

HOP2

Concept Definition

Apollo for Net Zero Technology Centre

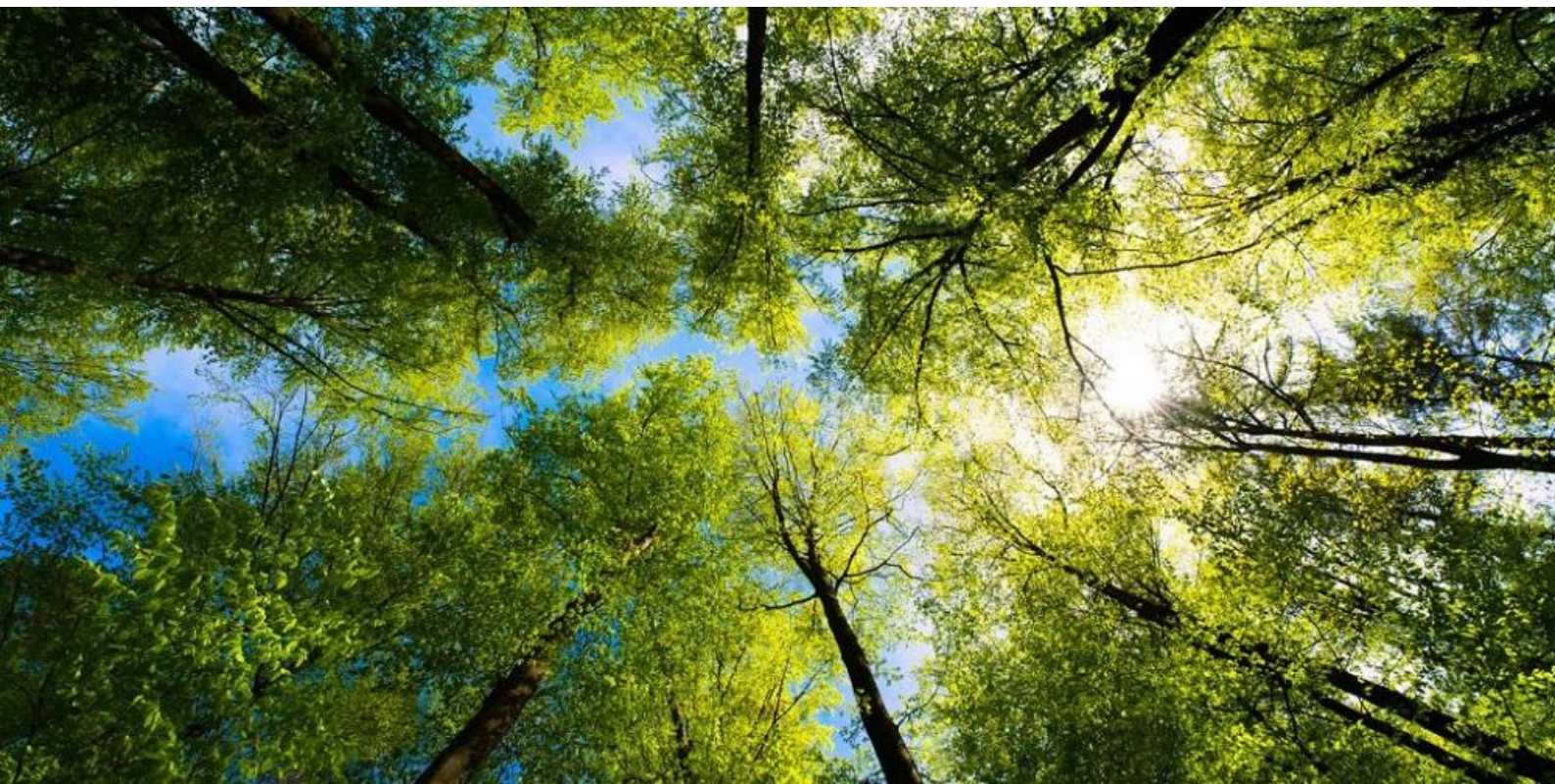


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Definitions and Abbreviations

Abbreviation	Description
AC	Alternating current
AHU	Air Handling Unit
ASME	American Society of Mechanical Engineers
BDV	Blowdown Valve
BoS	Balance-of-Stack
CoG	Centre of Gravity
DC	Direct current
ESD	Emergency Shutdown
GBS	Gravity Bearing Structure
H2	Hydrogen
HOP2	Hydrogen Offshore Platform 2 project – this project
HP	High Pressure
ISO	International Standards Organisation
KO	Knock-out
LP	Low Pressure
MOP	Maximum Operating Pressure
MOT	Maximum Operating Pressure
NOP	Normal Operating Pressure
NOT	Normal Operating Temperature
NZTC	Net Zero Technology Centre – the Client
PAH	Pressure Alarm High
PAHH	Pressure Alarm High High (trip)
PSV	Pressure Safety Valve
TEG	Tri-ethylene glycol
UKCS	United Kingdom Continental Shelf
HVAC	Heating, ventilation and air conditioning
RAM	Risk, Availability, and Maintainability analysis
FMEA	Failure Mode and Effect Analysis
TBD	To Be Determined



Executive summary

The Hydrogen Offshore Production Project (HOP2), funded by the Scottish Government's Just Transition Fund, is a pioneering effort aimed at demonstrating the practicality of large-scale offshore green hydrogen production. This report represents the output of the Concept Definition stage of the project relating to the remaining systems not covered By Others as part of the Balance of Plant (BoP), Balance of Stack (BoS) and primary electrical systems scopes.

A summary of the key outcomes of the design undertaken by Apollo for the Concept Definition study is presented in Figure 1 below.

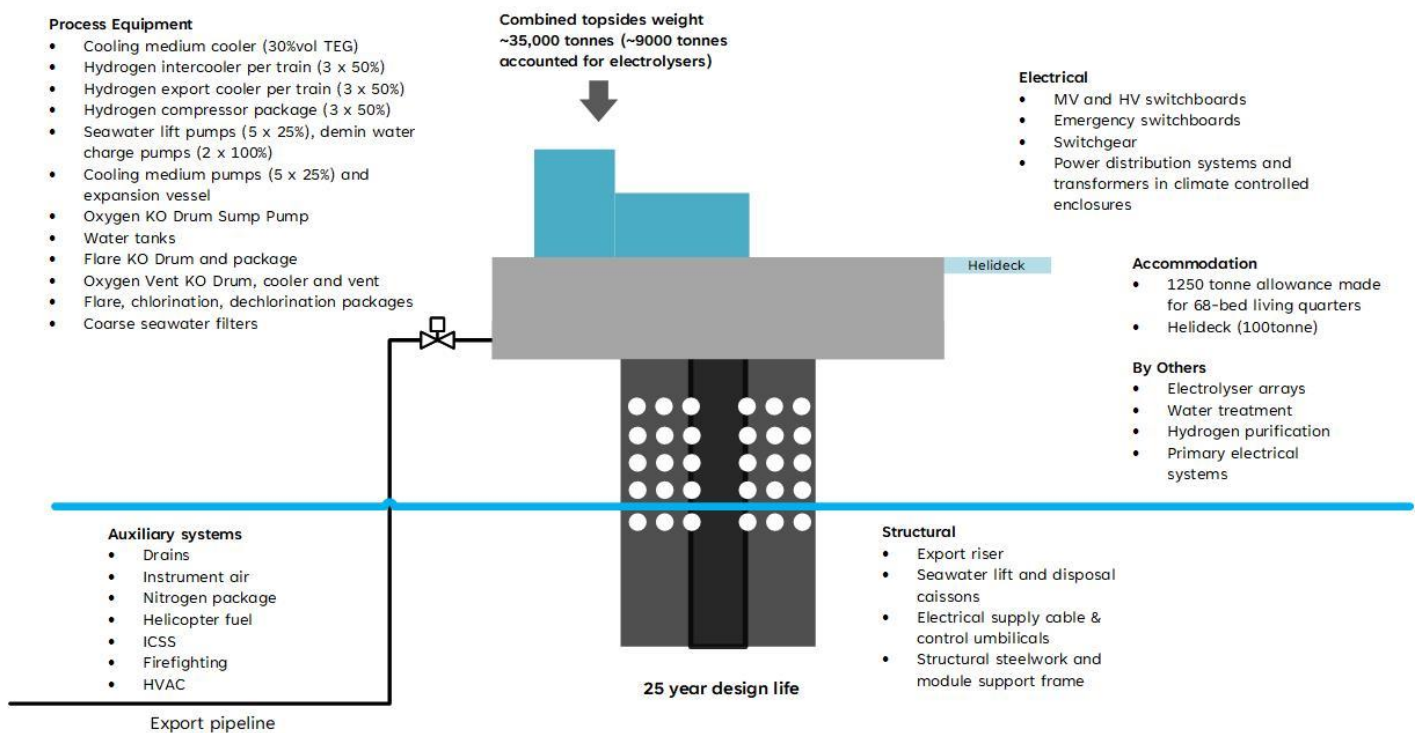


Figure 1 Key Design Data for HOP2 Project

Process

Process design has been undertaken in the Concept Definition stage for the main process systems within the study scope, supported by interface information from the BoP and BoS Contractors. The design comprises:

