. This will provide strict traffic control, enough space for these activities, scaffolding/ladders, a protection tent and security around the joint vaults.

6.3.14.2 H&S Risks

H&S risks associated with the onshore section are typical of that with other onshore utility work in the road:

- Traffic management and site security are two of the key risks associated with this type of work.

- The work must be mindful of working hours and sensitive receptors nearby, and the presence of vehicles and pedestrians.
- As the infrastructure may require wide excavation, risks associated with this include trench wall collapse, and appropriate trench wall shoring measures will need to be considered.
- Excavation near existing utilities needs care – especially around gas and electric utilities. It is possible that some utilities may not be accurately marked or recorded at all on as-built drawings.

7 Cost Assessment

7.1 Introduction

This section covers the cost assessment which compares the DEVEX, CAPEX, OPEX, DECEX, and NPV costs associated with the Concept Case against that of the Base Case.

7.2 Base Case

The Base Case for this study is based off the reference outlined in the basis of design (Task 2). This was followed closely to produce an accurate bottom-up model of each component and service needed to develop, procure, build, operate, and decommission the infrastructure. Each item identified was assigned a price based on various internal and public sources.

A high-level breakdown of the Base Case cost model is included below with the total cost of each sub-category.

7.2.1 DEVEX

Table 7-1 contains the summary of DEVEX for the Base Case. It is assumed that certain elements like land acquisition and rights of way would cost multiple times that of the concept case for onshore routing as separate routes would likely be required. Costs associated with permitting and approvals, feasibility studies will be incrementally higher only, given that this cost is still present for each OSW development with or without the shared infrastructure.

Table 7-1: Summary of DEVEX for the Base Case

Category	Sub-category	Cost (USDk)
Feasibility Studies and Site Assessment	Geotechnical Investigations	900
	Oceanographic Studies	600
	Environmental Impact Assessment (EIA)	1,300
Total Cost		2,800
Permitting and Approvals	Permit Applications and Regulatory Compliance	5,000
	Public Consultation and Stakeholder Engagement	2,100
	Legal and Professional Fees	2,800
Total Cost		9,900
Land Acquisition and Rights-of-Way	Easements and Access Rights	5,400
	Land Surveys and Title Investigations	1,350
Total Cost		6,750
Total DEVEX		19,450

7.2.2 CAPEX

Table 7-2 contains a summary of the CAPEX for the Base Case. It is assumed that offshore trenching is needed for each route, HDD is used for landfall installation, and onshore cable duct banks are utilized.

Table 7-2: Summary of CAPEX for the Base Case

Category	Sub-category	Cost (USDk)
Cable Supply	HVDC Onshore cable supply	36,000
	HVDC Offshore cable supply	25,000
Total Cost		61,000
Onshore Civil Works	-	399,000
Total Cost		399,000
Offshore Civil Works	Offshore cable installation	36,000
	Landfall HDD	187,000
Total Cost		223,000
Total CAPEX		683,000

7.2.3 OPEX

Table 7-3 contains the OPEX assumptions for the Base Case. The OPEX is based on typical inspection operations for an OSW development. Cable repair is assumed to be required twice over each development's lifetime. The total lifetime OPEX costs come from applying these yearly values over the lifetime of the windfarm, which in this case is 30 years.

Table 7-3: Summary of OPEX for the Base Case

Category	Sub-category	Cost (USDk)
Year 1-5 Operations	Onshore inspection	40
	Offshore inspection	1,000
Total Cost		1,040
Annual operations (every year)	Onshore inspection	200
	Offshore inspection	400
Total Cost		600
10 Yearly Operations	Onshore inspection & maintenance	80
	Offshore inspection & maintenance	4,000
Total Cost		4,080
Cable Repair	Onshore cable repair	300
	Offshore cable repair	18,000
Total Cost		18,300

7.2.4 DECEX

Table 7-4 contains the DECEX estimate for the Base Case. It is assumed that each development will leave cables in-situ, which is typical practice.

Table 7-4: Summary of DECEX for the Base Case

Category	Sub-category	Cost (USDk)
Decommissioning Planning and Engineering Studies	Decommissioning Studies and Reports	1,200
	Engineering Design for Decommissioning	1,200
Total Cost		2,400
Total DECEX		2,400

7.2.5 NPV & LCoE

The NPV cashflow and LCoE are shown in Table 7-5 below.

Table 7-5: Base Case NPV and LCoE Values

	Year	Cost USD $	PV USD $
CAPEX + DEVEX Year 1	0	234,150,000	**234,150,000**
CAPEX + DEVEX Year 2	1	234,150,000	**226,231,884**
CAPEX + DEVEX Year 3	2	234,150,000	**218,581,530**
OFW Year 1	3	1,040,000	**938,020**
OFW Year 2	4	1,040,000	**906,300**
OFW Year 3	5	1,040,000	**875,652**
OFW Year 4	6	1,040,000	**846,041**
OFW Year 5	7	1,040,000	**817,431**
OFW Year 6	8	600,000	**455,647**
OFW Year 7	9	600,000	**440,239**
OFW Year 8	10	600,000	**425,351**
OFW Year 9	11	600,000	**410,967**
OFW Year 10	12	22,380,000	**14,810,710**
OFW Year 11	13	600,000	**383,642**

OFW Year 12	14	600,000	**370,669**
OFW Year 13	15	600,000	**358,134**
OFW Year 14	16	600,000	**346,024**
OFW Year 15	17	600,000	**334,322**
OFW Year 16	18	600,000	**323,017**
OFW Year 17	19	600,000	**312,093**
OFW Year 18	20	600,000	**301,540**
OFW Year 19	21	600,000	**291,343**
OFW Year 20	22	22,380,000	**10,499,591**
OFW Year 21	23	600,000	**271,971**
OFW Year 22	24	600,000	**262,774**
OFW Year 23	25	600,000	**253,888**
OFW Year 24	26	600,000	**245,303**
OFW Year 25	27	600,000	**237,007**
OFW Year 26	28	600,000	**228,993**
OFW Year 27	29	600,000	**221,249**
OFW Year 28	30	600,000	**213,767**
OFW Year 29	31	600,000	**206,538**
OFW Year 30	32	4,080,000	**1,356,966**
DECEX	33	2,400,000	**771,223**
Net Present NPV			**717,679,827**
LCOE			**0.69**

7.3 Concept Case

The Concept Case for this study is based on Task 1 and Task 2. The Concept Case has been estimated with a bottom-up model with influence from engagement with stakeholders and the study team's wider experience in the industry. Each item identified was assigned a price based on various internal and public sources.

A high-level breakdown of the Concept Case cost model is included below with the total cost of each sub-category.

7.3.6 DEVEX

Table 7-6 contains the summary of DEVEX for the Concept Case. It is assumed that some savings would be seen versus the Base Case associated with a reduction in cable route planning activities.

Table 7-6: Summary of DEVEX for the Concept Case

Category	Sub-category	Cost (USDk)
Feasibility Studies and Site Assessment	Geotechnical Investigations	500
	Oceanographic Studies	400
	Environmental Impact Assessment (EIA)	535
Total Cost		1,435
Permitting and Approvals	Permit Applications and Regulatory Compliance	2,500
	Public Consultation and Stakeholder Engagement	1,200
	Legal and Professional Fees	1,700
Total Cost		5,400
Land Acquisition and Rights-of-Way	Easements and Access Rights	1,000
	Land Surveys and Title Investigations	200
Total Cost		1,200
Total DEVEX		8,035

7.3.7 CAPEX

Table 7-7 contains the summary of CAPEX for the Concept Case. Additional cost items can be seen over the Base Case associated with the offshore civil works associated with the shared infrastructure. The onshore civils works are higher per km due to works over a larger width in the roadway. The cable costs are assumed to be higher than the Base Case, requiring larger cable sizes to accommodate the design of the infrastructure.

Table 7-7: Summary of CAPEX for the Concept Case

Category	Sub-category	Cost (USDk)
HVDC Onshore cable supply	HVDC Onshore cable supply	54,050
HVDC Offshore cable supply	HVDC Offshore cable supply	36,800
Total Cost		90,850
Onshore Civil Works	Manufacture	69,200
	Site Preparation	6,600
	Transportation	3,008
	Construction	3,500
	Cable Installation	100

Total Cost		82,408
Offshore Civil Works	Manufacture	33,204
	Site Preparation	7,000
	Transportation	17,227
	Construction	466,000
	Cable Installation	3,000
Total Cost		526,431
Total CAPEX		699,689

7.3.8 OPEX

Table 7-8 contains the OPEX for the Concept Case. The OPEX in this case has additional inspection and maintenance required for the infrastructure itself. Cable repair is assumed to be required twice over each development's lifetime. The total lifetime OPEX costs come from applying these yearly values over the lifetime of the windfarm, which in this case is 30 years.

Table 7-8: Summary of OPEX for the Concept Case

Category	Sub-category	Cost (USDk)
Year 1-5 Operations	Onshore inspection	10
	Offshore inspection	200
Total Cost		210
Annual operations (every year)	Onshore inspection	40
	Offshore inspection	70
Total Cost		110
10 Yearly Operations	Onshore inspection & maintenance	10
	Offshore inspection & maintenance	3,000
Total Cost		3,010
Cable Repair	Onshore cable repair	70
	Offshore cable repair	19,000
Total Cost		19,070
Total OPEX		22,400

7.3.9 DECEX

Table 7-9 contains the DECEX estimate for the Concept Case. As with the base case, it is assumed that each development will leave cables in-situ, which is typical practice. There is synergy here as one set of plans needs to be developed for these routes, instead of six individual cases.

Table 7-9: Summary of DECEX for the Concept Case

Category	Sub-category	Cost (USDk)
Decommissioning Planning and Engineering Studies	Decommissioning Studies and Reports	200
	Engineering Design for Decommissioning	200
Total Cost		400
Total DECEX		400

7.3.10 NPV & LCoE

The NPV cashflow and LCoE are shown in Table 7-10.

Table 7-10: Concept Case NPV and LCoE Values

	Year	Cost USD $	PV USD $
CAPEX + DEVEX Year 1	0	235,908,000	**235,908,000**
CAPEX + DEVEX Year 2	1	235,908,000	**227,930,435**
CAPEX + DEVEX Year 3	2	235,908,000	**220,222,642**
OFW Year 1	3	210,000	**189,408**
OFW Year 2	4	210,000	**183,003**
OFW Year 3	5	210,000	**176,814**
OFW Year 4	6	210,000	**170,835**
OFW Year 5	7	210,000	**165,058**
OFW Year 6	8	110,000	**83,535**
OFW Year 7	9	110,000	**80,710**
OFW Year 8	10	110,000	**77,981**
OFW Year 9	11	110,000	**75,344**
OFW Year 10	12	22,080,000	**14,612,175**
OFW Year 11	13	110,000	**70,334**
OFW Year 12	14	110,000	**67,956**
OFW Year 13	15	110,000	**65,658**
OFW Year 14	16	110,000	**63,438**
OFW Year 15	17	110,000	**61,292**
OFW Year 16	18	110,000	**59,220**
OFW Year 17	19	110,000	**57,217**
OFW Year 18	20	110,000	**55,282**
OFW Year 19	21	110,000	**53,413**
OFW Year 20	22	22,080,000	**10,358,846**
OFW Year 21	23	110,000	**49,861**

OFW Year 22	24	110,000	**48,175**
OFW Year 23	25	110,000	**46,546**
OFW Year 24	26	110,000	**44,972**
OFW Year 25	27	110,000	**43,451**
OFW Year 26	28	110,000	**41,982**
OFW Year 27	29	110,000	**40,562**
OFW Year 28	30	110,000	**39,191**
OFW Year 29	31	110,000	**37,865**
OFW Year 30	32	3,010,000	**1,001,095**
DECEX	33	400,000	**128,537**
Net Present NPV			**712,310,837**
LCOE			**0.68**

7.4 Discussion

There are a few other considerations that could alter the cost or the value of the infrastructure. These are hidden costs/values that are difficult to capture within the cost model or assumptions that were made that, if adjusted, could change the cost.

7.4.11 General

The results of the cost model show that with this concept design, the cost is not significantly different than the Base Case in terms of lifetime NPV, assuming 6 OSW farms. There are other considerations to be taken account of as discussed in the report, however it is unclear if there would be cost savings or not if the concept design was to be used. The LCoE is only slightly different between the two cases, differing only by one cent.

The main places where cost savings can be found in the concept design are in the DEVEX. For the concept design, there was an estimated $11.5 million savings for DEVEX. However, the CAPEX for the concept design was $16.5 million more expensive than the Base Case. As discussed previously, the CAPEX of the onshore route is significantly less for the Concept Case than the Base Case, but the CAPEX of the offshore infrastructure is significantly more for the Concept Case than the Base Case.

The costs that affected NPV for both cases were the OPEX. The total OPEX costs were slightly lower for the concept design, which spread out over the 30-year lifetime of the wind farm developments made a difference of about $5 million.

The difference in cost for the lifetime of the two wind farms was only about $5 million, which is insignificant considering the magnitude of the costs and the amount of uncertainty in the costs. There are, of course, many considerations that should be taken into account that could substantially change the cost of either case. This cost study shows that with a generic Base Case and the first concept case, the price is comparable. However, with different variations in the concept case, prices could change substantially. Ultimately, if this infrastructure is to be progressed, the next step would be to undertake a more in-depth cost study supported by greater engineering design, site specific information, and feedback from contractors.

7.4.12 Sea defense refurbishment

One consideration to be made about the cost of the concept design is that the existing sea defense revetment along the harbor would be completely upgraded with the completion of this infrastructure. Since the offshore portion of the concept design would build infrastructure along the shoreline to house the cables, the entire revetment would be upgraded through deconstruction and rebuild. This is estimated to cost about $5-6 million per km or about $22 million for the 4 km route. In the Concept Case this upgrade is completely included within the offshore civil works that would be done to build the offshore cable infrastructure. This added value is not captured within the cost model but may be taken into consideration.

7.4.13 Harbor disturbance

The construction of the shared landfall infrastructure in the nearshore area is expected to have some disruption to the harbor, but this likely can be managed and minimized compared to cable installation directly through the harbor in the Base Case. In the base case, with six offshore wind developments, economic disruption to harbor activity would be expected to be significant It is expected that the shared cable infrastructure could offer significant economic savings in terms of disruption to harbor activities. More discussion is provided on this in Section 8.7.

7.4.14 Length of routes

Another consideration to be made is how the length of the infrastructure could significantly affect cost-benefit conclusions. As discussed in the assumptions section, this study made assumptions about the length of the infrastructure based on the example reference location used in the study. It was assumed that the offshore section is 4 km, the landfall section is 1 km, and the onshore route is 10 km. However, if the lengths of these sections were changed, the cost comparison could significantly change.

The Concept Case has cost advantages over the Base Case for the onshore shared infrastructure, whereas it is cost disadvantage for the offshore shared infrastructure. This is because the onshore infrastructure reduces 6 individual construction operations (in the Base Case) into a single construction operation (in the Concept Case) which is similar but incrementally more complex and larger than the Base Case. This leads to substation cost savings.

The offshore infrastructure requires a new type of construction not common for OSW developments. For the reference location used in this study, it solves a specific issue associated with offshore route constraints in New York City. Because of this, it generally adds cost over the

Base Case, under the assumption the Base Case is feasible in New York and costs remain generally in line with what is seen in the industry.

Therefore, increasing the onshore route length and decreasing the offshore route length will make the Concept Case more attractive in terms of costs, and vice versa.

The proposal of offshore infrastructure for the Concept Case is rather unusual compared to a “generic” landfall scenario, where presumably cables from multiple wind farm developments would approach a central landfall infrastructure. In this situation the Concept Case costs would not be so much different from the Base Case as they are for the reference location in this study.