- Process and Utility Flow Diagrams with integrated material balances
- Process Equipment List for major items of equipment depicting the results of the process equipment sizing, including:
 - Process datasheet for hydrogen compressors
 - Preliminary line list with line data developed for lines greater than 6" diameter
- Flaring, venting and process control philosophies
- Preliminary selection of variable speed drives for major rotating equipment
- Assessment of feasibility of recompressing low pressure hydrogen streams
- Assessment of segregating the cooling systems between hazardous and non-hazardous users



Structural, Layout and Construction

A revised layout has been produced for the HOP2 topsides based upon the updated process and primary and secondary electrical systems. Using modified volumetric norms an estimated dry weight of 31,600t was calculated for the latest HOP2 topside design, with the operating weight estimated as 35,000t. This weight estimate assumes integrated deck construction and includes an allowance for interface steelwork. The overall topsides volumetric density is 0.221t/m³ which compares well with the average norm for a North Sea integrated deck oil and gas platform (0.226t/m³). In comparison to the concept scope, weight reductions have been achieved using the 45MW PEM Electrolysers. However, these have been offset by a significant increase in the quantity and weight of electrical equipment required, as well as additional allowances for interface steelwork and appurtenance weights.

Given the volumetric weight estimating technique adopted, no additional contingencies have been included in the weight estimates. The estimated 35,000t topside operating weight constitutes 92% of the advised 38,000t topside weight limit for the existing Ninian Central GBS, leaving a 1.09 growth factor to account for future project growth or inaccuracy in the volumetric norms. Should the 38,000t topside weight limit be exceeded then this would need to be addressed by reducing the topsides production capacity.

The base case for the platform installation is considered to be an integrated deck design, as this would prove the most efficient in terms of topside weight and overall cost for the topsides (procurement & fabrication). However, at present the only vessel that could install a topside of this weight is the Allseas Pioneering Spirit. To provide flexibility in the installation method, this study looked at the viability of a more traditional modular installation methodology concept. It is concluded that a similar modular installation to the existing NCP topside is viable. However, this would likely increase the estimated operating weight to 37,800t which would leave little margin to the advised topside weight limit of 38,000t for the Gravity Based Structure (GBS), thus elevating the risk of incompatibility between the new topside structure and the existing NCP concrete gravity based. The modular concept would first utilise a Module Support Frame (MSF) which would be installed to the GBS in advance of the installation of several topsides modules. The rest of the topside structure would be split into modules to suit the chosen installation vessel. The largest individual module weight would likely be in the region of 7,500t, which would put the installation within the range of the Saipem 7000 and Heerema's Sleipner and Thialf vessels (the Thialf is likely to be marginal for a 7,500t module).

To mitigate against the complexity and costs of making connections to the existing GBS, it is proposed that appurtenances should be flexible catenaries where possible. This applies to the Import Power Cables, Hydrogen Export Riser and Umbilical. For the Seawater Lift Caissons, it will likely be more practical to utilise the existing conductor guides, subject to review of their integrity. It is proposed that the Seawater Lift Caissons are installed after the topsides using the east platform crane.

Electrical

An overall electrical load list and a single line diagram have been developed for the secondary electrical systems, including their architecture and interfaces with the primary electrical contractor. The following have been provided:

- MV and HV switchboards, emergency switchboards, switchgear, power distribution systems and transformers
- Backup and emergency power systems



Mechanical

The platform's crane design addresses heavy-lift requirements driven by the handling of a 45 Tonne electrolyser transformer. Detailed structural analyses and load assessments guided the specification of two offshore pedestal cranes, strategically located to achieve 80% platform coverage. The selected cranes meet offshore standards, with safe operational lifting capacities of over 50 tonnes, ensuring redundancy and compliance with API and DNV lifting codes.

A comprehensive HVAC design was developed to maintain optimal temperature within the platform's electrical rooms. Thermal load assessments identified cooling requirements of up to 23.4MW (6,651 Ton) across high-power modules, leading to the selection of five chillers and a series of high-capacity Air Handling Units (AHUs). The system ensures thermal stability, protects electrical equipment integrity, and meets offshore layout constraints with a modular ducting and airflow strategy.

To support hydrogen export operations, the platform will integrate three non-lubricated reciprocating compressors, configured in a 3x50% arrangement. Each unit handles 10,000 kg/h of hydrogen, compressing from 29 to 103 barg with inter-stage cooling and zero oil carry-over risk. This configuration enables full throughput flexibility, improves energy efficiency, and ensures compliance with hydrogen purity standards.

Operations and Maintenance (O&M) planning included a Failure Modes and Effects Analysis (FMEA) and a Reliability, Availability, and Maintainability (RAM) study. These assessments identified critical risks that could likely lead to the platform's downtime, such as the oxygen venting system and PEM electrolyser failures, and guided early mitigation strategies to enhance long-term facility reliability and uptime. This work specifies the importance of sparing philosophy and drove to include redundancy within single point failure of equipment within systems.

Control & Instrumentation

A preliminary specification for the ICSS requirements has been developed. The ICSS shall monitor, control and safeguard the topsides systems. It shall comprise of the following main systems while interfacing with package UCPs of topsides / subsea facility:

- PCS – Process Control System
- SIS – Safety Instrumented System, comprising:
 - ESD – Emergency Shutdown System
 - FGS – Fire and Gas System

The ICSS shall be supported by telecommunications infrastructure which shall provide robust, secure, and high-availability communications infrastructure ensuring safe, efficient, and continuous operations. In addition, fiscal metering shall be provided for hydrogen export.

Technical Safety

This study considered a range of leak scenarios of the HOP2, and high-level consequence modelling was performed. The impact of gas dispersion, explosion and jet fire has been assessed following a loss of containment for a variety of leak sizes and pressures across the process. The gas dispersion analysis demonstrated the potential for substantial flammable gas cloud volumes in the event of leaks at all conditions assessed. The explosion analysis identified the potential for significant overpressure in the event of an explosion (on the order of 0.35 barg at up to 9m) which would limit the practical effectiveness of using blast walls to mitigate the risk of explosions. The jet fire assessment demonstrated the potential for significant flame sizes



and potential impingement on adjacent equipment, however, the largest leaks (100mm and some of the 25mm) were not found to cause potential for steel failure due to the limited inventory.

Environmental

A preliminary review of the key environmental and consenting risks was undertaken and actions presented to mitigate impacts where necessary. An assessment of embodied carbon has been produced to estimate embodied and operation carbon emissions arising from the HOP2 project. Potential impacts from the construction and operation of HOP2 identified include seabed disturbance, discharge to sea, atmospheric emissions, underwater noise, and accidental events such as chemical spills and vessel strikes. These impacts could affect water quality, benthic organisms, fish, marine mammals, seabirds and other sea users. HOP2 has been designed to repurpose existing oil and gas subsea infrastructure and to utilise a nearby offshore wind platform as the power source, thereby reducing the need for subsea infrastructure and installation activities. The ultimate end use of HOP2 will reduce overall carbon emissions and impacts to environmental sensitivities in comparison to historic oil and gas use within the North Sea. As project design is further developed, scoping, Environmental Risk Identification (ENVID) and EIA will allow a more detailed appraisal of environmental impact and risks.

Cost Estimate

A Class 4 capital cost estimate has been compiled for the scope items, informed by the Mechanical Equipment List, vendor engagement, line data and other cost inputs developed during the Concept Definition study. The overall estimate for Apollo's scope was approximately £850 million (~30%/+50%) including allowance of 20% for Client costs and contingency of 20%.

Schedule Estimate

A preliminary Level 2 schedule has been compiled for the necessary engineering, design, procurement, construction, installation, commissioning and handover activities for HOP2. The overall duration from beginning of FEED to completion of commissioning was estimated at approximately 5 years based on the integrated deck concept for construction.



1 Introduction

1.1 Background

The Hydrogen Offshore Production Project (HOP2) is a pioneering effort aimed at demonstrating the practicality of large-scale offshore green hydrogen production, ranging from 500MW to 1GW. This is achieved through the strategic repurposing of existing oil and gas infrastructure in the UK Continental Shelf (UKCS) while also evaluating the merits of building an entirely new offshore green hydrogen facility. Figure 2 shows the overall extent of the offshore infrastructure which could be used in the future giving basis to the potential for repurposing as opposed to decommissioning.

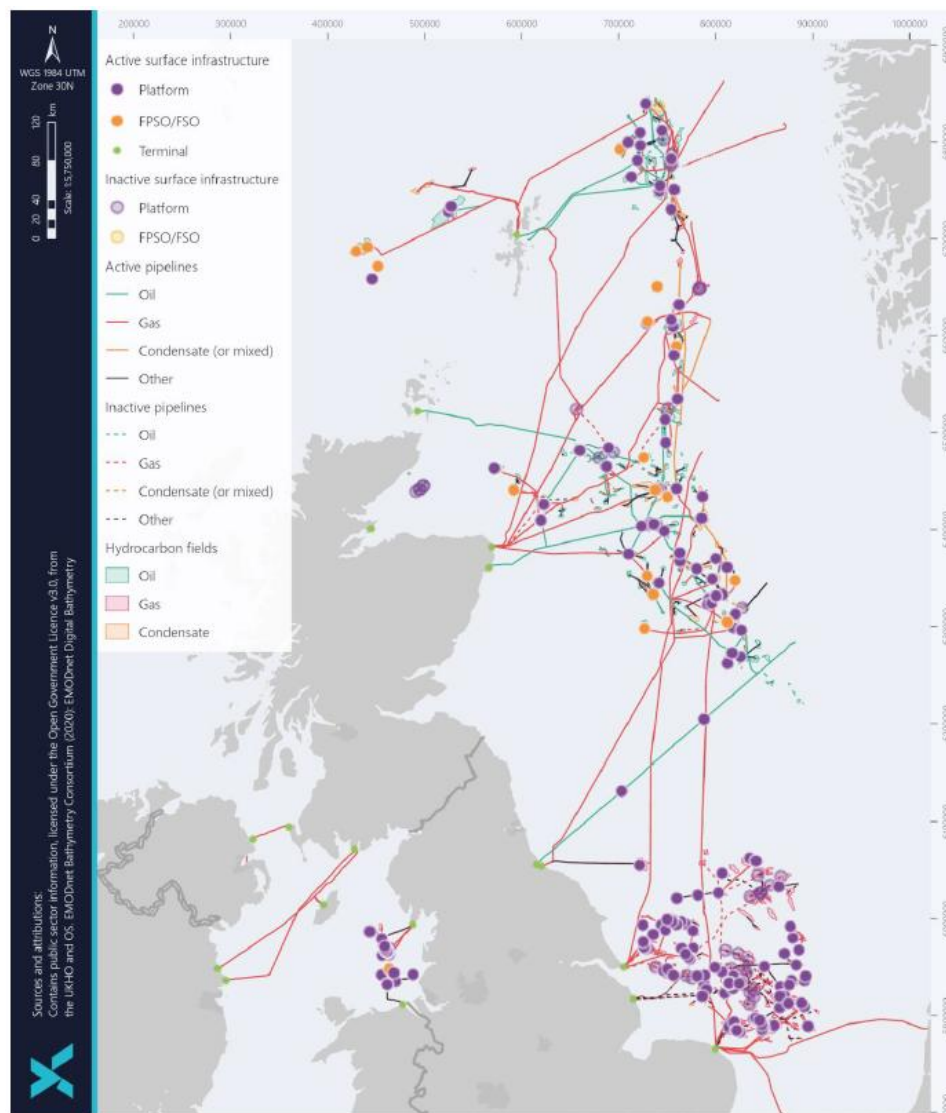


Figure 2 - Mapping of Oil & Gas Infrastructure on the UKCS

HOP2 is the recipient of funding from the Scottish Government's Just Transition Fund, with a core mission of establishing and strengthening the hydrogen production sector in Scotland. Its overarching goal is to generate positive outcomes in terms of job creation, skills development, education, and advancing the broader decarbonisation agenda, particularly in Scotland's North-East and Moray regions.



The North Sea holds a substantial share of cost-effective offshore wind resources, yet much of this potential is located far from the shoreline and existing electrical infrastructure. An opportunity lies in harnessing these remote wind resources by generating green hydrogen directly at the source of electricity generation, capitalizing on the repurposing of existing oil and gas assets.

Phase 1 of the HOP2 project is organized into three key segments: basis of study which has already been complete, concept development, and study reporting. Within the concept development phase, various specific activities have been earmarked for in-depth exploration.

1.2 Previous studies

Apollo supported the previous phase of the study in Phase 1. Apollo reviewed multiple options for the development of HOP2 comprising:

- Option 1A (Single Large Asset): Focused on repurposing a single large asset like the Ninian Central Platform, faced challenges in weight and appurtenance installation.
- Option 1B (Cluster of Assets): Involved repurposing a cluster of platforms for hydrogen production. However, this option was deemed impractical due to safety, process efficiency, and structural integrity concerns.
- Option 1C (Bridge Linked Platform): Utilized an asset complex of bridge-linked platforms, showing feasibility but requiring detailed planning and safety considerations.
- Option 2 (New-Build Layout): Envisioned a new-build asset, offering the most effective layout but with high economic implications and environmental impact.

The recommendations from Phase 1 were presented in Apollo's Phase 1 report and enabled selection of Option 1A (Single Large Asset) for Phase 2.

1.3 Study Objectives

The objective of the Concept Definition study was to further develop the concept of the centralised offshore hydrogen production facility according to the project phasing shown in Figure 2, ready for future design stages such as PreFEED.

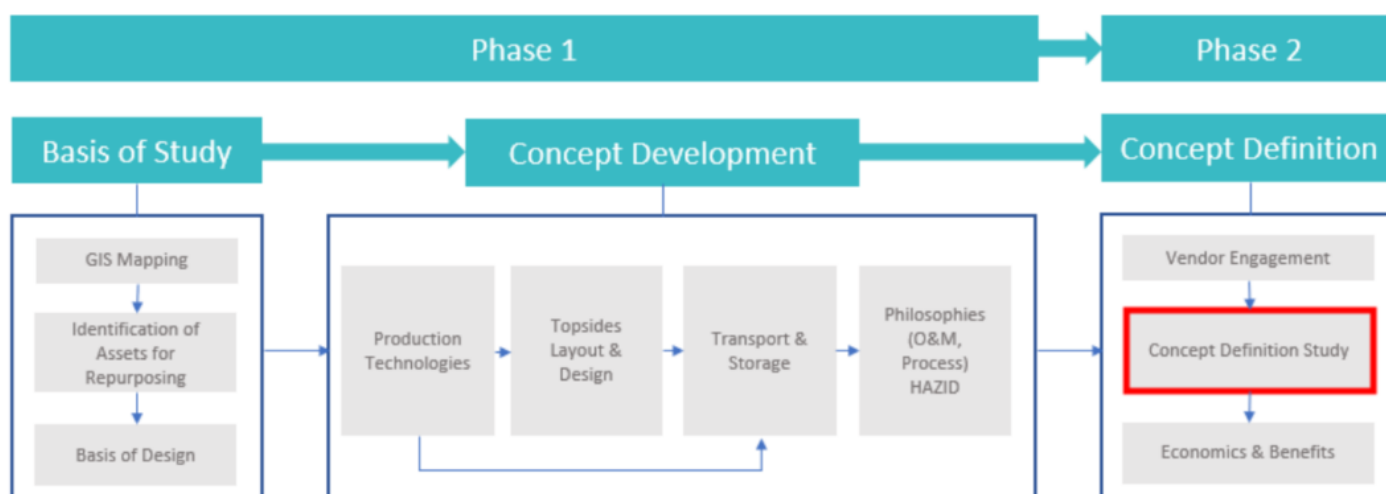


Figure 3 - HOP2 Project Phasing Diagram



1.4 Study Scope

The limit of the systems within Apollo's scope are shown in Figure 3, represented by the Engineering Contractor boxes in light blue. Exclusions from Apollo's scope include the electrolysis packages, water treatment, hydrogen purification and the primary electrical systems which have been undertaken By Others. Interface data has been exchanged between Apollo and the Other Contractors to enable the conceptual design of each system.