7.4.15 Number of OSW developments

The reference used for this study is that six OSW developments would utilize the infrastructure. If the number of OSW developments is less, there would be a reduction in the cost of the Concept Case, but it is expected the cost decrease would not be in proportion to the reduction of OSW developments. This means the fewer the number of OSW developments using the infrastructure, the less favorable the cost will be for the Concept Case.

8 Concept Evaluation

8.1 Introduction

This section presents the qualitative assessment of the study. This aims to bring together all the content from prior sections to provide a qualitative evaluation of the Concept Case, the associated technical and commercial attributes, risks, challenges, opportunities, advantages, and disadvantages. The topics discussed are:

Table 8-1: Concept Evaluation Criteria

Concept	Description
Cost efficiency of the concept compared to Base and Coordinated Cases	We will focus on drawing key conclusions regarding the CAPEX, DEVEX and overall LCOE of the project. Any cost efficiencies identified at this stage will be weighed up against risks identified throughout Task 2 and 3 and the regulatory implications discussed in Task 2.
Construction requirements & cable installation	We will prepare a top-level construction methodology to suit the selected dimensions of the conduit(s) and burial depth. This will address the following aspects of the construction operation. The impact of the concept on ease of cable installation will also be evaluated. This will cover both onshore and offshore operations.
Electrical redundancy	Redundancy issues and technical requirements from NY-ISO will be discussed including how the design performs in terms of redundancy and events that could cause failure, what features of the design have been implemented to ensure it is compliant with requirements.
Planning & development	A brief description of planning and development will be provided to start a framework that can be built on in the future.
Permitting framework	Based on the specific site identified for the shared cable tunnel and the initial concept design, we will use the constraints map developed as part of this task to develop a high-level permit matrix identifying the jurisdictional agencies and anticipated permits and approvals for the cable landing site and shared cable tunnel.
Environmental Impact	Based on the environmental constraints map put together in Task 2, we will describe the likely and potential environmental and social impacts, based on the construction method and the concept design itself. Issues and impact with nearby receptors will be identified.
Power Systems Regulatory Framework and Ownership Model	There are a range of regulatory and policy considerations associated with a shared infrastructure that warrant evaluation including: (1) ownership; (2) cost recovery; and (3) access rights and provisions. The study will address these considerations in an iterative fashion working with NYSERDA, utility stakeholders and prospective offshore transmission developers utilizing the stakeholder team that we determine to be appropriate in the project kickoff meeting. Also in this section, ownership models will be discussed. Following initial discussions with stakeholders and developers, proposals will be made for different ownership models citing projects of a similar nature with private and public funding.
Risks and Opportunities	This part of the study will identify the risks associated with the coordinated landfall concept including technical, commercial, environmental, and project risks. The Base Case will be used to

	benchmark the risks and identify any additional risks associated with the concept.
Recommendations for further work	The study is conceptual in nature and will likely identify areas of further investigation or improvements. A preliminary list will be submitted to NYSERDA for discussion.

8.2 Cost Efficiency

The Base Case and Concept Case have very similar costs when put through an NPV calculation. The two costs differ by only about $5 million, the Concept Case being slightly cheaper. Just based on this, it is unclear whether one case would be more cost efficient than the other.

There are many considerations that should be taken into account that could substantially change the cost of either case. One consideration to be made about the cost of the concept design is that the existing revetment along the harbor would be completely upgraded with the completion of this infrastructure. Since the offshore portion of the concept design would build infrastructure along the shoreline to house the cables, the entire revetment would be upgraded. If this revetment upgrade was factored into the final costs of both cases, it would add another $15-20 million to the Base Case. This would begin to make the Concept Case much cheaper and more efficient than the Base Case. Another consideration to be made is how the length of the infrastructure could significantly change costs. There were set lengths for offshore, onshore, and landfall cable routes that were decided within the concept design, however, if the lengths of these sections were changed, the cost model could significantly change. If the chosen landfall location was different, the offshore length could change, or if the onshore cable route was made longer, it could make the Concept Case CAPEX much cheaper than the Base Case CAPEX. This would also make the cost much more efficient. These considerations are discussed more in depth in the cost model section.

8.3 Construction Requirements

The concept design construction requirements are described in the Basis of Design in Section 4.6. The construction requirements are described in Section 6.2.2 and Section 6.3.9.

8.4 Cable Installation

The concept design cable installation requirements are described in Section 4.7. The requirements for cable installation are described in Section 6.2.3 and Section 6.3.10.

8.5 Electrical Redundancy

The novel technology case for the shared landfall cable has brought concerns about electrical redundancy and ability to withstand potential outage events. Transmission systems have a single contingency limit defined which is the amount of power that can be lost in the event of an outage event. In the NYISO region this limit is 1,320 MW in Zone J. This means that if a circuit fails, the most amount of power lost is 1,320 MW. The proposed shared landfall cable infrastructure design would accommodate 7-8 GW of power – 7.2 GW for 1.2 GW circuits and 7.92 GW for 1.32 GW circuits.

Electrical redundancy involves purposefully replicating crucial elements or operations within a system to enhance its reliability. This normally requires duplication of assets and physical separation of those assets.

The most similar existing example resembling this infrastructure is overhead line towers. Such towers typically accommodate multiple circuits. As such, certain system operators may specify power carrying capacity limits for the event a tower is damaged and affects all circuits which use it, so the damage to a tower affecting multiple circuits is considered a single potential event.

The shared landfall cable infrastructure has been designed to increase the protection of the system and minimize the chance of failure. Steps have been taken to create resilience within the concept design. For the offshore design, each circuit is within a secured cable chamber which provides physical security and protection. Additionally, the a-jacks and gabion baskets act as additional armoring. For the onshore design, the circuits are encapsulated in ducts in concrete. Airgaps are proposed between concrete banks for thermal reasons primarily but also acts as a physical barrier. It may be possible to further enhance physical security and protection of the concept design such as with steel plating, though this would add cost.

The design means that there is enough physical separation where one circuit should not affect another, such as if there should be a fire in one of the cable chambers or cable ducts. Joint vaults have not been addressed in detail in this study, but it is assumed each would be physically separate as well, and so the same applies. The physical protection on top of the circuits also provides reasonable safeguards against threats such as vandalism, heavy loads, and similar hazards. As the offshore infrastructure is built up, it is not possible for vessel traffic to traverse over top of the cables and the threat of anchoring is reduced. The main area of vulnerability will be where the submarine cable circuits collect near the entrance to the offshore concept design; this is where protection is minimal. However, if the cables were routed in the conventional way without the concept design, they would be laid through NY harbor through the Narrows in vicinity to one another; the situation and risks to the cables would be similar as the cable entrance of the concept design.

Through research and discussions with stakeholders, we could not find any prescribed limitations or restrictions that would affect the concept design. NERC CIP-014-1 addresses physical security for transmission facilities which seems to apply to substations only, and not cable route infrastructure.

This infrastructure would accommodate multiple GWs in one general location, which is unavoidable as it is at the heart of the concept's premise. It is of course possible that large, catastrophic scale events could damage, and outage multiple circuits housed in the concept design, though other existing critical infrastructure such as substations, utilities buried in roads, etc. are similarly susceptible. A major substation outage could affect more than 1,320 MW. An argument could be made to treat landfall and onshore cable infrastructure with the same conditions that apply to major onshore supergrid substations.

8.6 Planning and Development

The planning of the concept would require coordination with wind farm developers. The development of the concept would need to coincide with the cable installation, testing, and commissioning of all wind farms using the infrastructure.

To plan, design, and develop such infrastructure, the number of wind farm cables to accommodate needs to be defined early. There will be a desire to confirm this as best as possible early in the infrastructure design process, though it may be difficult to get developer commitments, as wind farm developers may be uncomfortable with not being in control of a section of the planned cable route without prior guarantees or direction by a public entity like NYSERDA. Wind farm developers may also choose to permit alternative routes in parallel to hedge this risk.

Ideally the planning and permitting process of the concept infrastructure would begin several years before wind farm developers, as demonstrating progress may provide comfort to developers that the solution is viable. To do so, it may require developing the concept at risk of stranded assets, which means there would need to be support through a public entity (this is discussed further in Section 8.9.)

8.7 Permitting Framework

The analysis that follows is a qualitative assessment of the primary risks and benefits from a permitting (including both permitting timing and permitting cost efficiency) for cable landing structured as a series of individual wind farm developments (i.e., up to six separate landfalls) as compared to a shared infrastructure development (i.e., up to six collocated cables).

8.7.1 Permitting – Timing

Overall permit acquisition for shared infrastructure would be the responsibility of one party, which would acquire all permits for each wind farm's cable approach and landing(s) as compared to six sperate permitting processes. Under this scenario, individual wind farms could exclude the shared infrastructure from their permitting envelope. While potentially more streamlined, under the shared approach, the central party should be prepared to justify choosing this approach with the permitting agencies, as it is not structured as and would not be considered a "full and complete project" by regulators. For example, if the remaining wind farm infrastructure (e.g., turbines) were not permitted and installed, the shared cable landing would provide no service. With no confirmed end users, the shared infrastructure would not be permittable. Therefore, the applicant would likely need to document anticipated construction activities and timelines for the remaining OSW infrastructure as part of this process. Note, similar approaches have been utilized for submarine fiber optic cable landings across the U.S. with success.

Collocating wind farm cable elements could result in significant time savings, as related construction and installation activities are able to be consolidated into fewer events (e.g., one mobilization and demobilization effort, one marine route survey, one set of agency and stakeholder meetings, fewer public hearings). Under the centralized infrastructure strategy, there would likely only be one set of construction contractors, who could schedule the construction for efficiency. Accommodating timing restrictions could be less complicated for this reason. The construction process could be streamlined and made more efficient, which could help to reduce the timeline for the completion of the construction.

However, it is important to note that collocating would entail a larger infrastructure footprint in comparison to that for an individual wind farm's cables, which could extend the permitting timeline for those components. For example, a single cable approach and landing would likely be issued a nationwide permit (NWP) #57 from USACE, as it is anticipated to have relatively minimal individual and cumulative adverse effects on the environment and result in no more than ½ acre of permanent impacts to waters of the U.S. Shared infrastructure, however, may exceed the NWP #57 threshold, and be issued an Individual Permit (IP). If so, then an IP requires a more detailed and comprehensive review, while an NWP provides a streamlined and simplified permit process. IPs may require extensive mitigation measures to minimize adverse impacts on the environment, which would result in additional costs and time for the project.

Shared infrastructure, although anticipated to result in time savings, could introduce risk into OSW developers' permitting schedules. The developers would have less control over their project timelines, as they would not be permitting the infrastructure but would need to utilize it to come to market. Careful planning would be required to coordinate all parties, with significant time window buffers to account for any delays. Additionally, the process of coordinating and developing a shared landing could be more complex than developing separate landings, as multiple stakeholders (e.g., OSW developers) may be involved in the planning process.

Something to be aware of when seeking out permits for work in this area is the consideration of economic activities within the harbor. The NY harbor is one of the busiest in the country, and there are constantly vessels traveling through the area. Any permits that would be issued by a regulatory agency would most likely want the applicant to consider the vessel traffic in this area and the economic activities that are related to the vessels. The installation of six wind developments would have significant impact on economic activity in the harbor.

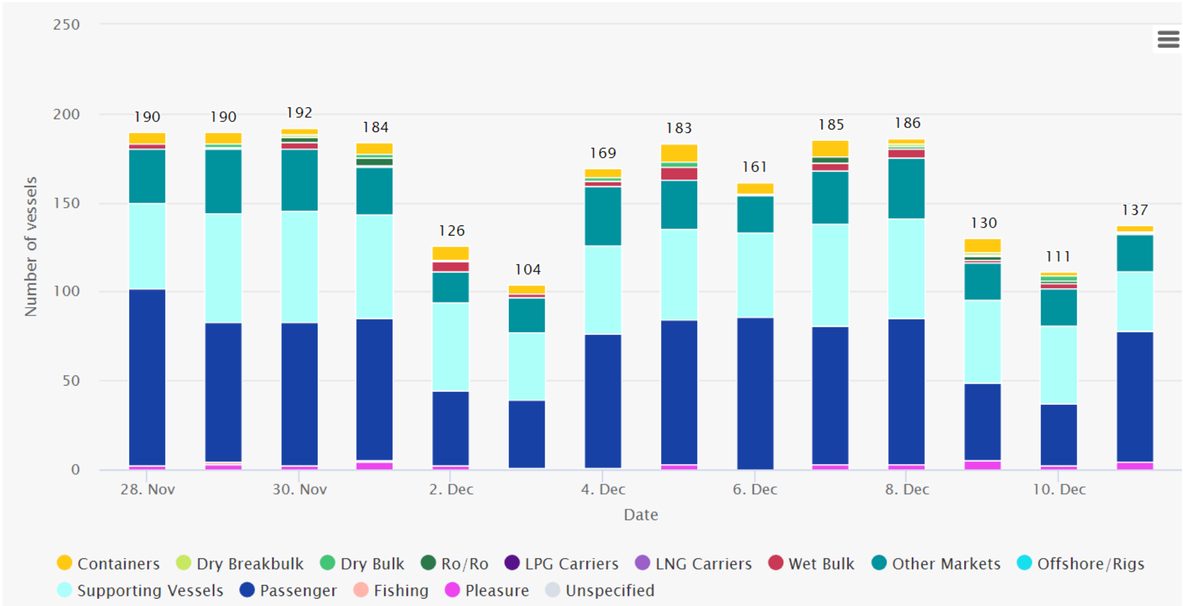
The construction of the shared landfall infrastructure in the nearshore area is expected to have some disruption to the harbor, but this likely can be managed and minimized compared to cable installation directly through the harbor in the Base Case. It is expected that this could offer significant economic savings in terms of disruption to harbor activities.

Minimization of the disruption surrounding timing of construction/installation is the best management practice that an applicant can present to the regulatory agencies.

It is probably impossible to fully avoid disruption to the harbor. However, recognizing the "ebb and flows" of commercial vessel traffic in an area and targeting installation (weather-dependent) to coincide with less vessel traffic flow would likely provide a cost benefit. Anytime there is less installation vessel down time, the better.

Below is a graph that shows the vessel traffic, including the number and type of vessel, in the New York Port from November 28th, 2023 to December 11th, 2023. [7] This and historic data from the Port can show when the lowest traffic times are in the port.

Figure 8-1: Vessel Traffic in the New York Port, 11/28/23-12/11/23



8.7.2 Cost Efficiency

Under the collocation approach, the project could experience substantial cost savings through consolidated project activities (e.g., mobilization/demobilization, marine route survey). Fewer contracts for construction activities (e.g., Protected Species Observer [PSO]) and permitting efforts would also need to be negotiated. Consolidating multiple projects into one could lead to a reduction in overhead costs, such as administration, supervision, and management costs, as these functions can be streamlined and centralized. Any mandated mitigation efforts could also be completed in this manner.

By utilizing shared infrastructure, permit acquisition costs could be drastically reduced. For example, one suite of permit submittal and application fees would apply, rather than paying for each individual project separately and incurring these costs up to six times. Furthermore, the number of easements, assessed at $12.74 per linear foot in New York, for a set of cables may be lower for collocated cables than for up to six individual routes. Cables not in a consolidated corridor, however, may incur separate easements, similar to installing cables individually. One set of crossing agreements could also be warranted, resulting in potential cost savings for the project.

Federal and state agencies may require potentially costly terms, such as a post-installation monitoring plan and decommissioning plan, which could be developed and implemented in concert under the shared infrastructure approach. Agencies may also require a commitment for replacement/compensation of damaged or lost fishing gear that becomes entangled in the cable system. By collocating the cables, the risk of entanglement is reduced, therefore reducing the risk of having to compensate fishers.