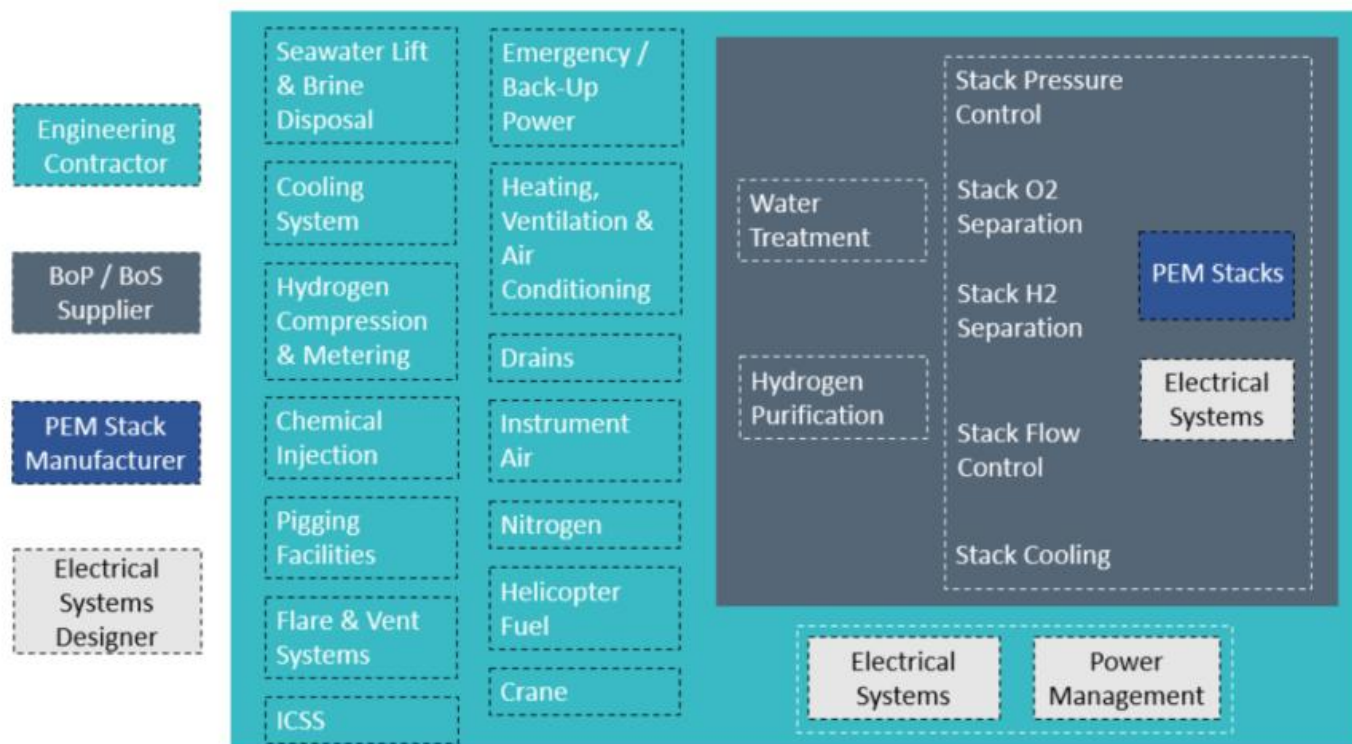


Figure 4 – Concept Definition Study - Topsides Scope Overview

1.5 Study Approach

The Concept Definition study (the subject of this report) comprised multi-disciplinary design of new topsides for the Ninian Central Platform (NCP) based on revised concepts for the electrolysis, water treatment, hydrogen purification and primary electrical systems. The Concept Definition study was undertaken by a multi-disciplinary team comprising:

- Process
- Mechanical (including Heating, Ventilation & Air Conditioning (HVAC), as well as Operations & Maintenance (O&M))
- Electrical
- Structural (including Piping, Layout and Construction)
- Controls & Instrumentation
- Technical Safety
- Environmental
- Estimating (cost and schedule)



Figure 5 below shows the overall outputs from the study.

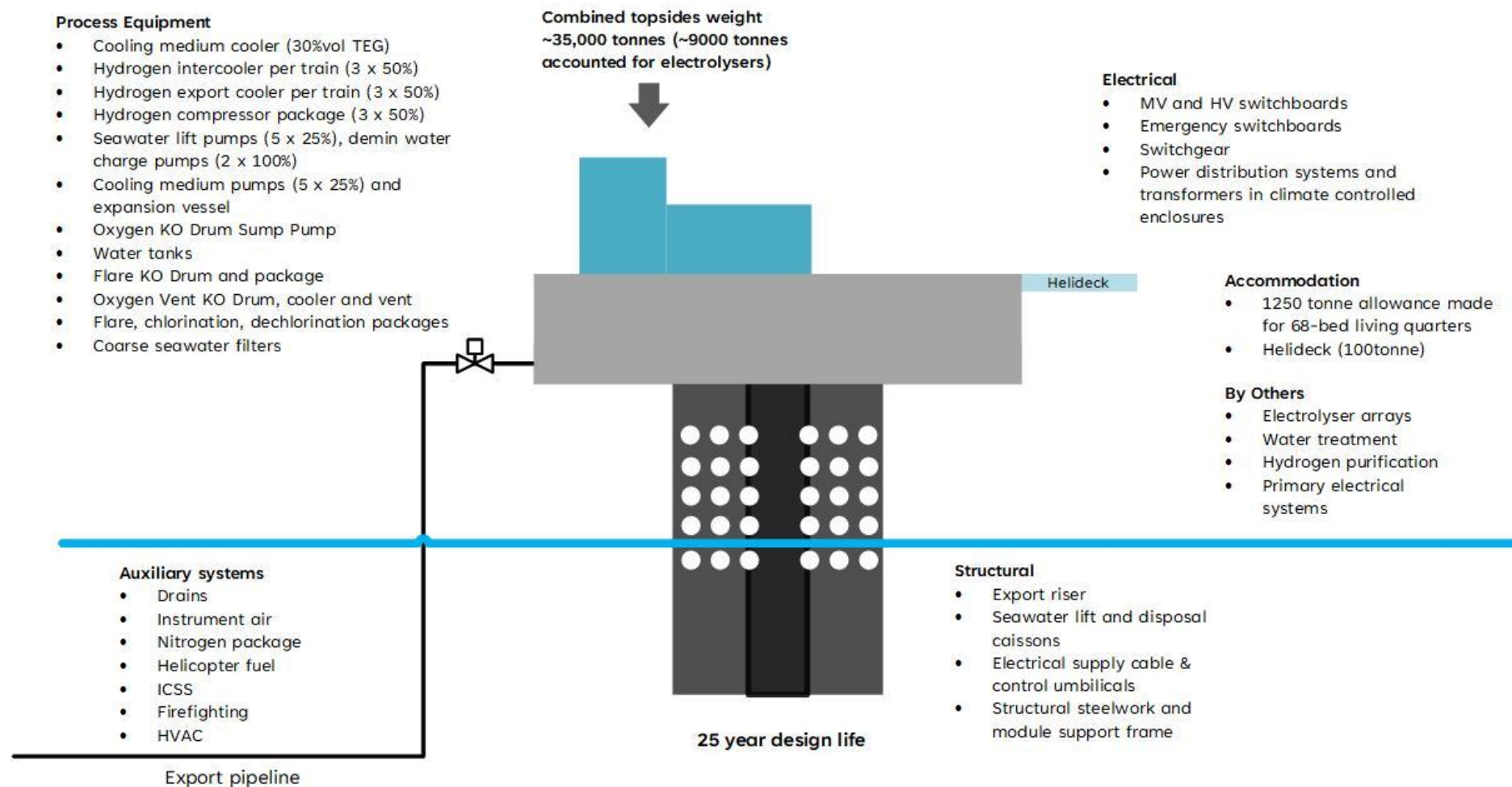


Figure 5 Key design data for HOP2 project

The structure of this report comprises a summary of the multi-disciplinary design outputs, the results of the estimating activities, as well as recommendations for future work.



2 Process

2.1 Process Introduction

The process design during the Concept Definition stage of HOP2 has been significantly revised from previous phases following efforts to decrease the total mass of the new hydrogen topsides. The revised electrolysis configuration is based on 12 overall hydrogen production trains, as well as hydrogen purification to reduce water content to pipeline specifications. The battery limit pressure for the hydrogen export was given as 100 barg at the interface with the pipeline riser. Figure 6 below shows a block flow diagram for the process, supplied by NZTC [1].