8.8 Environmental Impact

The analysis that follows is a qualitative assessment of the primary risks and benefits from an environmental impact standpoint for a cable landing project structured as a series of individual projects (i.e., up to six separate landfalls) as compared to a shared infrastructure project (i.e., up to six collocated cables).

It would likely be very challenging for multiple independent projects to install cables through the Narrows, as this waterway is highly constrained with heavy vessel traffic and anchoring, as well as congestion. The collocation of cables and landing infrastructure provides greater opportunity for effective routing that avoids impacting sensitive resources (e.g., eelgrass), protected areas (e.g., marine protected areas [MPAs]), maritime activities (e.g., prime fishing areas), and both natural and manmade obstructions (e.g., submarine cables). Marine spatial planning would be significantly simplified through the shared infrastructure approach, as one ideal route could be developed rather than up to six separate and ultimately subpar routes and landings. Impacts on land could also be lessened by consolidating the landings, with a greater ability to avoid ecologically and culturally significant areas (e.g., National Register of Historic Places [NRHP] locations, nesting sites, etc.). It is also important to note that there are a substantial number of Environmental Justice communities (i.e., census block groups that are composed of populations that have a higher percentage of minority populations or low-income populations or both) near the conceptual landfall location and along the notional onshore routes. EJ concerns could potentially be lessened under the shared infrastructure approach as fewer EJ communities would be exposed to potentially negative project impacts as compared to the individual project approach that could impact more individual EJ populations, while also maintaining the energy – related project benefits.

With respect to the specific area being assessed in Brooklyn, it should be noted that there are sensitive resources and protected areas in the vicinity that, if traversed, could complicate project development and extend the permitting timeline. For example, the Gateway National Recreation Area is a federal Marine Protected Area (MPA) in and near the entrance of the Narrows that, if routed through, may subject the project to additional permits, permits conditions, and restrictions. The regulations governing MPAs vary depending on the specific MPA and the agencies responsible for its management. Note, however, that routing around these areas is easily achievable. There is also Habitat Area of Particular Concern (HAPC) for summer flounder in the project area, which would require additional coordination with NOAA Fisheries to determine methods of minimizing impacts to protected species and habitat. The presence of ocean disposal sites, wrecks, submarine cables, moorings, and other manmade obstructions are extensive in the project area, so careful siting of project infrastructure will be crucial.

While impacts would be reduced in the shared infrastructure scenario, one collocated project would have a larger project footprint than a single individual project. Therefore, as mentioned above, certain permit impact thresholds may be exceeded (e.g., USACE NWP vs IP). However, by having a shared landing, the overall environmental impact could be decreased, as the physical footprint of the landing and the associated infrastructure (e.g., BMHs) would be reduced when compared to six individual landings. Another potential downside to collocating cables is that the shared cable corridor would be larger than an individual project's corridor, thereby restricting the maneuverability and flexibility of route selection.

Overall, collocating could streamline planning, permitting, outreach, and construction processes, resulting in potentially significant time and cost savings. A summary is provided in Table 8-2.

Table 8-2: Shared Infrastructure Approach Pros and Cons

	Pros	Cons
Timing	• Time savings due to consolidated project activities • Easier accommodation of timing restrictions	• Coordination with developers could be more complex and time consuming. • Potentially longer permitting timeline (e.g., NWP vs IP) when comparing combined project to a single individual project. • Could introduce risk into developers' permitting schedules.

Cost Efficiency	• Cost savings due to:
	  ○ Consolidated project activities and reduction in overhead costs
	  ○ Reduced permitting effort
	  ○ Lower application fees
	  ○ Lower annual costs (e.g., easements)
	  ○ One set of crossing agreements
	  ○ Lowered risk of expensive post-installation requirements (e.g., entangled fishing gear, several post-installation monitoring activities)
		• Cables not in a consolidated corridor may incur separate easements, similar to installing cables individually

Impacts	• (Assumed) smaller overall footprint in marine environment and on land in comparison to sum of all individual projects • Greater ability to avoid sensitive resources, infrastructure, and obstructions • Less impacts to EJ sensitive communities	• Larger cable corridor could have less flexible routing than individual cables

8.9 Power Systems Regulatory Framework and Ownership Model

8.9.3 Overview

There are a range of regulatory and policy considerations associated with common landfall that warrant evaluation, including:

- How would development rights be allocated

- Who would own the facilities
- How would cost recovery for the facilities be established
- What are appropriate access rights for OSW developers

As demonstrated below, many of the decisions with respect to each of these considerations are interrelated. In addition, it is important to recognize that common landfall infrastructure would be to a large degree appurtenances where their treatment is governed by the existing market structure, including the approach to transmission development, and various regulatory considerations. For example, it would be inappropriate to conduct a competitive solicitation for the right to develop common landfall infrastructure if generator lead lines were solely being used to connect to the onshore grid since under such an approach the risk associated with ensuring that the infrastructure was fully utilized would be very high unless the development risk is backed by a governmental entity or there were a requirement to utilize these facilities, likely leading to stranded investment.[1] Conversely, if a coordinated offshore transmission grid was to be developed, then the framework for establishing this offshore transmission grid would need to be considered.

While the concept design focuses on a New York City site, the discussion of regulatory considerations of common landfalls has a broader geographic scope. Given these considerations we frame our discussion of these different aspects of regulatory considerations in terms of different transmission development models. Under “utility led” and “third-party led” common landfall infrastructure development models, the responsibility for development and ownership is clear.[2] However, both these models have outstanding questions regarding cost recovery and access rights.

8.9.4 Development Rights for Shared Cable Infrastructure

The establishment of development rights for share landfall and cable route infrastructure for OSW will be influenced by the specific jurisdiction’s market structure as well as the party proposing the common landfall.[3] Anyone can propose or initiate work on the consideration of share landfall and cable route infrastructure including policymakers, regional transmission organizations, transmission owners, OSW developers, non-governmental organizations, or third-party

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[1] Clearly, under such an environment (i.e., where OSW developers are free to develop generator lead lines) there’s less apparent value associated with being awarded the right to develop share landfall and cable route infrastructure.

[2] Under the utility led model development is under the aegis of the utility and can benefit from its access to local infrastructure. Whereas third-party led development is undertaken by independent transmission developers. A third alternative development model is OSW developer led common landfall development. This model is only likely to be employed when the developers are mandated to undertake such investment. As discussed further below, New Jersey considered mandating such an approach (i.e., requiring developers to build common landfall infrastructure that would be used by subsequent OSW projects in its 2023 RFP.

[3] Development rights refer to the responsibility for the development of transmission infrastructure.

developers. While there often is a tie between the party that initiates discussion of share landfall and cable route infrastructure and the party that seeks to develop it, there does not need to be.

There are three types of parties that may propose share landfall and cable route infrastructure for OSW development: (1) the regional transmission organization (RTO) or a public agency such as the New York State Energy Research & Development Authority or Massachusetts Department of Energy Resources; (2) the local transmission owner (TO); or (3) a third-party developer. Under the RTO/Public Agency model project construction is generally assigned to another party, i.e., the local TO or a third-party developer.

- RTO Development Rights: With responsibility to ensure the grid is operated reliably, RTOs are generally more reactive with respect to transmission project development, focusing primarily on reliability solutions or when directed to do so by others, such as New York Public Service Commission authorizing NYISO to undertake a project under the Public Policy Transmission Planning Process. Under FERC Order 1000 RTOs are generally responsible for implementing competitive transmission development processes. Under this framework it would be up to RTOs to assign the development rights for common landfalls. Although RTOs would be unlikely to lead the development of share landfall and cable route infrastructure, they are likely to have important input given the importance of selecting a landfall location that is close to a point of interconnection (POI) that can accommodate the delivered energy.

- TO Development Rights: the local TO may be best placed to develop common landfall infrastructure, as a strategy to reduce the environmental impacts of cable landings as well as the cumulative costs of such landings over time. While the TO is unlikely to be focused on minimizing the cumulative cost of OSW connections, it is likely to valuable insights on how to do so.[4] Clearly, a critical consideration will be the scope of the TO's service territory compared to the potentially broader geographic scope of where the OSW generation is likely to be landed. Furthermore, the TO may be better positioned to finance and recover costs for this investment as a regulated transmission asset where the investment is made for the future benefit of customers. For congested urban areas they may have access to desirable real estate and transmission corridors that will facilitate permitting and overall project development process. As discussed further below, the ability and willingness of TOs to pursue such projects would be influenced by the regulatory environment in which they operate.

- Third Party Development Rights: third parties' ability to develop share landfall and cable route infrastructure can be complicated by FERC Orders 888 and 889 that require TOs

[4] Policymakers are most likely to be most focused on minimizing the cumulative cost of these landings as well as the cost of interconnecting all of the OSW to the onshore grid.

and RTOs to treat all parties on a non-discriminatory basis.[5] This could impair the ability of such third parties to identify the most desirable locations for common landfall infrastructure since a critical issue will be determining preferred POIs that have sufficient available takeaway capacity or can be cost-effectively upgraded. However, this challenge can likely be overcome by providing information on POIs to all parties that have Critical Energy/Electrical Infrastructure Information (CEII) clearance, reducing the need for third parties to coordinate with the local TO or RTO to identify desirable landfall locations. Common landfall infrastructure located near existing generation facilities that are being repurposed as major POIs may provide the best opportunity for third parties (e.g., Rise Light & Power's repurposing of Ravenswood), with development rights accompanied by known takeaway capacity at such sites.

The ability and willingness of TOs to pursue such projects will be influenced by the regulatory environment in which they operate. In many restructured jurisdictions (e.g., the US Northeast) where TOs are generally just wires owners,[6] undertaking such a proactive investment project is outside of the scope of traditional onshore transmission investments that typically involve little to no risk. For example, the Brooklyn Clean Energy Hub, which has been proposed by Con Edison, is being developed by the utility's competitive transmission development affiliate, not its regulated transmission operations.

The TO would only be willing to undertake such an investment if it were guaranteed a return on the entire investment. In many jurisdictions a "used and useful" investment test is employed whereby the investment must be demonstrated to be physically useful before its costs can be recovered from ratepayers. Under such a standard a regulator might find that if only one-third of the common landfall is being used that the entire investment is not "used and useful" and as a result its entire costs cannot be recovered from ratepayers. This issue will need to be resolved if TOs are to make such investments. Without such regulatory certainty the returns that these TOs receive do not compensate them for taking such risk. However, in some instances they have competitive transmission affiliates that are better positioned to take on such risks or alternatively the TOs can work in partnership with states to de-risk the investment.[7]

8.9.5 Ownership of Shared Cable Infrastructure

Decisions made with respect to development rights are likely to determine infrastructure ownership. Cost recovery considerations may influence whether a competitive process to award

[5] Because the common landfall infrastructure does not contain any electrical assets it is unlikely to be subject to these or subsequent FERC orders that provide for open access for transmission facilities. However, a legal opinion on this issue should be obtained.

[6] Restructured power markets are where different entities generate power than transmit and distribute power, allowing for greater competition in power generation. This includes much of the US Northeast.

[7] National Grid's Greener Grid Brayton Point project and Eversource's Southeastern Massachusetts Clean Grid project's that would interconnect up to 3,600 MW of OSW to the ISO-New England grid in Southeastern Massachusetts are examples of such projects.

development and ownership rights is utilized, or whether development rights are assigned to an incumbent utility where such infrastructure development would be consistent with its mandate.

Ownership and operation of the shared infrastructure would likely fall to either the TO or a third-party developer. RTOs would not own the common landfall as they do not own transmission assets. OSW developers are also unlikely to develop or own share landfall and cable route infrastructure because they have little interest in facilitating access to transmission facilities to competitors. Finally, public entities that have a procurement role such as NYSERDA typically do not own such assets.

- TO Assigned Ownership: The incumbent utility (e.g., ConEd or NYPA) could be assigned ownership of the shared cable assets. This is simpler than administering a competitive process to identify the developer and owner. However, it does not provide the same opportunities for innovative designs or cost containment etc. as a competitive process may engender [8].

- Third Party Competition for Ownership: For there to be successful third-party development of such infrastructure, there must be a clear line of sight regarding how the costs of developing and building the common landfall will be recovered (e.g., in transmission tariff, fees from OSW developers). In addition, third-party development of such infrastructure requires explicit specifications in any procurement documents on the technical aspects of the landfall (e.g., location, right of way, dimensions, and various engineering considerations).

Consideration needs to be given to the ability to develop these specifications in sufficient detail or whether assigning responsibility to an incumbent utility provides desirable optionality that allows these specifications to evolve as necessary and appropriate. Alternatively, allowing third-party development opens up the process to creative technical solutions and the opportunity for cost containment that can be attractive. Once again, third-party development will require detailed specifications as well as a comprehensive engineering review to ensure that the proposed design will achieve necessary performance requirements.

Competitive models are more appropriate in some jurisdictions than others. For example, in New York, where the competitive Public Policy Transmission Planning Process model has been successfully employed a number of times, competition can be used to award development and ownership rights for share landfall and cable route infrastructure. However, in North Carolina, there is not the same reliance on competitive processes for transmission development and it likely would be more appropriate for the incumbent utility to develop such infrastructure.

8.9.6 Cost Recovery

There are two primary models for cost recovery of the common landfall facilities. Costs can be recovered from OSW developers through an access charge or be embedded in the relevant transmission tariff. The risk profiles to these two alternatives differ markedly.

- Cost Recovery from OSW Developers: An access charge could be assessed OSW developers to allow them to utilize the common landfall. This cost recovery approach poses considerable risks to the shared infrastructure owner given the uncertainty regarding the desire of developers to utilize the facilities. This cost recovery risk would be mitigated where the common landfall is the preferred landing point for a favored POI. In addition, OSW developers could be mandated to utilize the common landfall in the power procurement process. For example, the BPU's 2023 OSW RFP specified the landfall location and required bidders to offer at least one option for "Prebuild Infrastructure" that will include common landfall infrastructure and an interconnection to the Larrabee Tri-Collector Solution, the transmission solution that was selected under the BPU's State Agreement Approach (SAA).[8,9] The BPU staff and PJM explored an option where the SAA solution selected in 2022 would be modified to include the Prebuild Infrastructure. Ultimately, the BPU elected to conduct a competitive solicitation to determine who would build this Prebuild Infrastructure.

- Cost Recovery via Transmission Tariffs: Under this alternative, ratepayers would be allocated the costs of the common landfall infrastructure either across the entire RTO or the relevant state. Local transmission utilities (e.g., NYPA) are likely to seek to recover costs via the RTO's transmission tariff and the RTO (i.e., NYISO) may require FERC approval to recover costs through its wholesale transmission service charges.

The cost recovery framework should be linked to the approach for the cost recovery of the broader interconnection facilities and would be impacted by whether these facilities are part of a coordinated transmission network, as determined by the RTO. Specifically, cost recovery for a coordinated transmission network will likely require that the costs be recovered in the transmission tariff for those customers that benefit from the facilities, with similar treatment for the common landfall infrastructure.

Cost allocation should continue to be based on the beneficiary pays principle. If a Massachusetts procurement leads to OSW being developed and delivered to Massachusetts electric distribution companies, these costs including any associated transmission facilities whose need is triggered by the OSW development should be allocated to Massachusetts ratepayers. Other states within the RTO (i.e., ISO-New England) should not bear any of these costs unless they are realizing benefits from these facilities. However, if the facilities are delivering energy throughout the RTO to states beyond Massachusetts such as Rhode Island and Connecticut, then it would be appropriate to look at regional cost sharing mechanisms. By the same token if common landfall infrastructure were built in New York but was relied upon by OSW developments that were

[8] The SAA was the solicitation that sought transmission solutions to connect the state's remaining OSW procurement target to the onshore grid.