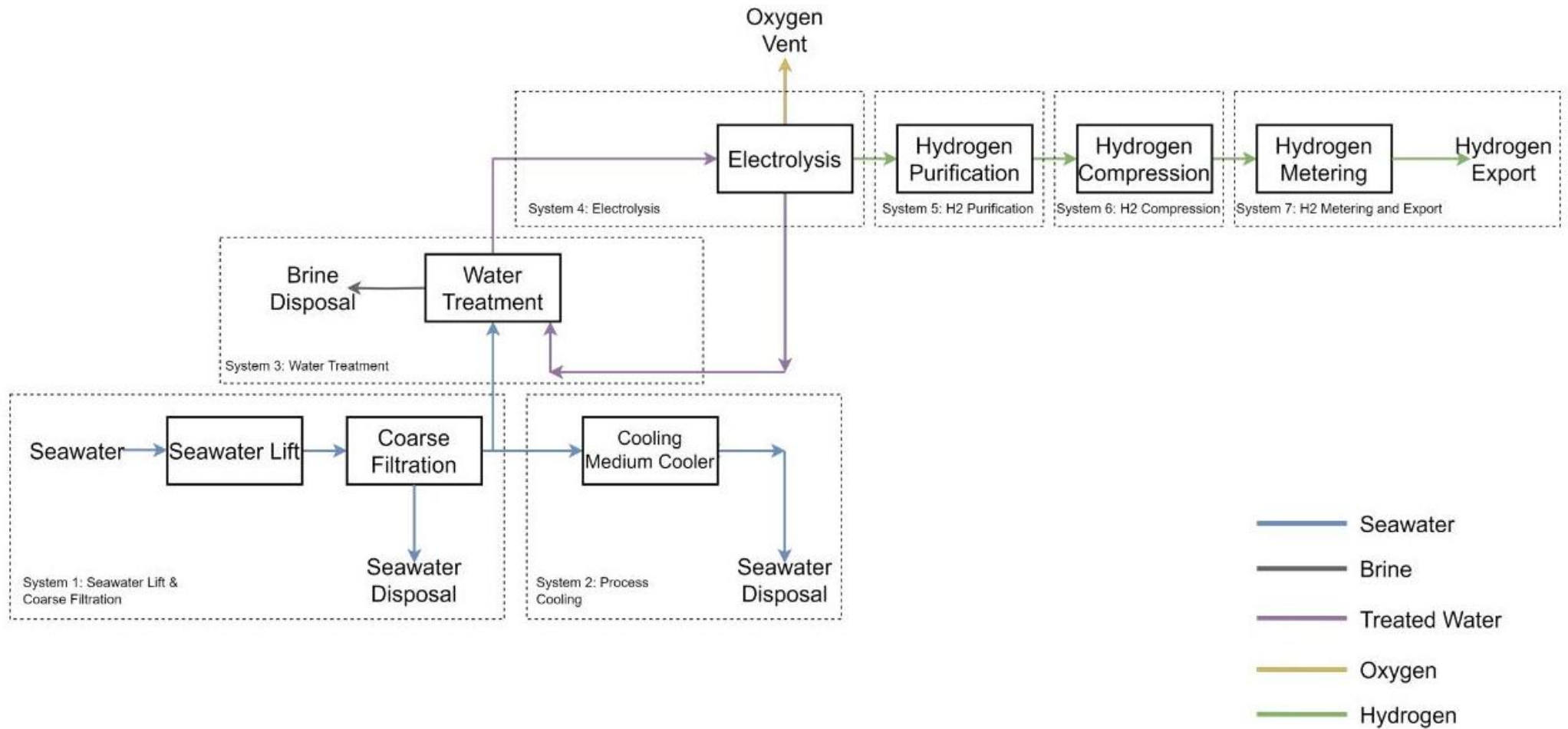


Figure 6 HOP2 block flow diagram [1]



2.2 Process Description

2.2.1 Seawater

Purpose

The seawater system provides:

- Once-through seawater cooling for ultimate heat rejection from the HOP2 heat emitters
- Feedstock for demineralised water production for the electrolysis process
- Collection and disposal of reject streams from the demineralisation process and filter backwash through a new dedicated overboard dump caisson

Description

Seawater Lift Pumps P-1101A-E (5 x 25%) will be submerged in the existing caissons and pump seawater from within the Jarlan Wall into the seawater filters F-1101A-J (10 x 25%) at 5 barg, shown on PFD-001 [2]. Each seawater lift pump P-1101A-E is provided with a dedicated 18" line. Sodium hypochlorite (14wt%) is injected from the chlorination package A-1101 directly into the seawater caissons at a concentration of 1-2mg/L continuously and shock dosing up to 5mg/L. The 18" seawater flow lines convey the chlorinated seawater to the seawater filters F-1101A-J (configured as 2 x 100% per pump where 100% per pump is 25% of the total for the facility). Filter backwash is routed directly to the 36" common outfall header. Downstream of the seawater filters F-1101A-J, the seawater is combined into a common 36" seawater supply header. The 36" common seawater header supplies chlorinated seawater to multiple users, comprising:

- Dedicated minimum flow line supplied with a restriction orifice and automatic pressure differential controller
- The chlorination package A-1101 for measurement of chlorine content
- The de-chlorination package A-1102 and onward to the desalination package A-1201 to produce demineralised water. The de-chlorination package injects sodium bisulphate solution into the chlorinated seawater stream to convert hypochlorite into chloride and prevent rapid corrosion of downstream equipment which is subject to high temperatures.
- The Heating, Ventilation and Air Conditioning (HVAC) package A-2201 chillers for cooling and heating duty
- The cooling medium trim cooler E-1102 for cooling duty
- The cooling medium main cooler E-1101 for cooling duty

The common 36" seawater discharge header collects seawater exiting the heat exchangers, the filter backwash from F-1101A-J, as well as the reject streams from the desalination and electro de-ionisation (EDI) packages A-1201A/B and A-1202A-E, respectively. The discharge header discharges the wastewater overboard outside the Jarlan Wall to avoid recirculation through a new overboard dump caisson.

2.2.2 Demineralised Feed Water

Purpose

The purpose of the demineralised feed water system is to produce demineralised water for the electrolysis process and to provide buffer storage of the demineralised water to facilitate start-up of the electrolysis process.



Description

Seawater downstream of the de-chlorination package A-1102 is conveyed to the water treatment packages A-1201A/B (2 x 50%), shown on PFD-001 [2]. The design of A-1201A/B is By Others. Demineralised water from A-1202A/B is collected and buffered in the array feed water tank T-1201 at 60°C. The array feed water tank T-1201 is blanketed with nitrogen to prevent ingress of atmospheric carbon dioxide into the demineralised water during storage. The nitrogen purge also protects against the occurrence of a flammable atmosphere in the event of hydrogen ingress via minor water recycle streams from the electrolysis package.

The demineralised water charge pumps P-1201A/B (2 x 100%) suction side collects demineralised water from the array feed water tank T-1201 and the discharge side sends the demineralised water to the EDI packages A-1202A-E (5 x 20%) at approximately 9 barg. The design of A-1202A-E is By Others. The reject water from A-1202A-E is sent to the seawater discharge header prior to discharge overboard. The permeate water from A-1202A-E is transferred to the electrolyser packages A-1301A-L (12 x 8%) at 8 barg. The design of the electrolyser packages is By Others.

The array feed water tank T-1201 also collects recovered water from the hydrogen purification package A-1401 and the oxygen vent KO drum V-1701.

2.2.3 Hydrogen

Purpose

The hydrogen system purifies, compresses and meters hydrogen for export.

Description

The hydrogen produced by the electrolyser packages A-1301A-L is saturated with water vapour, shown on PFD-002 [3]. The hydrogen is collected in a common header and supplied to the gas purification packages A-1401A/B (2 x 50%) at approximately 29 barg. The design of A-1401A/B is By Others. Dry hydrogen is collected from A-1401A/B in a common hydrogen header and transferred to the hydrogen compressor packages A-1402A/B/C (comprising of hydrogen compressors K-1402A-C, as well as coolers E-1402/3A-C and supporting systems, all arranged as 3 x 50% parallel trains). The compression is undertaken in two stages in series with intercooling. The discharge pressure of the compressors is approximately 103 barg and reduced to 102 barg downstream of the product coolers.

From the compression train, the high-pressure hydrogen is sent to the hydrogen metering package A-1403 (1 x 100%) which measures the export flow rate to fiscal metering standard as well as quality control of oxygen and Wobbe Index specifications. Downstream of the metering package, the export hydrogen leaves the project through the interface point with the export pipeline at 100 barg at the interface. A pig catcher A-1404 is provided to enable pipeline commissioning and maintenance.

2.2.4 Oxygen

Purpose

The purpose of the oxygen system is to collect warm humid oxygen from the electrolyser packages, cool the stream and recover water vapour to reduce the quantity of fresh make-up required by the electrolysis process. Oxygen is vented to atmosphere at a safe location by a common vent.

Description



Water-saturated oxygen produced from the electrolyser packages A-1301A-L is collected in a single common header at 65°C, shown on PFD-002 [3]. The risk assessment of potential for hydrogen cross-over into the oxygen line is By Others. The oxygen is cooled to condense water vapour by the oxygen vent cooler E-1701 and the two-phase mixture separated in the oxygen vent KO drum V-1701. The cooled, dehumidified oxygen is vented to atmosphere via an oxygen vent stack at approximately 40°C, discharging at a safe location. Water recovered in V-1701 is pumped by the oxygen KO sump pump P-1701 (1 x 100%) at approximately 1 barg discharge pressure into the array feed water tank T-1201.

2.2.5 Cooling

Purpose

The cooling system transfers heat from the HOP2 process users to the once-through seawater coolers.

Description

The cooling system is a closed loop of 30vol% TEG in water (TEG), shown on UFD-002 [4]. The TEG system expansion vessel T-1501 – operating at approximately 47°C is a vertical pressure vessel that allows for thermal expansion volume within the TEG loop. T-1501 is provided with a temporary connection for first fill and ongoing top-up with totes of TEG. Corrosion inhibitor and biocide are injected into T-1501. The headspace of T-1501 is purged with nitrogen to prevent oxygen ingress (for limiting oxidation corrosion) as well as hydrogen detection (in the event of a heat exchanger leak).

Cooling medium circulation pumps P-1501A-E (5 x 25%) suction sides are connected to the TEG system expansion tank T-1501 and the discharge side sends TEG to the cooling medium main cooler E-1101 at approximately 4.5 barg which is provided with an operational bypass to direct part of the TEG flow downstream of E-1101. In normal operation, approximately half of the TEG bypasses E-1101, while the portion cooled by E-1101 exits at 33°C and both streams are mixed downstream to achieve an average temperature of 42°C.