[9] This could be viewed as confirmation of the attractiveness of common landfall infrastructure as an element of any large transmission solution to connect OSW subsea infrastructure to the onshore grid.

supplying both New York and New Jersey, then the cost of these facilities should be allocated to customers in these two states and across two RTOs.

If facilities are to be pre-built for a connection where only a limited amount is to be used initially, for example 2 GW of a 6 GW connection, an argument could be made that costs should not be fully recovered at this time since only one-third of the facility's capacity is being used. In this instance, the “used and useful” ratemaking principle should be interpreted liberally and should not be a constraint on recovering the cost of these facilities. Otherwise, developers building these facilities will not know the future utilization of the facility and will be subject to uncertainty regarding whether they can recover all of their costs prior to the facilities being fully utilized.

8.9.7 Access Rights

Access provisions include who will be granted access to the common landfall and the criteria for granting access. Access rights can be granted after the infrastructure is built or negotiated as part of the development process.

The appropriate treatment for access rights needs to consider the cost recovery approach. For example, if the cost for these facilities is directly allocated to Massachusetts ratepayers, then there should be protections so that the financial support that these customers provide is recognized by ensuring access to these facilities for OSW developments with long-term PPAs with Massachusetts counterparties. This could include allocating a pro rata share of the costs to ratepayers from other states (e.g., Rhode Island) that receive energy from OSW developments that utilize the common landfall facilities.

However, there may be a need to ensure that open access requirements for transmission facilities are satisfied. This will depend on whether a shared landfall consisting of a series of duct banks is considered to be “transmission facilities”.

- Access Rights Determined on First Ready, First Served Basis: Such an approach would depend on OSW developers approaching the common landfall owner to gain access. Allowing mid-development OSW farms to hold the rights to the common landfall may be problematic if the wind farm does not become operational, while other neighboring wind farms seek alternatives.

- Access Rights Determined through Auction: An auction will provide access rights to those parties that value them the most highly. Such an auction aligns with FERC open season procedures and provides open access. If this auction is conducted before the facilities are built it can also help in determining the desired sizing of the facilities. Such an approach also addresses cost recovery issues, with OSW developers covering the cost of these facilities.

Once a decision has been made to construct the common landfall facilities, the entity in the state conducting the procurement could notify prospective participants that the facilities are available and indicate the terms under which they are available (e.g., annual or monthly fee or free to the first qualified user if costs recovered directly from utility ratepayers). Ideally, the procurement entity would indicate to prospective bidders that use of the common landfall would be viewed as reducing the environmental impacts associated with cable landfalls, with such projects scoring more favorably in any assessment of such impacts in the scoring framework. Bidders in the procurement would then determine whether they would elect to use these facilities.

8.9.8 Recommendations

As outlined above, there are numerous considerations associated with establishing development rights, ownership, cost recovery and access rights for common landfall infrastructure. The underlying market structure and perceived need for these facilities will likely influence which mix of solutions is most appropriate. In restructured markets there is a wide range of development and ownership alternatives, with the preferred approach influenced in part by the anticipated benefits of a competitive process to award these rights. As discussed, New Jersey has elected to employ a competitive process to award the development/ownership rights, with this decision likely influenced by the broad scope of the required facilities (i.e., includes ducts and vaults from the landfall to the onshore substation about 10 miles).

The appropriate approach for cost recovery depends on the decisions made with respect to the prior two considerations. For example, a TO led development will likely result in the recovery of shared infrastructure costs in the relevant transmission tariff. In fact, most development approaches are likely to result in costs being recovered through the transmission tariff rather than directly assigned to OSW developments. Costs can be directly assigned to OSW developers when there is a requirement that they use these facilities to access on the onshore transmission grid (e.g., in New Jersey's most recent RFP).

If speedy development of these facilities is important (e.g., there are a limited number of viable landfall locations and one location is highly preferred), then assigning development rights to the TO is likely to result in expedited development and construction by avoiding the need for a competitive process to award development rights. However, such an approach does not offer the benefits that a competitive process can offer, including the opportunity for innovative technical solutions and cost containment.

8.10 Risks and Opportunities

The share landfall and cable route infrastructure presents many risks since it has not been done before, however with the risks come opportunities. There are several risks that are undertaken with this study that relate to costs, logistics, and regulations.

Table 8-3: Risks summary

Risk	Description
Unclear who would initiate the infrastructure	Since multiple developers would be involved in this, it is unclear who or what entity would lead this shared cable infrastructure, whether it would be one or more of the developers involved or another organization like an RTO or public entity.
Timing of infrastructure	All the wind farms that are involved in shared cable infrastructure need to be synchronized enough so that the timelines line up to install the landfall export

	cables at the same time. The synchronization of these wind farms will probably have to be coordinated by one entity, whoever initiates the shared infrastructure.
Participation	For the shared infrastructure to work, there will need to be a minimum number of developers to agree to participate in the infrastructure. Developers may not want to be involved in the shared infrastructure because it is something that is new and uncertain, so ensuring there are enough developers that want to be involved is critical.
Stakeholders Regulatory framework	There are many stakeholders involved with shared infrastructure, and this brings risks associated with each stakeholder. Some examples of stakeholders include the Public Service Commission, the US Army, the Coast Guard, local residents, town boards, and many more. Any of these groups could have issues or objections to the infrastructure that could cause serious delays or even cancellation.
Power systems framework	There are several uncertainties of how the infrastructure development would fit within the existing power systems framework, as it relates to ownership models, development rights, and cost recovery.
Costs	The cost evaluation done with this report is only a concept level study. To have a true idea of what this will cost will require a much more detailed study. There is also general cost uncertainty around this infrastructure because of the novelty of it and the fact that it has not been done before. With any infrastructure of this size, there will be uncertainty around inflation and contractor costs which can have huge impacts on costs. Historically, the cost of many large infrastructure projects in the US have tended to be delivered overbudget.
Installation feasibility	This study has presented general method statements for installation of cables in the offshore cable infrastructure. However, there is uncertainty regarding feasibility of this until more engineering detail is undertaken regarding the infrastructure itself and feedback is sought from installation contractors.

While there are several risks related to the infrastructure presented in the study, there are also many opportunities that make using this novel technology superior. Some of the opportunities relate to permitting, costs, and design.

Table 8-4: Opportunities summary

Opportunity	Description
Permitting	While there are risks related to who would be initiating shared infrastructure, having one entity who oversees this could streamline certain processes like permitting.
Environmental and stakeholder impacts	Having one landfall location and one area where all the cables will be installed limits negative impacts on the surrounding community.
Costs to the consumer	Even though there are many risks relating to costs, ultimately, the cost to build the novel technology could be significantly cheaper than the cost to build the Base Case design.

Wind farm development	This prevents the issue of wind farm developments who begin earlier having a better landfall cable location while wind farms who begin later will have very limited options to choose from that would cost more and not be ideal.
Cable protection	The concept case has the potential to be safer and more secure than the Base Case due to additional physical armoring and separation and moving cables away from dredging and anchoring hazards through the narrows.
More efficient use of cable corridors & landfall sites	In terms of logistics, there are not many places to put a landfall cable in New York City, so having 6 wind farms with one landfall cable location is optimal. Having all this infrastructure in one location makes it easier to locate if any other infrastructure will be built in this area in the future. There are also many opportunities relating to the onshore design of shared infrastructure. If using the traditional method, it would not be possible to put 6 cables under a road. The novel technology is thermally optimized and creates the opportunity to do more with what is being used.
Sea defense refurbishment	The installation of this onshore infrastructure can also be used to simultaneously upgrade the pre-existing sea defense. If the sea defense were to be upgraded on its own, it could cost an estimated $16.5 million. If the concept design was carried out, the sea defense would be simultaneously upgraded while the offshore cables were installed, saving around $16.5 million on separate upgrades. The sea defense would also be routinely maintained throughout the lifetime of the cables because of routine maintenance and inspection on the cables.

9 Conclusion

The aim of this study is to quantify and assess the benefits and risks of a shared landfall and onshore infrastructure concept to co-locate transmission cables from multiple OSW developments. This report coordinates industry stakeholders' challenges and insights; creates a well-supported basis for design concept based on stakeholder input and industry standards; and executes a design concept with possible next steps forward to addressing many of the key problems associated in coordinated transmission.

Landfall and onshore utility congestion for OSW is a huge problem, not only in the United States, but more globally as well especially in more mature OSW markets. A solution for this would be welcome if OSW is going to be built at the size and rate required to address decarbonization targets. The main focus of this study, shared landfall and onshore infrastructure for co-located cable systems, has the potential to solve this widespread issue.

This study is based on a reference location on the east coast of the US, in New York City, given the presence of the NY Bight OSW lease areas nearby. If this type of solution works, the East Coast of the US could set an example for other locations to follow.

This study has developed designs for offshore, landfall, and onshore sections for co-located cables which can accommodate bulk power from OSW of more than 7 GW and up to 6 separate wind farms. The design that was created in the Concept Case is an innovative method for onshore cables to allow for more efficient use of space. The design is optimized in terms of efficiency, electrical redundancy, space, and safety.

After reviewing the costs for both the Base Case and Concept Case, the two cases cost about the same though the Concept Case is slightly cheaper in terms of lifetime NPV. However, there are many nuances and unknowns that could change the costs, and a high margin of error in the costs due to uncertainties. The cost assessment also shows that the onshore infrastructure would save cost compared to the Base Case, whereas the offshore infrastructure would cost more than the Base Case, though this does not account for additional costs related to more difficult routing and landfall for later wind farm developments due to cable congestion.

There are a multitude of other benefits besides cost that make shared infrastructure for co-located cables worth considering, including:

- Reduced permitting / planning risk for OSW developments
- Reduced construction disruption to communities
- Reduced environmental impact from construction
- Reduced cable congestion
- Reduced impact on other users of NY harbor
- Added sea defense resiliency

10 Recommendations for Further Work

Moving on from this study, there are still significant barriers to overcome and more engineering design to be undertaken before the shared landfall and cable route infrastructure could be implemented in New York or other places.

This initial feasibility study is the first step in the process of developing this infrastructure that has the potential to support the growing OSW industry. Future steps that could be taken to ensure the success of this infrastructure are identified and described in Table 10-1 below.

Table 10-1: Recommendations for further work

Recommendation	Description
Assess other case studies	Other case studies that have similar concepts to this one should be reviewed to determine how this design can be adapted and improved, and the outlook in terms of cost-benefit. These case studies can be from other locations in the US and around the world.
Create task force or working group	Creation of a task force or working group is an option to address outstanding issues related to regulatory challenges. For this infrastructure to be built, there are several regulatory issues and challenges that need to be addressed. For a specific location such as NY, a working group could focus on outlining the appropriate development and regulatory framework including how development and ownership rights should be established, and what are the appropriate cost recovery and access right frameworks.
Stakeholder feedback	This study includes a section on stakeholder feedback, however there are several more stakeholders who were not interviewed who would have valuable feedback and input. Additional stakeholders should be interviewed about the presented design and methods to gain even more feedback on the study. Another round of stakeholder feedback on this completed study would also be useful.
Grid interconnection	Steps should be taken to develop a specific grid interconnection plan for this infrastructure and relevant OSW developments. Having this infrastructure tied into a grid infrastructure plan for OSW in New York and other regions will help define where the infrastructure would be best located, how far it extends onshore and offshore, timescales, wind farm needs, and identify specific sites and route options for the infrastructure.
Cable route	While this study introduces a preliminary cable landfall and onshore cable route, this set up is not definitive. A specific landfall location and onshore cable route should be determined for a specific case. This item is linked to the grid interconnection above.
More detailed engineering	The preliminary engineering work presented in this report has helped develop the concepts and provided analysis for these ideas. Much further engineering work would be required to develop a real infrastructure development for co-located cables though. Once a specific site is identified

	for development, a site-specific feasibility study is likely to be initially required, followed by a more detailed front-end engineering and design work would be undertaken. Engineering studies will include civil engineering, electrical engineering, and further work on cable thermal modeling, once more detail on requirements is obtained from specific OSW developments. The applicability of active monitoring systems could also be investigated. Further studies to ensure stability and robustness of the solutions include: • Utilities surveys • Hydrographic and topographic surveys • Revetment Design Stability analysis • Soil investigation • Current and tidal studies • Hydraulic model analysis • Armor stone specification and sourcing
Site investigations	Site investigations should be performed for the specific site to be developed. This would involve reviewing as-builts of existing utilities, civil works, and other infrastructure (including sea defense). Then site surveys would be undertaken related to geological data and to confirm desktop utility data.
Sea defense	A thorough review of the as-builts of the existing sea defense should be performed to gain a deeper understanding of necessary works to deconstruct and rebuild the sea defense.
Contractor input	There are several portions of this report that should be supplemented with review and input from contractors. Input should be gathered from a general construction contractor about the costs of building the infrastructure. Transport and installation contractors for OSW should be consulted regarding cable installation and repair methods, and cable installation and repair costs.
Detailed cost study	The cost study presented in this report is a very high-level review of costs for the presented concept design methodology. Once a specific site and use case is identified, a more in-depth feasibility study and review of costs should be performed to determine the true economic feasibility of this infrastructure.
Electrical redundancy	The topic of electrical redundancy and physical security could be raised and opinions sought from RTOs, regional reliability and coordination councils, and NERC, specifically if the applicability of NERC CIP-014-1 should be extended to cover shared cable infrastructure.

11 References

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12 Appendix A – Permitting Matrix

A permitting matrix of permits, consultations, and approvals potentially required is provided in Table 12-1.

Table 12-1: Permitting matrix of permits, consultations, and approvals potentially required

Jurisdiction	Agency	Potential Permit /Consultation	Comments
Federal	U.S. Army Corps of Engineers New York District	Individual Permits	Required for dredge, fill, and other work in federally regulated waters, with some exceptions for which Nationwide Permits can provide coverage.
	NOAA Fisheries and US Fish and Wildlife Service	Endangered Species Act (ESA) Consultations, Essential Fish Habitat (EFH) Assessment, and Marine Mammal Protection Act (MMPA) Consultations	ESA Consultation - Potential to cause harm to threatened and endangered species and/or designated critical habitat. Requires a detailed Biological Assessment (BA) of potential impacts to ESA-listed species. EFH Assessment – Potential to affect EFH and EFH species. An EFH assessment (appendix to BA) would identify potential impacts to fish species within the 200 nm of the shoreline. MMPA Consultations – Authorization is required for the “take” of marine mammals; consultation with the Services will determine whether there is a need for authorization under the MMPA. Typically, MMPA is triggered by significant underwater noise impacts from construction and/or site characterization survey impacts. General Notes: The endangered North Pacific right whale and Atlantic sturgeon are both species of great concern to the Services and are present in the New York Bight. Concerns regarding electromagnetic field (EMF) exposure will need to be addressed.

			Mitigation measures (e.g., Protected Species Observers and reduced vessel speed during installation) should be anticipated. Additional consultations (e.g., Migratory Bird Treaty Act, Bald and Golden Eagle Protection Act [terrestrial activities]) may be required.
	US Coast Guard	Approval for Private Aids to Navigation (PATON) Local Notice to Mariners (LNM)	USCG has jurisdiction over marine traffic and national security out to 12 nm from shore. USCG oversees boating safety, and the placement of PATONs, which are buoys, lights, or day beacons owned and maintained by any individual or organization other than the USCG. The USCG determines the type of aid, lighting, and marking for privately owned marine obstructions or other similar hazards to navigation. The USCG is also responsible for establishing any restricted zones around the facilities that may be desirable and for coordinating traffic during construction of the Project.
	U.S. Department of Defense	Consultation	Consultation with the DoD regarding the proposed location of the offshore interconnection cables is anticipated to be required.
	National Park Service	Right-of-Way Permit	Required for utilities to pass over, across or through a National Park System, which includes areas of land and water administered by the National Park Service.
State	New York State Department of Environmental Conservation	State Environmental Quality Review (SEQR), Water Quality Certification (WQC), State Pollutant Discharge Elimination System Permit (SPDES), Freshwater and Tidal Wetlands Permit, etc.	SEQR – Requires all state and local government agencies to consider environmental impacts equally with social and economic factors during discretionary decision-making. The preparation of an Environmental Impact Statement (EIS) is anticipated to be required, which is extensive. WQC - Required for any activity that may result in any discharge into waters of the US, under Section 401 of the Clean Water Act (CWA).