A slipstream of cool TEG is directed to the cooling medium trim cooler E-1102, while the majority of the TEG is transferred to the electrolyser packages A-1301A-L (12 x 8%) via piperacks on both process decks. Each electrolyser array package take-off is provided by a tee-piece connection from the TEG supply header. Downstream of the electrolyser array packages which transfer heat into the TEG, the TEG return lines are combined into a common header that transfers the hot TEG at 60°C along the piperacks to the desalination packages A-1201A/B (2 x 50%). The common TEG header is split into two to provide hot TEG to each of the desalination packages which transfer the heat from the TEG to the desalination process (i.e. the opposite direction from all the other TEG heat exchangers on the HOP2 project). The design of A-1201A/B is By Others. Warm TEG exiting the desalination packages A-1201A/B at 48°C is combined into a single header together with returning warm TEG slipstream from the E-1102 leg.

The slipstream of cool TEG that exits E-1102 is sent to the process heat exchangers at 23°C in hazardous areas on both process decks, connected by individual take-offs from a common header. The users comprise:

- Oxygen vent cooler E-1701 (1 x 100%)
- Gas purification packages A-1401A/B (2 x 50% connections, further detail of splits into individual heat exchangers By Others)
- Hydrogen intercoolers E-1402A/B/C (3 x 50%)
- Hydrogen product coolers E-1403A/B/C (3 x 50%)



- A bypass line comprising a restriction orifice and manual valve with position set and locked at commissioning.

The warm TEG return lines from the process heat exchangers (as well as the bypass) are combined into a single return header at approximately 40°C and mixed into the main TEG return header prior to returning to the TEG system expansion vessel at approximately 47°C.

2.2.6 Hydrogen Flaring and Venting

Purpose

The hydrogen flaring and venting systems provide safe disposal routes for hydrogen from the process in the event of process upset, maintenance and/or other process depressuring requirements.

Description

Various hydrogen flare users are combined into a common hydrogen flare header which is swept with nitrogen from the nitrogen package A-1801 to prevent air ingress, shown on UFD-001 [5]. The nitrogen purge is for the whole header to the flare stack, which includes a continuously sparking tip to ensure ignition of any hydrogen. The hydrogen flare header discharges into the flare KO drum V-1601 which separates entrained water from the gases before sending the gas to the flare package A-1601. The flare package A-1601 comprises the flare stack, tip, ignition and flame detection equipment; the flare is not lit when there is no gas release into the flare header. The flare tip includes a molecular seal to minimise the quantity of nitrogen purge required to keep the header free of air.

The process releases into the hydrogen flare header are not normally expected to include substantial quantities of water as the majority of the flare users would have dry hydrogen inventories. Therefore, the liquid knock-out function of V-1601 is not expected to recover substantial quantities of water, and the liquid discharge line has been connected to discharge overboard.

The electrolyser packages A-1301A-L are each provided with a secondary small hydrogen vent to discharge small amounts of low-pressure hydrogen (<5 kg/hr total for all arrays at 0.5 barg, as informed by NZTC [6]). Four options were considered to process the low-pressure vent streams, comprising:

- Recompression into the product line: not feasible by inspection due to the low suction pressure. Installing a dedicated compressor would not be practicable because such a low inlet pressure would require substantial energy and likely outweigh the merit of recovering the energy which could otherwise be directed towards production of hydrogen. In addition, a low-pressure compressor would create a high pressure / low pressure interface from the higher-pressure downstream equipment which would require consideration.
- Combination into main hydrogen flare: not feasible because the main hydrogen flare header may operate at higher pressure (>2barg).
- Dedicated very low-pressure flare: not feasible due to the low flowrate (<5 kg/hr) which is significantly lower than the minimum size of flare generally deployed in industry.
- Dedicated cold vents: recommended option, each array provided with a dedicated vent which is to be directed away from sources of ignition.



2.2.7 Nitrogen

Purpose

The nitrogen system provides inert nitrogen gas for preventing the mixing of air with flammable process gas prior to, during and after activities such as maintenance. In addition, nitrogen is used for continuous purging the flare header and stack.

Description

The nitrogen package A-1801 generates nitrogen of at least 95% purity from a dedicated air intake and buffers the nitrogen in a receiver, shown on UFD-001 [7]. Exhaust air from the nitrogen package is discharged to the atmosphere. From the nitrogen receiver, individual nitrogen users (such as the flare header purge) are connected to the nitrogen distribution header with hard-piped connections of either piping or instrument tubing, where appropriate.

2.2.8 Auxiliary Systems

Table 1 below describes the auxiliary systems to be provided for the project, shown on UFD-001 [5].

Table 1 Auxiliary systems process description

System	Purpose	Description
Instrument air A-1901	Provide instrument air to pneumatically-actuated valves and accumulators	Containerised instrument air compression, filtration, drying, instrument air receiver and distribution header.
Heating, ventilation, air conditioning (HVAC) A-2201	Provide cooling to electrical equipment rooms. Secondary purpose to provide heating in winter to maintain minimum operating temperature.	Chillers, chilled water distribution, air handling units (AHUs), air ducting
Backup and Emergency Power Supply Packages A-2001 and A-2101	Provide backup, startup and emergency power when offsite renewables power is not available.	Packaged diesel generator skids with on-skid day tank storage

2.3 Process Control Philosophy

2.3.1 Major Control Loops

Seawater flow control

The seawater pumps P-1101A-E are supplied with variable speed drives (VSD) to respond to changes in demand for seawater flow as well as compensate for tidal variations in suction head. Each end user of seawater is controlled by a flow control valve, plus the bypass line which is controlled by a pressure differential controller that opens on high differential pressure. Additional pumps will automatically start at staggered levels of decreasing discharge pressure to provide additional seawater flow.

Demineralised water

The level controller on the array feed water tank T-1201 resets the setpoint of the water treatment packages A-1201A/B. The flow controller downstream of the demineralised water charge pumps P-1201A/B is reset by the electrolyser package total flow setpoint.



TEG cooling

The cooling medium main cooler E-1101 flow controller setpoint is set according to the total load of the facility, the flow control valve increases or decreases the flowrate of warm bypass TEG to maintain the flowrate of the combined stream. The temperature of the combined stream is maintained by a temperature controller acting on the seawater flowrate on the cold side of the main cooler E-1101.

Individual flow controllers are provided per train for each of the TEG users to control the quantity of cooling for each section of the process individually. A bypass flow line is provided to allow minimum flow of TEG through the loop during offline periods to prevent sedimentation and microbial growth in the lines. The bypass line is provided with a manual valve operated by a handwheel that is to be set during commissioning and locked in position.

2.3.2 Normal Startup and Shutdown – High Level Sequence

Pre-start checks

The pre-start safety checks comprise:

- Nitrogen and instrument air packages (A-1801 and A-1901, respectively) are required to be operational
- Electrical and control systems are required to be fully functional and ready to start
- Nitrogen purges of systems handling hydrogen all proven complete
- Demineralised water buffer storage is sufficient to commence hydrogen production, load with bunkered demineralised water from temporary connection if necessary

Seawater lift and cooling

Once the pre-start checks are complete, one of the seawater lift pumps P-1101A-E will be started, commencing the lift of seawater which is initially sent to the HVAC chillers A-2201 to cool the control, electrical and the variable speed drive (VSD) equipment associated with the duty seawater pump. Excess seawater is discharged to the disposal overboard via the pressure differential controller bypass. The chlorination package A-1101 is started simultaneously with the seawater lift pump.

TEG cooling

Once the HVAC cooling is operational, the flow of seawater is increased and additional flow sent to the cooling medium main cooler E-1101 and cooling medium trim cooler E-1102. One of the cooling medium circulation pumps P-1501A-E is started to enable the flow and cooling of TEG. The E-1101 TEG bypass is normally closed at start-up as E-1101 can accommodate the full start-up TEG flowrate, therefore, all the TEG is directed via the cooling medium main cooler E-1102 into the cooling medium trim cooler E-1102, through the bypass flow line and return to the TEG system expansion vessel T-1501. Circulation of TEG through the heat exchangers is then commenced and the cooling medium system is operational, further flow of TEG and further cooling medium circulation pumps may be started in response to demand for cooling.

Electrolysis

The electrolyser arrays A-1301A-L are activated once the stack cooling is established. Demineralised water is drawn from the array feed water tank T-1201 by starting the duty demineralised water charge pump P-1201A/B on minimum flow using the VSD. The electro deionisation packages A-1202A-E are then started and forward flow of demineralised water provided to the electrolyser arrays. The start-up description of the electrolysis process is By Others.