			SPDES Permit - Required for construction activities involving soil disturbances of 1 or more ac or less than 1 ac if determined stormwater discharges may result in a violation, under Section 402 of the CWA. Wetlands Permit – Required for projects in or near wetlands. Depending on the cable route, a Freshwater Wetland Permit and/or Tidal Wetlands Permit may be required. General Notes: -NYDEC also provides input to DOS' coastal zone consistency determination. -Depending on cable route, other required permits may include: Wild, Scenic and Recreational Rivers Permit (for projects within a wild, scenic, and recreational river corridor) -Protection of Waters Permit (required for disturbing the bed/banks of a stream with a specific classification) -Incidental Take of Endangered/Threatened Species (Required if the action is likely to result in take of listed animal or involve an adverse modification of occupied habitat)
	New York State Office of General Services	Easement	Required to install utilities above or below lands now or formerly under the waters of state-owned waterbodies.
	New York State Historical Preservation Office	Section 106 of the NHPA Concurrence	Federal and state agencies must consider the effects of their undertakings on historic and cultural resources and afford the Advisory Council on Historic Preservation a reasonable opportunity to comment on such undertakings. A cultural resource survey, including a field study of archaeological or historic features, may be required.
	New York State Department of Transportation	Permit	Required for work on state-owned roads.

	New York State Department of State, Office of Planning and Development	Coastal Zone Management Program Federal Consistency Certification	Federal actions (including those requiring federal permits/approvals) that affect any use or natural resource of the coastal zone must be certified as *consistent with the policies of a State's federally approved coastal zone program*. In New York, the coastal policies are those in the New York Coastal Management Program (NYCMP) and any applicable Local Waterfront Revitalization Programs (LWRP). Note: In New York, the enforceable coastal policies extend state jurisdiction into federal waters (see Policy 29 of the New York State CZMP).
Local	New York City Department of City Planning	New York City Waterfront Revitalization Program Consistency (coordinated with DOS for CZMA review)	WRP review is required for any project located within the Coastal Zone boundary and which also requires a federal agency permit/authorization.
		Environmental Justice Considerations	In NYC siting analyses that evaluate the economic, social, environmental, resiliency and engineering benefits and impacts of renewable projects must be inclusive of robust equity metrics that consider EJ sensitive communities.
		Other potential local requirements/permitting considerations	Floodplain review, Zoning review, Grading permits, local stakeholder engagement.

Additional notes:

- If the cable project receives any government funding, review under the National Environmental Policy Act (NEPA) will be required.
    - Assume OSW farms will be reviewed under NEPA by BOEM.
- In New York, there's a Joint Application Form (JAF) that can be sent to USACE, NYDEC, NYOGS, and DOS.
- Permitting timelines can be long due to the level of environmental review required, stakeholder engagement (required), and understaffed state agencies.
    - State agencies require coordination with fishing groups for work in waters off New York, which can be complicated and time intensive as New York does not have an organized fishing group.

- Agencies may dictate timing of installation due to environmental (e.g., ESA-listed species migration/foraging/activities) or fishing activities (e.g., avoid installing during peak fishing season).
- Additional requirements may include a commitment for replacement/compensation of damaged or lost fishing gear that becomes entangled in the cable system, a post-installation monitoring plan, and decommissioning plan.
- Depending on cable route and project siting, New Jersey state agencies may need to be engaged (in addition to New York agencies).
- Best practices for cable installation: avoid hard substrate and utilize HDD whenever possible will at least need to be considered.
- Letters of support (e.g., fishing industry, regional NGOs, elected officials, power companies) may play an important role in the permitting process.

13 Appendix B – Unit Rates

This appendix contains the raw data for personnel rates, plant rates, and unit rates that were used in the cost model calculations.

Table 13-13-1: Personnel Rates

Day Rates	Amount Per Day (USD)
MANAGEMENT AND SUPERVISION	
Contracts Director	$107
Project Director - inc vehicle	$107
Design Manager	$107
Contracts Manager	$91
Commercial Manager	$91
Senior Planner	$86
Project Manager	$81
Senior Works Manager	$79
Senior HSE Manager	$79
Environmental Lead	$79
Section Agent	$76
Works Manager	$74
Foreman	$69
Public Liaison Officer	$69
Quantity Surveyor	$69
Engineer	$66
Document Controller	$60
Cost Clerk	$50
ENGINEERING PERSONNEL	
Electrical	--
Lead Electrical Engineer	$145
Senior Electrical Engineer	$139
Electrical Engineer	$132
Senior Designer	$106
CAD Operator	$53
Civil/Structural	--
Technical Director	$143
Senior Associate	$126
Associate Director	$116
Principal Engineer	$102
Senior Engineer	$95
Principal Technician	$92
Senior Technician	$82
Project Engineer	$75
Graduate Engineer	$68
Technician	$68
LABOUR	
Plant Operator (Specialist)	$36
Plant Operator	$32
General Labor	$32
Drain layer	$33
Banksman	$32
Electrician	$66

Laborer	$212
Semi-skilled tradesman	$264
Skilled Tradesman	$317
Trades Foreman	$370
Electrical Engineer for electrical installation works	$476
Mini digger and operator up to 3 metric ton	$476
Mini digger and operator 3.5 to 8 metric ton	$529
Wheels excavator and operator	$529
Tracked excavator and operator 21 to 30 metric ton	$688
Tracked excavator and operator up to 20 metric ton	$635
30 metric ton dump track and operator	$952
Dumper 6 metric ton	$159
Dumper 9 metric ton	$264
Rides on Roller 1,200mm	$106
Compressor and tools	$106
OFFSHORE WORKS	
Superintendent	$3,573
Assistant Super Day	$2,453
Assistant Super Night	$2,453
Shift Foreman	$1,794
Rigger Foreman	$1,503
Rigger Team Leader	$690
Rigger	$598
Welder Foreman	$1,748
Welder Team Leader	$1,150
Welder	$997
Crane Operator	$2,223
Crawler Crane Operator	$598
Storekeeper	$2,177
Assistant Storekeeper	$1,748
Safety Officer	$2,223
Tower Operator / Captain Advisor	$2,545
Mechanic / Hydraulic Technician	$2,223
Field Engineer	$2,683

Table 13-13-2: Plant Rates

Day Rates	Amount Per Day (USD)
ONSHORE PLANT	
3T Excavator	$87
8T Excavator	$125
13T Excavator	$204
21T Excavator	$248
21T Excavator (GPS)	$306
Excavator Attachments - V Ditch Bucket	$29
Excavator Attachments - Grab	$219
Excavator Attachments - 21T Hammer	$184
D61 Bulldozer	$481
D61 Bulldozer (GPS)	$606
10T Articulated Dumper	$204
30T Articulated Dumper	$396
12T Self Propelled Roller	$160

120 Twin Drum Roller	$39
135 Twin Drum Roller	$57
7m Telehandler	$102
Agricultural Tractor (>160BHP)	$205
Plate Compactor - Small	$15
Plate Compactor - Large	$19
Trencher	$3,000
4-6 passenger car	$131
Mini bus	$317
Pick up (4WD)	$229
Flat Bed Truck 2 t to 4.5 t	$287
Flat Bed Truck 4.5 t to 7 t	$337
Flat Bed Truck 10 t	$396
Kenworth or Tractor and Trailer	$785
Flat Bed Trailer 10 t	$449
Flat Bed Trailer 20 t	$494
Flat Bed Trailer 30 t	$543
Flat Bed Trailer 40 t	$597
Flat Bed Trailer 50 t	$657
Up to 30 t - crane	$1,094
31 to 45 t - crane	$1,799
46 t to 75 t - crane	$2,247
76 t to 100 t - crane	$3,141
101 t to 150 t - crane	$3,689
OFFSHORE FABRICATION/TRANSPORTATION	
Transport barge after sail away (reimbursable)	$9,309
Transport barge incl. two ballast engineers	$12,694
OFFSHORE INSTALLATION	
Heavy Lift Vessel	$557,393
Towing tug (100Mt BP)	$41,249
Towing tug (100Mt BP) standby	$41,249
Escort tug (35Mt BP)	$25,148
Escort tug (35Mt BP) standby	$25,148
Cable Lay Vessel	$208,378
Multicat Workboat - HDD, Mattressing / Rock Bags. Pull in HDD. PLGR. Boulders.	$55,568
High Bollard Pull Cable Lay Vessel with Cable Plough	$312,568
Rock Armor Installation	$104,189
Prelay dredging vessel	$76,405
Crew Transfer Vessel	$12,000
Shallow Water Diver Support Spread (air diving)	$8,200
Cable Lay Barge (Nearshore)	$166,703

Table 13-13-3: Material Rates

Component	Description	Unit	Price Per Unit
Fuel	White Diesel for plant & Equipment	Liters	$2
Tank of fuel	Diesel for an HGV lorry	per 250l tank	$608
Aggregates	Subbase	t	$19
Aggregates	Capping	t	$17
Sand		t	$30
Ducts	HDPE SDR17 180mm Diameter	m	$21
Ducts	HDPE SDR11 180mm Diameter	m	$32
Ducts	HDPE SDR17 63mm Diameter	m	$4
Ducts	HDPE SDR11 63mm Diameter	m	$4
Protection Tiles	Heavy Duty Cable Protection tile	m	$24
Geogrid	Naue 40/40	m2	$3
Pre-cast Concrete		m3	$1,000
Concrete pour (5000 PSI)		m3	$247
CBS		m3	$159
Reinforcement Steel	Cut & Bent	t	$1,653
Helical piles	3m long + pile cap	per item	$3,000
Stainless Steel band	estimate from LME with 50% mark-up	t	$1,260
A-Jack	estimate	per item	$100

14 Appendix C – 320 kV HVDC Cable Data

This appendix contains the cable data used for the analytical and CFD rating studies presented in this report.

Table 14-1: 320 kV HVDC cable data

Item	Description
Nominal AC voltage	320 kV
Conductor CSA	3000, 2500, 2000 mm^2
Assembly type	Single-core
Design temperature	Max. conductor temperature = 70°C Max. temperature rise across insulation = 9°C
Max. Direct Current (DC) resistance at 20°C	0.0062, 0.0072, 0.009 Ω/km
Conductor type	Copper, round stranded
Conductor diameter	64, 62, 54 mm
Conductor screen	Extruded semi-conducting crosslinked compound Thickness (t) = 2.0 mm, TR (ρ_T) = 3.5 K·m/W
Insulation	Cross linked polyethylene t = 20.0 mm, ρ_T = 3.5 K·m/W
Insulation screen	Extruded semi-conducting crosslinked compound t = 1.5 mm, ρ_T = 3.5 K·m/W
Water blocking layer	Semi-conducting swelling tapes t = 1.56 mm, ρ_T = 6.0 K·m/W
Metallic sheath	Aluminum wire screen and sheath t = 2.44 mm
Water blocking layer	Semi-conducting swelling tapes t = 0.7 mm, ρ_T = 6.0 K·m/W
Sheath and armor bedding	Polyethylene t = 5.3 mm, ρ_T = 3.5 K·m/W
Armor	5.6 mm diameter galvanized steel wires
Outer serving	Polypropylene yarn t = 5.0 mm, ρ_T = 6.0 K·m/W
Cable outside diameter	162, 160, 152.6 mm

15 Appendix D – CFD Analysis

Shared Landfall and Cable Route Infrastructure

Computational Fluid Dynamics Study of Onshore Infrastructure

Client:	Offshore Wind Consultants
Project/Proposal No:	3758_004_001
Version:	1.0
Date:	2023-05-17

Document Information

Project Name:	Shared Landfall and Cable Route Infrastructure
Document Title:	Computational Fluid Dynamics Study of Onshore Infrastructure
Client Name:	Offshore Wind Consultants
Client Contact:	Jeff Fodiak
Client Address:	ABL, 100 Wall Street, Suite 2202,New York, NY 10005, USA
Document Status:	Final for Issue
Author:	G. Callender
Reviewed:	-
Approved:	M. Hird
Date:	2023-05-17
Version:	1.0
Project/Proposal Number:	3758_004_001
ITPEnergised Office:	4th Floor, Centrum House, 108-114 Dundas Street, Edinburgh, EH3 5DQ

Revision History

Version	Date	Authored	Reviewed	Approved	Notes
1.0	2023-05-17	G Callender	-	M. Hird	First issue

The Tony Davies High Voltage Laboratory

UNIVERSITY OF Southampton

Report Number: 1	**Date:** 12/05/2023
Client: ITPEnergised	
60 Elliot Street, Glasgow, UK, G3 8DZ	**Enquiry**: Offshore windfarm finite element cable rating study
Contact: Rob Spice	
Email: rob.spice@ITPEnergised.com	
Tel: +44 7564 521593	
Web: https://www.itpenergised.com/	

Scope of Project: George Callender received an enquiry from ITPEnergised to undertake FEA simulations for HVDC offshore windfarm export cables underneath a road. Details as per scope of work issued by George Callender to ITPE on 4th January.

Summary: A range of thermal models were constructed of the cable installation, including combined CFD and radiative heat transfer simulations in air domains. The results demonstrated that, for the environmental factors present at the site, cable overheating was likely if only natural cooling was considered and the most onerous ambient temperature assumption of 37degC is used. A set of recommendations for future investigations have been made that may allow a natural cooling solution.

	Report prepared by: Dr George Callender
The Tony Davies High Voltage Laboratory Building 20, University Crescent Electronics and Electrical Engineering University of Southampton Southampton SO17 1BJ, UK	George Callender **Reviewed by:** Prof Paul Lewin
Tel: +44 (0) 2380 593238	**Email:** tdhvl@soton.ac.uk **Website:** www.highvoltage.ecs.soton.ac.uk

Part 1: Introduction

This report will investigate the feasibility of a novel HVDC cable installation, provided to TDHVL by ITPE energised. The installation consists of 6 DC bipoles in duct banks, with air gaps placed between them. The purpose of this study was to ascertain:

1. What is the thermal impact of the air gaps on the heat transfer from cables?
2. Can natural cooling, that is buoyancy driven flow in air domains, prevent cables from exceeding their maximum operating temperatures?

Due to the iterative process of these simulations, with additional feedback and data provided at different stages in the project, the results are presented in Section 3 in a chronological fashion.

Part 2: Model Implementation

2.1 Heat Transfer Theory and Model Geometry

The finite element analysis (FEA) model solves the heat equation, the partial differential equation governing heat transfer, on the model geometry

$$C_v \frac{\partial \theta}{\partial t} - k\nabla^2\theta = Q \tag{1}$$

where θ is the temperature, C_v is the volumetric heat capacity, k is the thermal conductivity (inverse of thermal resistivity) and Q is the volumetric heat source. Continuity of heat flux and temperature is enforced at all boundaries. Within solid domains, such as soil, backfill and concrete, heat transfer takes place by conduction only which is captured by solving (1). Within air filled domains conductive, convective and radiative heat transfer is considered.

Heat transfer by radiation is treated as an incoming and outgoing heat flux at solid-air boundaries. This requires the solution of a ray tracing problem in order to determine view factors. The normal heat flux leaving a boundary due to radiation is

$$\vec{n} \cdot \vec{q}_{\mathrm{rad}} = \varepsilon(\sigma\theta^4 - G) \tag{2}$$

where ε is the emissivity of the material at the boundary, σ is the Stefan-Boltzmann constant and G is the radiation into the surface from other radiating surfaces. The emissivity of all boundaries is set to 0.9 in all simulations, which is typical for cable systems [1,2]. In reality the emissivity will be dependent on the colour and finish of such surfaces.

Heat transfer due to convection is captured as a heat flux within air domains

$$\vec{q}_{\mathrm{conv}} = C_v \vec{u} T \tag{3}$$

where the velocity $\vec{u}$ is determined through a numerical solution of the incompressible Navier Stokes equations. A Boussinesq approximation is made to consider the impact of buoyancy, where a forcing term is applied due to the fluid due to density variations, but otherwise density variations are ignored. This is a standard approach for modelling heat transfer in air at low velocities.

In the initial set of models details of the cable geometry were not included. Instead, a circle of equivalent size to the outer diameter of the cable is inserted into the model as a uniform volumetric heat source, with the total losses in the circle set to 31 W/m, based on data supplied by ITPEnergised. For all models in this report the heat flux has been supplied by ITPEnergised and has not been independently checked by the author. In later models the full cable geometry is considered, based on data supplied by ITPEnergised.

The geometry of the installation environment was constructed based on a technical drawing shown in Figure 1. It should be noted that the installation does not have a uniform cross section, and at intervals grates are placed above the air gaps. However, the cross section below will experience the highest temperatures, and it was found to be sufficient, with certain modifications, for all of the investigations conducted in this report.

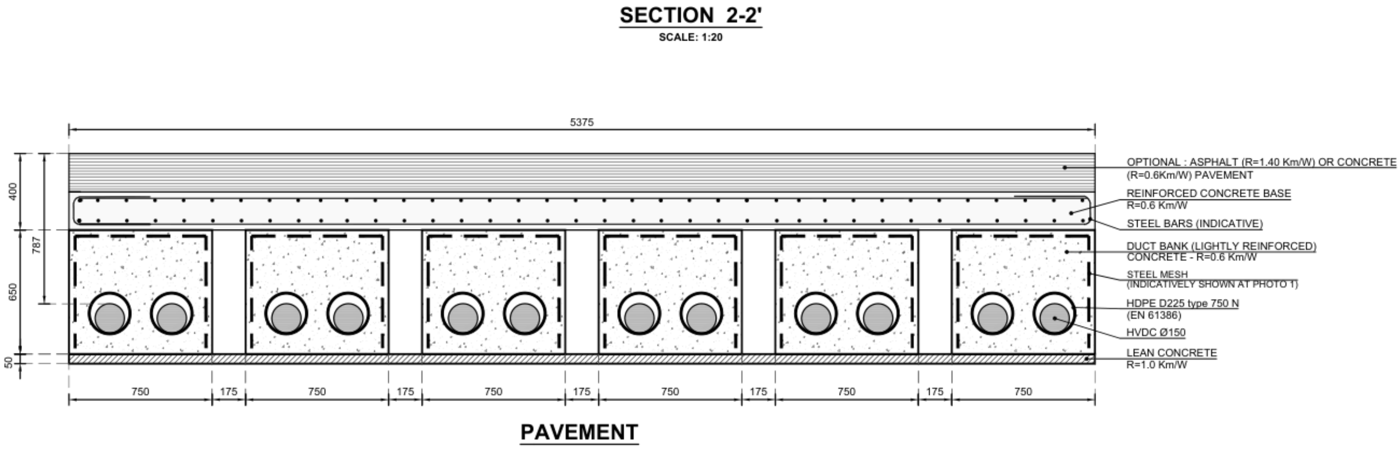


Figure 1 – Cross sectional drawing of the cable installation system upon which the model geometry was based [3].

2.2 Material Properties

Cable thermal properties were provided by ITPEnergised and will not be discussed further beyond stating that the values used were consistent with the author's prior experience with cable systems and the values provided in IEC 60287-2-1 [4]. The default thermal properties of air within COMSOL were used throughout this work.

Due to issues with numerical convergence of stationary CFD studies, all models, except those where the air domain is treated as a solid with an equivalent thermal resistivity, are time dependent. All models are run until a steady state condition is reached thermally; typically the flow field is always time dependent due to the formation of vortices. To account for the fact that the time constant of the flow field is significantly lower than the time taken for the solid domains to reach steady state temperature, the volumetric heat capacity of all solid domains is set to 1kJ/Km^3, 3 orders of magnitude lower than its true value. However, this unphysical value does not impact the final steady state temperature which is of interest.

2.3 Implementation

The model was implemented in Comsol 6.1 using the "Heat Transfer in Solids and Fluids" physical library, coupled to the "Surface to Surface Radiation" library. For the CFD models, the "Laminar Flow" library was used to solve the incompressible Navier Stokes equations. Triangular elements were used for 2D models, for 3D models a triangular boundary mesh was swept through the model domain to create triangular prism elements. Quadratic order elements were used for heat transfer calculations, linear order elements were used for radiation calculations and CFD modelling. The numerical solver and the relative tolerance used was not varied from the Comsol default. Time steps sizes were adjusted on a case-by-case basis to ensure convergence, typical step size restrictions were 0.1s or below.

Part 3: Results and Discussion

In this section the simulation investigations undertaken in this project are discussed chronologically. Key findings are made at each stage, which were used to inform the next modelling step.

3.1 2D Slice Model of Heat Transfer through Natural Cooling with Road Covering

Initially a 2D slice model was constructed of the cable installation, by construction this ignores any longitudinal heat transfer along the cables due to the grates. The model settings are provided in Table 1, a surface plot of temperature is provided in Figure 2.

Table 1 – Model Settings for Stage 1

Property	Value
Ambient Temperature	25°C
Cable Outer Diameter	162mm
Cable Model	Equivalent Circle/Cylinder
Cable Losses	31W/m

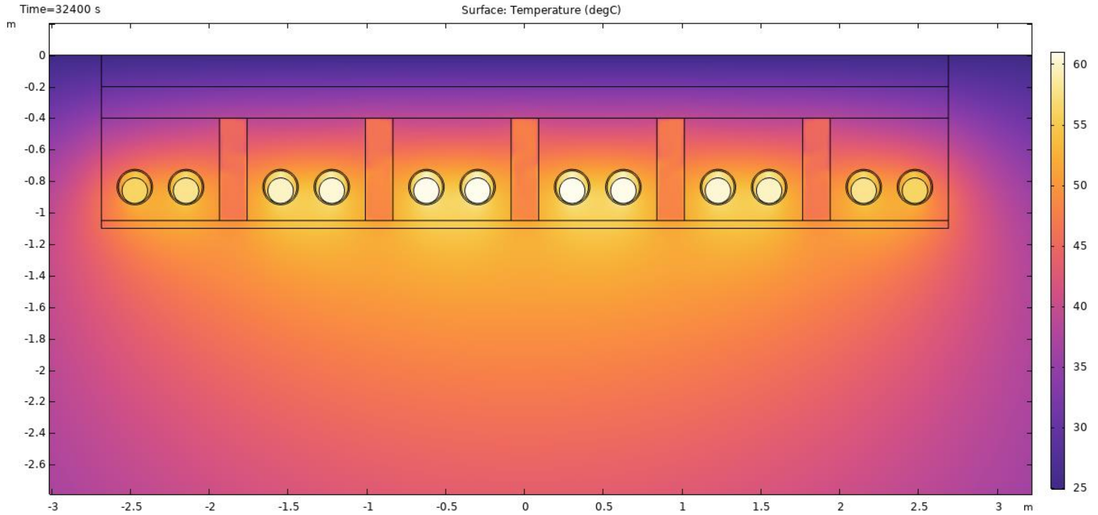


Figure 2 – Surface plot of Temperature for 2D slide model with convective and radiative heat transfer in air domains.

Key findings

- The peak surface temperature of the cables is ~61degC, which is above the 55°C target to ensure conductor temperatures are below 70°C.
- There is clearly significant mutual heating, with the central circuits being 3°C warmer.
- A crude model of the system treating the air domains as solid (i.e. ignoring convective and radiative heat transfer) found that they have an equivalent thermal resistivity of 1.7 Km/W, suggesting that filling these domains with a lower TR solid material would lead to lower cable temperatures. This should not be treated as a general result which is true for any air domain, it simply applies to this system.

This motivates a model which considers the impact of the grates, which will allow additional cooling.

3.2 2D Slice Model of Heat Transfer through Natural Cooling with Grates

In reality the proposed cable installation has grates spaced at regular intervals. To provide a rough upper estimate of the cooling that could be achieved by these grates the model developed in Section 3.1 was altered to remove the road and concrete lid above the air gaps, allow ambient air at 25degC to flow next to the duct banks as shown in Figure 3. All model settings are as per Table 1.

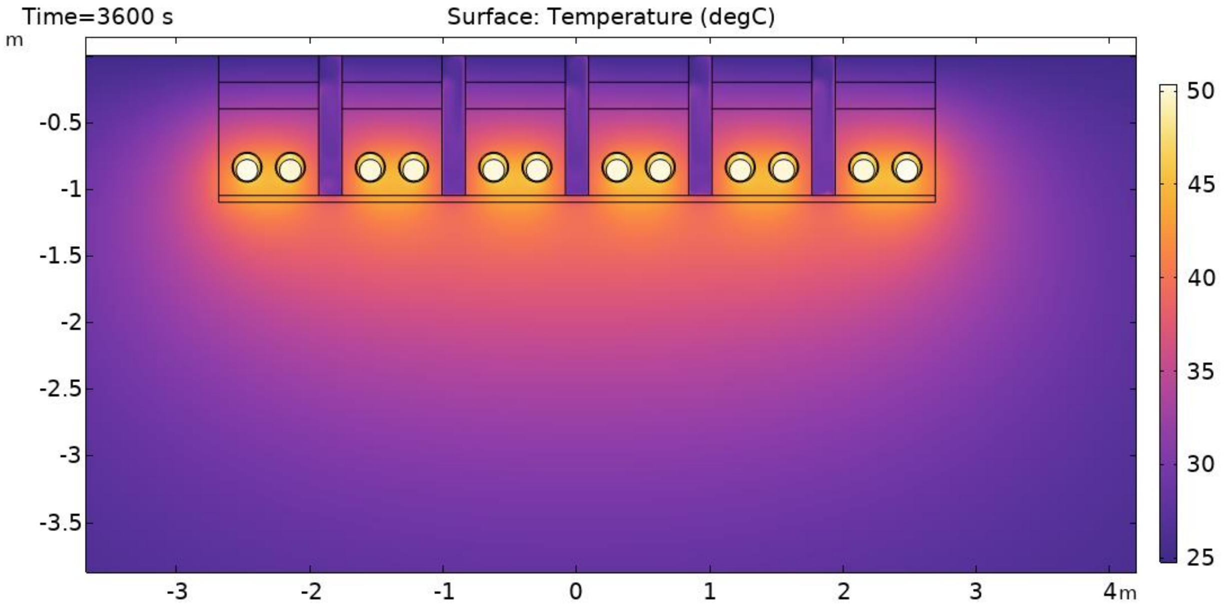


Figure 3 – Two dimensional slice thermal model with outlets placed at the top of each air gap.

Key Findings

- Outlets above each air gap reduced the cable temperature to ~50degC. As the permissible cable surface temperature is ~55degC, this suggests that, were the entire system to be grated along the full length, the maximum operating temperature of the cables would not be exceeded if the ambient air temperature can be taken as 25degC.
- As grates will not be present along the entire length of the installation, such a model is optimistic. Air flow will be impeded by the concrete lid along the majority of the route that is between the grates, reducing convective cooling.

This motivates a 3D model which considers longitudinal heat transfer.

However, in order to construct a 3D model it is first necessary to reduce the computational cost. Given the symmetries of the system the computational cost can be greatly reduced by only considering the central air gap and surrounding cables, with thermally insulating "mirror" boundary conditions at the midpoint of the ducts. This is slightly conservative, but given there are 2 copies of the system each side of the central air gap, it is not excessively so. In Figure 4 the results of a 2D slice model considering only the central gap is considered, it can be seen that the cable surface temperature is comparable to the Figure 3, the absolute difference is 0.2degC.

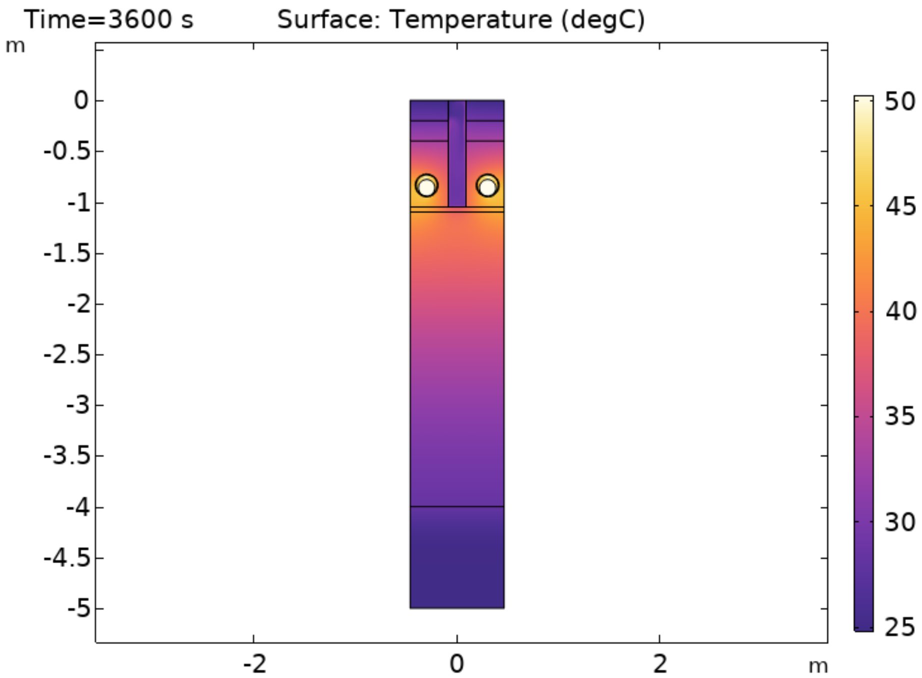


Figure 4 – Two dimensional slice model considering only the central air gap with zero heat flux boundary conditions at the lateral extents of the model.

3.3 3D Model of Longitudinal Heat Transfer through Natural Cooling with Grates

In reality grates are not present along the entirety of the circuit length; at present the working assumption is that they are every 200m. It was then decided to consider the impact of buoyancy driven flow longitudinally along the cable route. Given there is some flexibility of the spacing of the grates an initial three-dimensional FEA model with a 30m spacing between the grates was constructed, which also reduces the computational cost of the model.

As discussed in the previous section, to reduce the computational cost of a 3D CFD model only the central air gap was considered, with the 3D model having the same cross section as Figure 4, with the concrete lid and road present over the air gaps for the majority of the length, see Figure 5. The grate was considered by extruding the 2D model geometry, with the grate section set to have the same area as that proposed in the design documents, i.e. the blue surface in Figure 5 has an area of 0.255m^2, which is based on the true surface area of 850mm x 300mm, but in the model the dimensions are 1.4571m x 0.175m, with 0.175m based on the size of the air gaps between the duct banks [3]. The assumption is that what is critical for the cables far from the grate is the total area through which air may enter/leave the system.

Another important parameter in this model is the effective thermal conductivity of the cable cylinder, which will influence longitudinal heat transfer through the cable towards the grate. Based on cable dimensions and thermal properties provided by ITPE in Table 3, 111 W/mK was calculated to be the effective longitudinal thermal conductivity. All model settings are as per Table 1.