Water treatment

Once hot TEG at 60°C is produced from the electrolyser arrays A-1301A-L, the water treatment plant is started, the de-chlorination package A-1102 is started and forward feed of seawater to desalination is commenced. The seawater system operational and additional flow of seawater can be provided by increasing the speed of the operating seawater lift pump P-1101A-C or starting additional pumps. The demineralised water system is then operational and additional forward flow of demineralised water can be achieved by adjusting the speed of the duty demineralised water charge pump P-1201A/B. The description of the desalination process start-up is By Others.

Oxygen cooling

Water collected in the oxygen vent KO drum V-1701 because of cooling by the oxygen vent cooler E-1701 will cause the liquid level to rise in V-1701. The non-condensable oxygen vapour leaves the oxygen vent KO drum V-1701 and is vented to atmosphere via the oxygen vent stack. Once the liquid in the oxygen KO drum V-1701 reaches the minimum level, the oxygen KO dump pump P-1701 will be automatically started under level control, initially on full recycle. Once the level in the oxygen KO drum V-1701 reaches the normal liquid level, the V-1701 level controller will be switched to automatic mode and condensed water returned to the array feed water tank T-1201. The oxygen system is then operational.

Hydrogen purification and compression

Initially, the hydrogen produced by the electrolysis arrays A-1301A-L is directed to flare because the gas is initially off-specification with nitrogen, oxygen and water. Note the oxygen content is not expected to be sufficient to permit a flammable atmosphere, it is standard industry practice that a safety trip within the electrolyser package would shut the process down before an internal flammable composition would be reached. The design of the safety trips in the electrolyser packages is By Others. Once satisfactory hydrogen quality is achieved from the electrolyser packages, the forward flow of hydrogen to the gas purification packages A-1401A/B is commenced to enable the drying of the hydrogen. The description of the start-up of the gas purification packages A-1401A/B is By Others.

Once dry hydrogen is produced from the gas purification packages A-1401A/B, forward flow to the hydrogen compressor packages A-1402A/B/C is commenced to displace nitrogen and the compressors are lined up to flare. Once the hydrogen compressor packages A-1402A/B/C are free of nitrogen, a single compressor may be started on minimum flow to build hydrogen pressure. The final segment of high-pressure hydrogen piping and metering package are then pressurised and nitrogen displaced by hydrogen. Once the hydrogen system is on-specification, export may begin. The facility is then fully operational and the start-up procedure complete. Additional hydrogen compressors can be started in response to increased flow of hydrogen from the electrolyser array packages A-1301A-L. It is expected that the master controller to be designed and specified by the compressor vendor would intelligently adjust stroke rate, volume and potentially a stepless valve to achieve direct turndown to approximately 30% per compressor (i.e. minimum of 1,500 kg/h minimum per 1 x 50% compressor operating). Turndown below 30% would be provided by opening a partial recycle from the compressor discharge to the inlet.

Shutdown

Shutdown will be undertaken in reverse of start-up, beginning with unloading of the hydrogen compressors. Seawater and TEG flows will be maintained throughout shutdown to ensure residual heat is rejected from the process and avoid causing a high temperature excursion. Nitrogen purging of individual segments will commence once hydrogen production stops and continue until the appropriate number of volume changes of



nitrogen in each segment has been verified. The hydrogen/nitrogen mixture from the purging will be directed to flare. TEG flow is stopped once the process equipment has cooled down, but seawater flow is required to continue to maintain HVAC cooling until the HVAC chillers are no longer required.

2.4 Emergency Shut Down Philosophy

The shutdown system shall be divided into 4 hierarchical levels based on the severity of the shutdown [8]:

- Level 1 Emergency Shut Down (ESD): Abandon installation (prepare to)
- Level 2 ESD: Emergency shut down and depressurisation
- Level 3 ESD: Process shutdown, no depressurisation
- Level 4 ESD: Shutdown of individual process packages

Individual trains have been provided with ESD valves to enable emergency isolation in the event the basic process control system (BPCS) fails to maintain key operating parameters. The ESD system shall aim to prevent further escalation to relief by undertaking automatic actions to rectify abnormal operating conditions and shut equipment down if necessary. Relief valves have been provided within isolatable sections to protect against scenarios that would not be adequately resolved by the ESD system such as fires.

2.5 Variable Speed Drive (VSD) Selection

Variable Speed Drives (VSD) have been recommended for two pumps:

- P-1101A-E: Recommended to be controlled by VSD due to variation in suction head because of tidal range as well as ability to minimise starting currents for large motors.
- P-1201A/B: Recommended to be controlled by VSD due to variation in discharge head requirements: at part load the static head requirement may be decreased if only the lower level of electrolyser arrays is operating. In addition, the reduction of frictional losses in the lines at part load (potentially as low as 10%) would encourage the use of VSD to minimise wasted pump head.

2.6 Assessment of Segregation of Cooling System

The study has provided indirect TEG closed loop cooling for hazardous areas of the plant. The selection of an indirect TEG loop enables the detection of leaks and compartmentalises the potential for a leak of hydrogen (or oxygen) to transfer to equipment and areas that would not normally be in a hazardous area.

Two options were considered for providing cooling to the HVAC which comprises a large cooling demand (approximately 30MW.th i.e. of the same order of magnitude as the cooling medium main cooler E-1101 design basis), as summarised in Table 2 below. HOP2 is recommended to proceed with direct seawater cooling for the HVAC as titanium options are readily available for chillers, and the disbenefits of additional head and pipework have been minimised as far as practicable during the development of the process layout.

Table 2 Selection of HVAC coolant

Option	Pros	Cons
Dedicated TEG loop	Permit the use of carbon steel materials in the chillers	Fully dedicated TEG loop required with ancillaries (expansion drum, pumps) that cannot be shared with the process cooling loop which is hazardous



Direct seawater cooling	Only requires the chillers to be suitable for seawater (titanium or equivalent), no separate cooling equipment required	Additional seawater pipework to the chillers rather than adding capacity in the cooling medium main cooler E-1101 and/or trim cooler E-1102. Potential for additional head requirement from the pumps if the HVAC chillers become the design case for head loss for the seawater lift pumps.
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3 Mechanical

This section presents the mechanical design for the HOP2 Concept Definition Phase, defining the required mechanical equipment and systems to operate safely and efficiently the offshore hydrogen production facility. The concept includes the specification of major mechanical systems including lifting equipment, HVAC, compression systems, and operability and maintenance studies. The major equipment and systems were designed as follows:

- The crane design is defined through detailed structural analysis to ensure safe handling of heavy equipment under offshore conditions.
- The HVAC system has been designed to meet the cooling demands of heat-generating electrical modules, with capacity, airflow, and ducting based on thermal load assessments.
- The compressor system specification defines the operating conditions and integration approach for the hydrogen compression units.
- The operations and maintenance strategy is supported by a Failure Modes and Effects Analysis (FMEA) and a Reliability (Appendix G), Availability, and Maintainability (RAM) study (Appendix H), which together identify critical failure points and optimise the system’s uptime throughout the facility’s lifecycle.

3.1 Vendor Engagement

Vendor engagement has been undertaken during the Concept Definition phase to support the mechanical equipment selection and cost estimating activities for major mechanical equipment items. Refer to table below for a summary of the vendors that have provided valuable information to the study.

Table 3 Vendor engagement

Equipment type	Vendors
Heat exchangers	AICS, Alfa Laval, Kelvion
Hydrogen compressors	Burckhardt, Chart

3.2 Cranes

The crane requirements for the HOP2 facility have been specified from a combination of structural calculations, lifting capacity evaluations, and layout considerations tailored to the operational demands of the 500MW offshore hydrogen production facility, see Appendix C. The loading driver for crane requirements is defined by the need to safely handle the heaviest single lift associated with platform equipment, this lift being the 45 tonne 55MVA Electrolyser Transformer (E025).

The configuration and layout of the crane system involves two pedestal cranes, each strategically positioned at a 90-degree angle relative to one another to maximise operational coverage while minimising interference. This layout covers approximately 80% of the platform’s area, including all designated drop zones, shown in Figure 7 below.