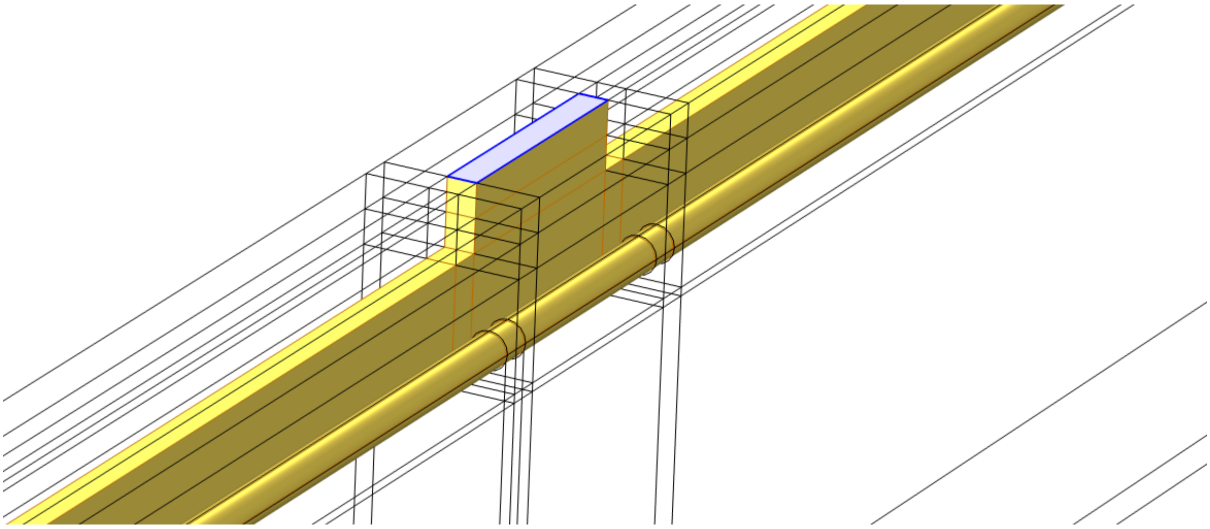


Figure 5 – Highlighted air domains in the three-dimensional CFD model, note that this includes air within the HDPE ducts. The air inlet/outlet corresponding to the grate is highlighted in blue. The short extruded sections either side of the grate are for mesh control purposes.

Due to the computational costs associated with a 3D CFD model, and the necessity to run a time dependent simulation for the purposes of stability, only the initial rise of the cable temperature from ambient was simulated. Model results at the end of this transient are provided in Figure 6 and Figure 7.

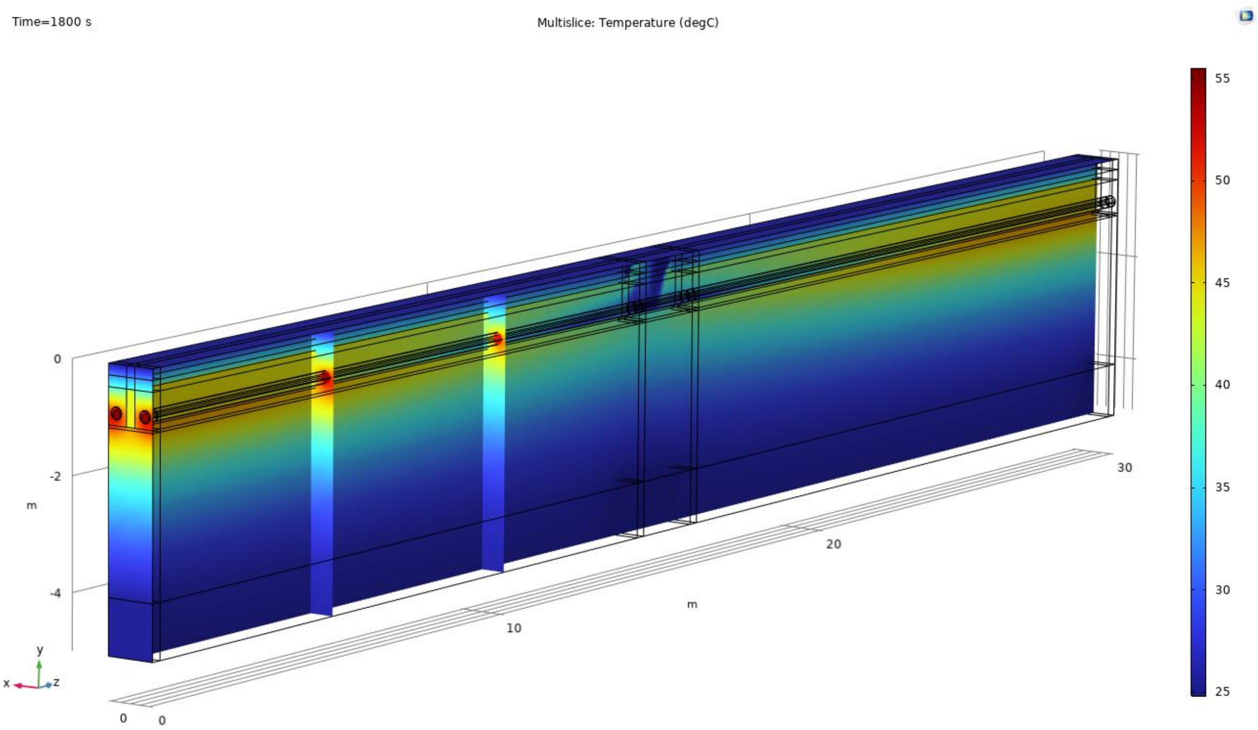


Figure 6 – Temperature slice plot along 30m length of three dimensional grate model <u>at the end of the simulation run</u>. The ambient air entering the system at the grate can be seen in the central section. Cable surface temperature increases with distance from the grate.

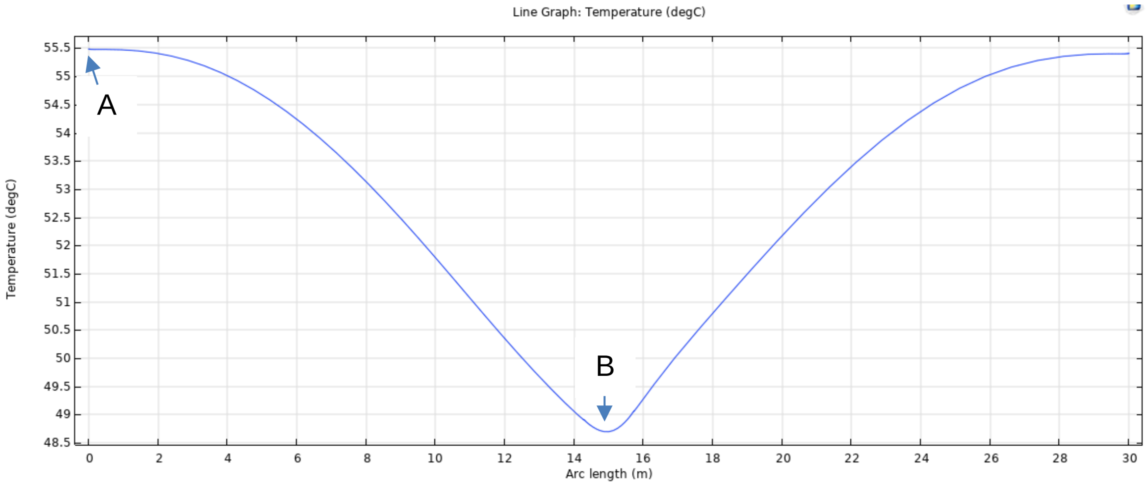


Figure 7 – Cable surface temperature along the 30m 3D grate model <u>at the end of the simulation run</u>. The cold central section corresponds to the location of the grate. Letters A and B correspond to the end points of the dotted curves in Figure 8.

It is necessary to extrapolate from these transients to the final, steady state temperature of the grate model. To do this, it was assumed that the shape of transient is comparable to that of the 2D case for no grates (discussed in Section 3.1), where, due it being a 2D model, the model can be run to a steady state condition. Dilation factors were then applied to time and temperature, to minimise the error between this curve and the 3D FEA results. This shape is most appropriate to describe the temperature rise where the cables are at their highest temperature, between the grates, which is the critical location to consider in the system to prevent overheating. An example of the procedure applied to two locations in Figure 8. It should be noted that, to accelerate the transition to steady state the volumetric heat capacities of the solid domains are artificially low, as discussed in Section 2.2.

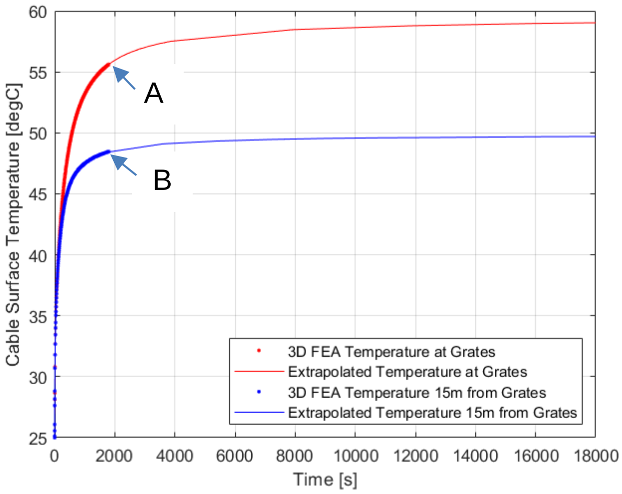


Figure 8 – Demonstration of the temperature extrapolation undertaken to determine steady state temperatures of the 3D FEA model. Note that the use of low volumetric heat capacities in solid domains leads to artificially fast transients. Letters A and B correspond to the locations indicated in Figure 7.

After further discussions with ITPE, **conducted after the first issue of the report**, additional simulations were constructed for the grate case, with the final temperatures determined using the same extrapolation procedure. The results are provided in Figure 9.

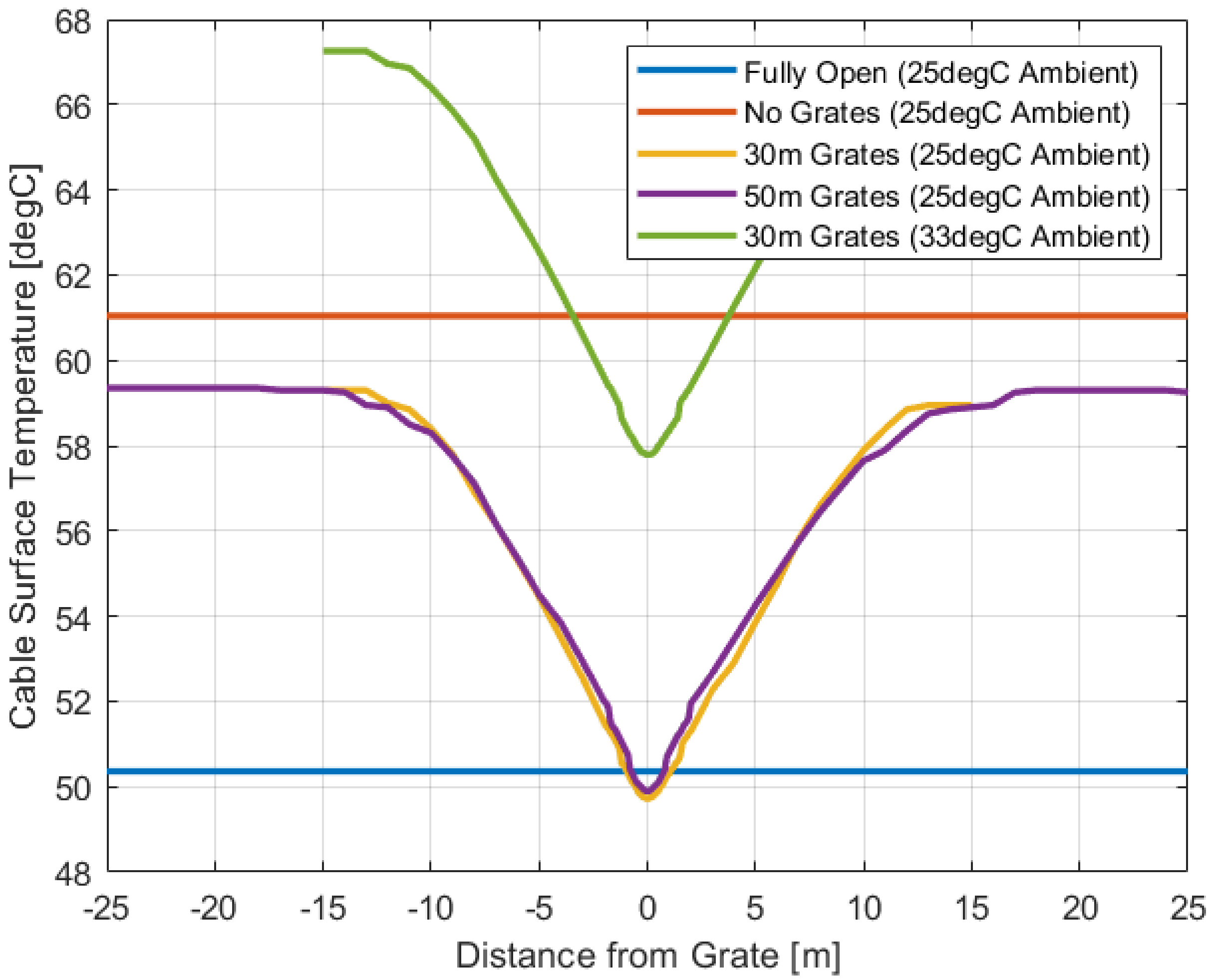
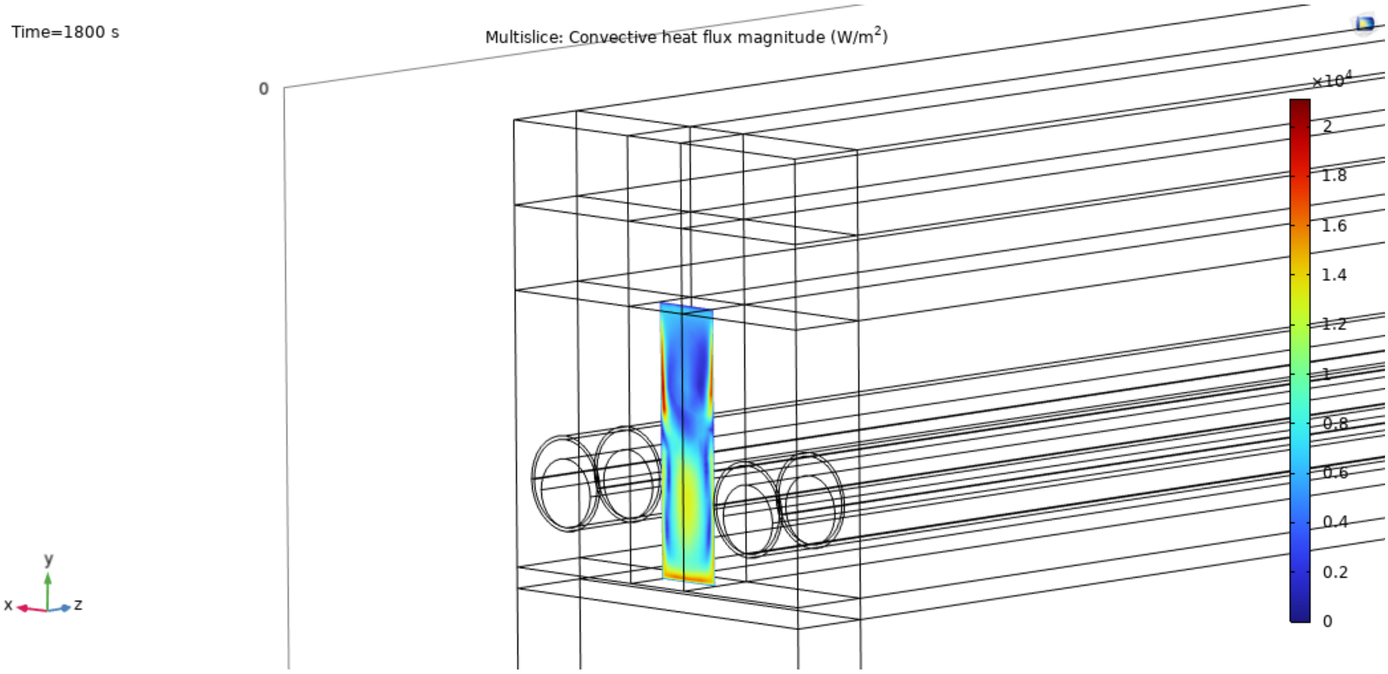


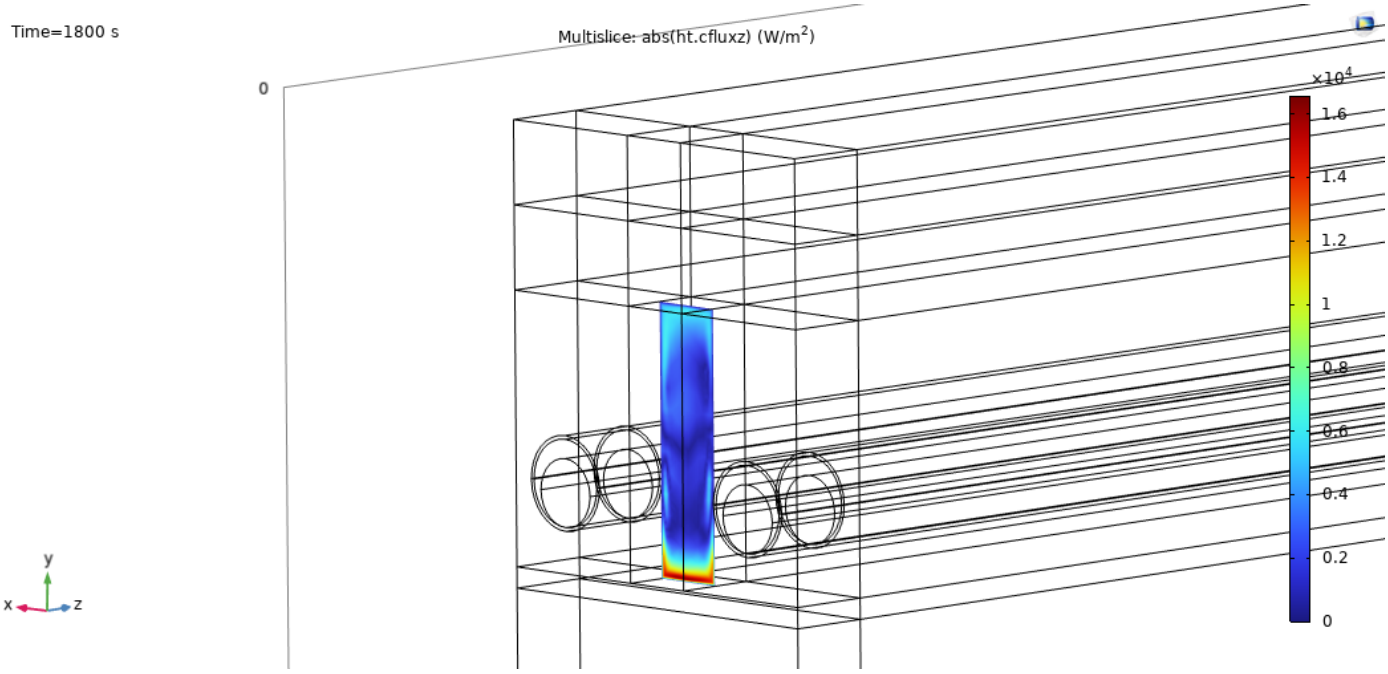
Figure 9 – Final steady state temperatures for a range of grate conditions. The results for no grates and fully open are taken from Section 3.1 and Section 3.2 respectively.

Key Findings (updated after first issue)

- **The effects of the grate are relatively marginal at distances greater than ~10m from it**, where the cable temperatures are ~0.5degC lower than they would be without a grate. Upon examination of the simulation results, it is apparent that there is still longitudinal convective heat transfer, further from the grate, as there is little impedance to cold air flowing at the base of the air box between the duct banks, see Figure 10b. As such the temperature rise to the limit of infinite grate separation, i.e. "No Grates" in Figure 9, may occur over very large distances.



(a) Convective Heat Flux Magnitude



(b) Longitudinal Component of Convective Heat Flux

Figure 10 – Convective heat flux near the midpoint between grates.

- Cable surface temperatures greater than 55degC are observed 15m from the grate (corresponding to the midpoint for a 30m grate spacing). Therefore, we do not think that naturally cooled cables are permissible in this scenario if the maximum cable operating temperature is 70degC, assuming a 15degC temperature rise across the cable at maximum current. If the maximum operating temperature of the cable is larger, for example 80degC, then overheating is unlikely if the ambient temperature can be taken as 25degC, but is likely if the ambient temperature is taken as 33degC, as the cable surface temperature exceeds 65degC in this case. **The simulation results suggest that the maximum permissible ambient temperature is, approximately 30degC for a cable with a maximum conductor temperature of 80degC.**

After running this model, additional data was provided by ITPE as follows:

1. A conservative ambient air temperature at the site of 37°C is possible, and should be used in future modelling. This will significantly increase cable temperatures further.

2. New cable design information resulted in a smaller cable diameter, 131mm. This is likely to increase cable temperatures as it will increase the thermal resistance of the interior of the HDPE duct.

This motivates a model that includes forced convection to see whether this prevents overheating with an ambient temperature of 37°C for the new cable design.

3.4 3D Model of Longitudinal Heat Transfer through Forced Cooling

In this section a new set of model parameters are used, as outlined in Table 1 and Table 3.

Table 2 – Model Settings for Stage 2

Property	Value
Ambient Temperature	37°C
Cable Outer Diameter	131mm
Cable Model	All components considered, as per Table 3

A 30m modelling domain longitudinally was considered, ignoring grates. It was assumed that the air temperature into this domain was at 37°C moving with a normal inlet velocity of 5m/s, see Figure 11. This value was chosen as it is fairly typically for cable tunnel systems, see comments on Littlebrook head house in [2]. Due to the formation of slow-moving boundary layers at the edges of the air domain, the peak velocity is slightly higher than 5m/s at the outlet due ensure conservation of volume.

The time dependent CFD model was initialized with a temperature distribution calculated ignoring convective heat transfer, assuming that the entirety of the air domain between the duct banks was at 37°C, essentially assuming perfect cooling due to the forced convection. This solution ignores any convective heat transfer within the HDPE ducts, which makes relatively little difference as the small size of the duct interior means that within it heat transfer is predominantly via radiation. The initial conductor temperature from this starting point is nearly 65°C, as shown in Figure 12.

From this starting point, only the inlet boundary is set to 37°C, with a time dependent simulation used to model the heating of the system due to the temperature rise in the air domain. After only 170s, which required 14 hours of computational time, the maximum conductor temperature of 70°C was exceeded.

Table 3 – Cable Design Information

Description	Material	Thickness (mm)	Diameter (mm)	TR (K.m/W)
Conductor	Copper, circular compacted, watertight		64.0	0.0025
Conductor screen	Extruded semi-conducting compound	2.0	68.0	3.5
Insulation	Extruded cross-linked polyethylene (XLPE)	20.0	108.0	3.5
Insulation screen	Extruded semi-conducting compound	1.5	111.0	3.5
Longitudinal water-block	Swelling tape	1.6	114.1	6.0
Metallic sheath	Aluminium/PE laminate	0.24	114.6	0.004201681
Metallic screen	47 no. aluminium wires	2.2	119.0	0.004201681
Bedding	Swelling tape	0.7	120.4	6.0
Insulating oversheath	PE12	5.0	130.4	3.5
Semiconducting oversheath	Semicon PE	0.3	131.0	3.5

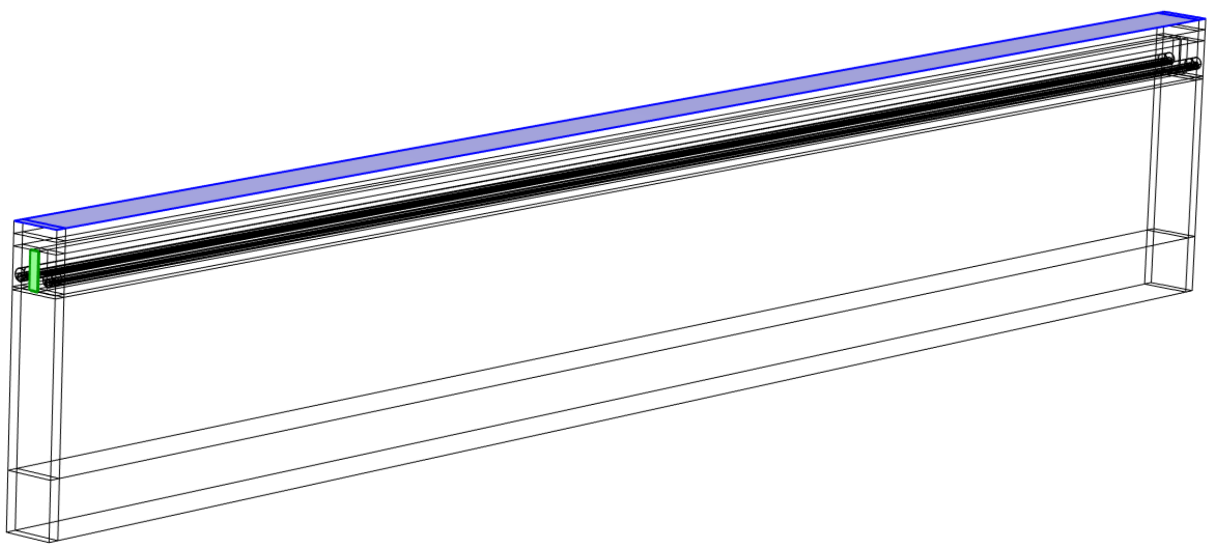


Figure 11 – Model domain for forced cooling, all coloured (blue/green) boundaries are treated as

fixed isotherms at 37°C, the air inlet boundary is indicated in green.

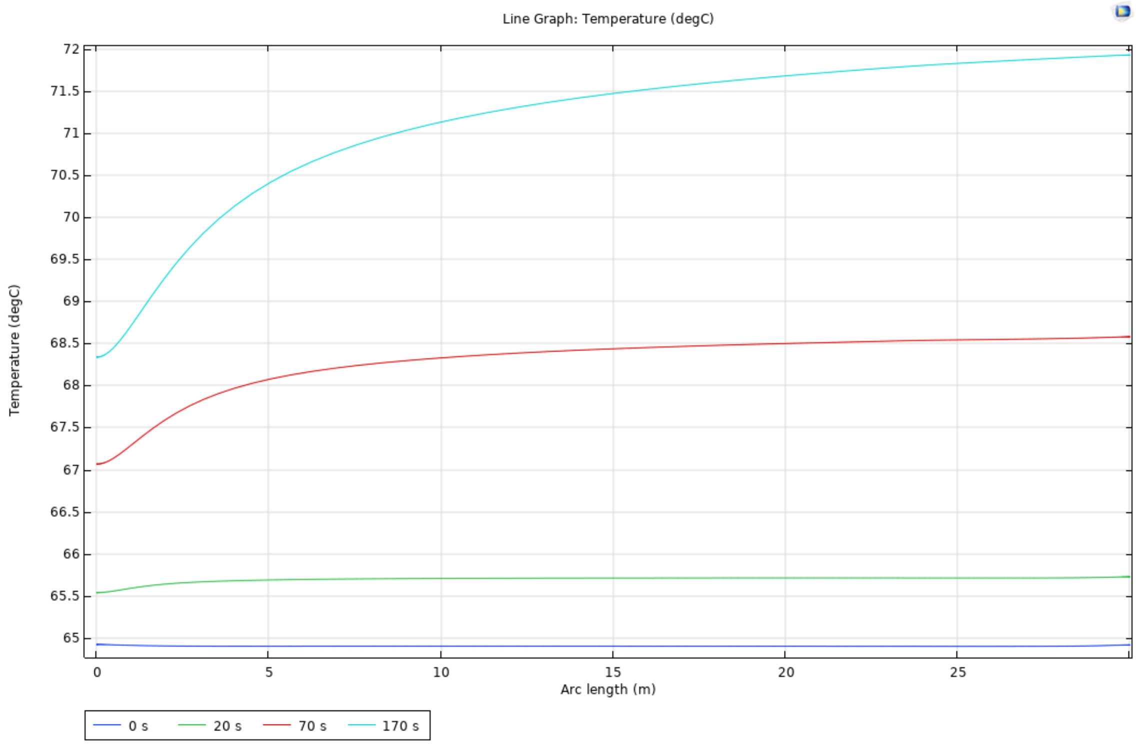


Figure 12 – Cable conductor temperature along the model length for forced convection. The inlet boundary is at $x = 0$m for this figure.

Key Findings

- For an ambient temperature of 37°C, it seems unlikely that even forced cooling due to fans can prevent the cables exceeding their maximum operating temperature for this installation configuration.

Part 4: Conclusion and Future Work

A set of simulation investigations have been undertaken to simulate heat transfer from a proposed cable system of 6 HVDC bipoles in close proximity under a road.

Throughout the work the modelling assumptions used were increasingly conservative, e.g. higher ambient temperatures and smaller cables, which served to increase cable temperatures. The main finding is that due to the high ambient temperature at the site, the proposed design will not prevent cable overheating even using forced cooling through air fans.

TDHVL understand that the air domains were utilised to help mitigate mutual heating between circuits. It should be noted that, while the air domains do inhibit mutual heating between circuits, this is as a direct consequence of the relatively poor thermal properties of air, which fundamentally leads to higher cable temperatures.

On the basis of these results a set of recommendations for potential future work can be made:

1. **Environmental Parameter Assessment** - Given that the installation will be fed by wind power an assessment of the relationship between ambient temperature at the site and wind speed at potential generation locations could allow the very high ambient temperature assumption of 37°C to be relaxed.

2. **Optimise Design for Forced Air Cooling** - The installation is not well suited for forced convection due to the relatively narrow air gaps. To assess whether forced convection due to air movement can achieve the desired rating larger air gaps are required.

3. **Consider Water Cooling –** Forced water cooling through pipes installed close to the cables offers excellent heat transfer and would significantly reduce mutual heating between circuits. In the author's opinion it would likely allow cable conductor temperatures to remain below 70°C even with an ambient temperature of 37°C.

4. **Improved Thermal Conduction** - Removing all fluid (air) domains and filling them with low thermal resistivity solid material is likely to be thermally preferrable. Mitigation of high thermal resistivity soil surrounding the installation could further reduce cable temperatures and could be rapidly assessed through simulation investigations. Using additional solid domains would also allow the ambient temperature assumptions to be relaxed, as the thermal mass of the system would be larger as at present the presence of the grates results in air at ambient temperatures in the vicinity of the cables.

For the proposed installation conditions the simulation results suggest that the maximum permissible ambient temperature is, approximately, 30degC for a cable with a maximum conductor temperature of 80degC, and 20degC for a cable with a maximum conductor temperature of 20degC.

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[2] J. A. Pilgrim. Circuit rating methods for high temperature cables. University of Southampton, Electronics and Computer Science: EEE, Doctoral Thesis, 175pp. 2011.

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[4] Electric Cables – Calculation of the Current Rating, IEC, 60287-2-1:2015, 2015.

16 Appendix E – Drawing Package

Provided separately in PON 4476-D6.4 Rev A Drawing Package for Shared Landfall and Cable Route Infrastructure Feasibility Study [9].