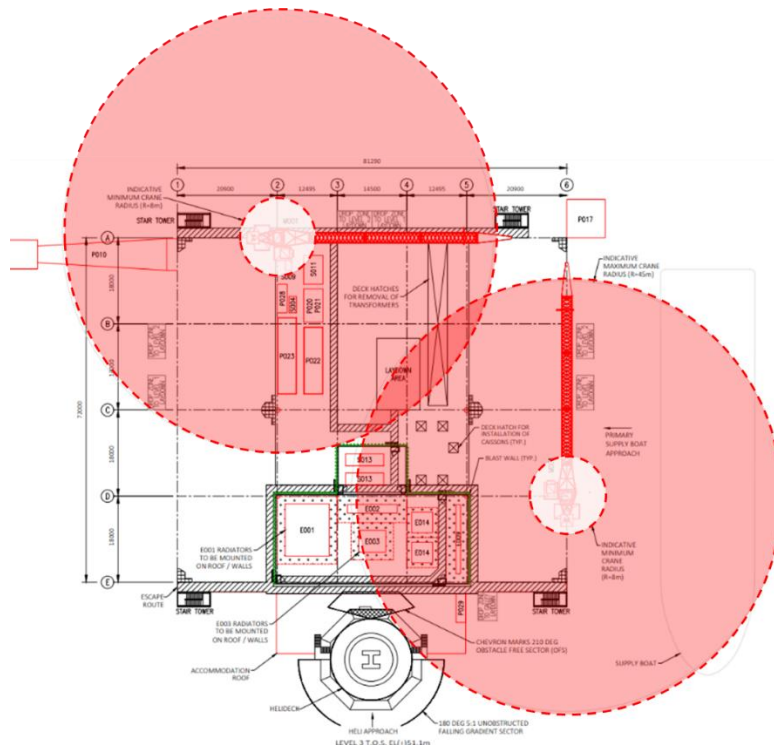


Figure 7 Crane's operating area

The selected crane is a commonly used design used for offshore platforms. It features a 45m box boom made of S690QL high-strength structural steel, with a hollow rectangular cross-section measuring 0.8m in width, 1.2m in height, and 25mm in wall thickness. The crane is mounted on an 8m tall pedestal with a 2.5m outer diameter and has 60mm wall thickness, designed with a stable base capable of withstanding substantial overturning moments without structural compromise.

The crane's lifting capacity was assessed using both API spec 2C and DNV-ST-0378 standard methodologies. From the calculations carried out using the API guidelines, accounting for the stated boom's geometry and material properties yield (see Appendix C Crane requirements), gives a static lifting capacity of 52.48 tonnes at full reach of 45m. After applying a dynamic amplification factor of 1.1 (used for fixed offshore platforms) and a conservative load chart reduction factor of 0.95, the crane's safe operational lifting capacity is of **50.22 tonnes**.

Further validation under DNV-ST-0378 guidelines (see in Appendix C Crane requirements), confirms the pedestal structure itself is capable of withstanding lifting loads up to 299.48 tonnes, thereby establishing the boom as the limiting component of the crane's safe load capacity.

The 45-tonne transformer lifting operation occurs at a 30m horizontal reach, this being the reach required to service the north laydown area, at a boom angle of approximately 48.2°. In this maximum lift operation, the crane remains within 60% of its maximum lifting capacity, well under its safety operational limits.

The proposed crane selection ensures safe, reliable, and compliant lifting operations aligned with offshore industry standards.

3.3 HVAC System

As part of the HOP2 Concept Definition Phase for a 500MW offshore hydrogen production facility, a comprehensive Heating, Ventilation, and Air Conditioning (HVAC) analysis was conducted to define the HVAC



requirements of the electrical rooms of the HOP2 facility. The scope included the sizing of cooling systems, airflow demands and ducting sizing for each of the platform's electrical rooms. The design requirement is to ensure optimal room temperature for the electrical equipment performance, while accounting for the platform's spatial constraints.

The drivers for HVAC system sizing are the significant heat gains from high-capacity electrical equipment, including transformers, rectifiers, switchgear, and harmonic filters. These components continuously provide heat during operation. Without adequate cooling, it will lead to overheating, resulting in equipment degradation and operational hazards. It is assumed optimal electrical equipment performance is 20°C with a $\pm 15^\circ\text{C}$ [9]. Also, seawater cooling design temperature is assumed to be 15°C [10], which, after the chillers, will make the air supply temperature of around 6°C. A schematic of how the HVAC system works can be seen in Figure 8.

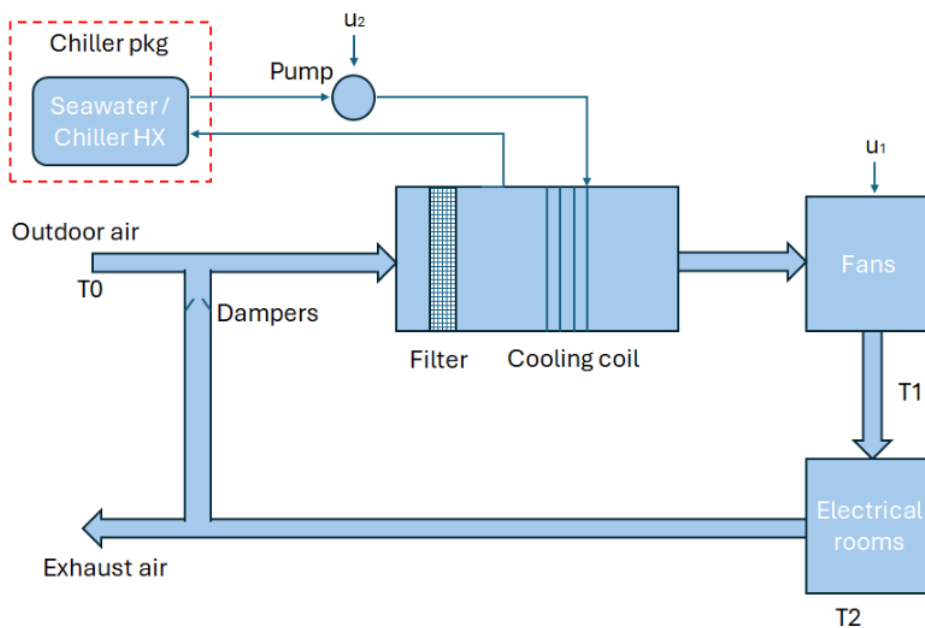


Figure 8 HVAC Block flow diagram

The HVAC calculations (see Appendix D HVAC Requirements) follow guidance from ASHRAE standards and manufacturer specifications. Equipment selection was guided by catalogue data from reputable vendors (Trane, Carrier), to extract design data, including specifications, ratings, sizes and weight.

3.3.1 HVAC Requirements

Cooling loads were calculated for each electrical room based on heat added to the room due to the equipment's power losses converted into heat, minus the room's heat dissipation due to the heat conduction of the wall's surface and the ambient air. Rooms were categorised by their electrical equipment and room sizes, as shown in the Figure 9 below.



Figure 9 Rooms categorisation for HVAC requirements



Table 4 Cooling requirements

Room	Equipment	Conductive losses (kW)	Total cooling required per room (Ton)
A	Transformers (E025) 2 x Thyristor rectifier (E026) 2 x DC Switchgear (E027) QCOMP (E028)	631	687
B	Transformers (E025) 2 x Thyristor rectifier (E026) 2 x DC Switchgear (E027) QCOMP (E028)	521	718
C	Generators (E022/23)	456	182
F	Variable speed drives (E024) 2 x HVAC XFMR (E015) HVAC SWBD (E012) 2 x Harmonic filters (E007) 2 x Harmonic filters (E008) 66kV GIS (E005)	1115	260
G	Main transformer (E001) 275kV GIS (E002) 2 x 6/11kV XFMR (E014) 11kV SWBD (E009)	1115	71
H	8 x transformer (E035) switchboard (E034)	894	69

Rooms C.1, D, D.1, and E have minor equipment with combined loads under 100kW, which, when calculating the room's cooling requirements, result in negligible or negative values. Therefore, these rooms are not considered for active cooling. However, a 60,000 CFM AHU will be placed to cool or heat up these rooms in case of extreme temperatures. For this extreme scenario, a duct of 8 ft² has been selected to feed cooling or heating to these rooms.

The total platform cooling requirement, which accounts for 10 Rooms A/B, Room C, Room F, Room G and Room H operating simultaneously, after applying a conservative 90% load factor to account for not all equipment operating at its full capacity, it was calculated the total cooling load is of 6651 Ton. To address this, five 1500 Ton chillers were specified following discussions with vendors to support the concept. These units fit within the mezzanine deck footprint and offer redundancy, energy efficiency, and ease of integration (see Appendix D HVAC Requirements).

The Air Handling Units (AHUs) were sized to match airflow requirements following cooling requirement calculations (see Appendix D HVAC Requirements). The following AHUs have been selected to provide the required airflow:

- Rooms A & B together require over 1,465,000 CFM, served by 12 x AHUs, each rated at 125,000 CFM.
- Room C, F, G and H require 108,000 CFM, covered by 2 AHUs, each rated at 60,000 CFM.



The ductwork was designed for efficient routing and minimal interference with structural and deck size limitations. Duct sizing is based on an exhaust velocity of 2000 ft/min [9] (assumed for main ducts). The maximum individual duct size is capped at 30 ft² for practicality. For larger flow rates, multiple ducts of this size will be used per room. From the ducting calculations carried out in Appendix D HVAC Requirements, the ducts are required for each of the rooms are shown in Table 5below.

Table 5 ducting requirements

Room	ducts
A	3 x 30 ft ²
B	3 x 30 ft ²
C	20 ft ²
F	28 ft ²
G	8 ft ²
H	8 ft ²

This modular ducting strategy simplifies installation and maintenance while ensuring that airflow requirements are met across all rooms. The duct routing proposed is shown in Figure 10.

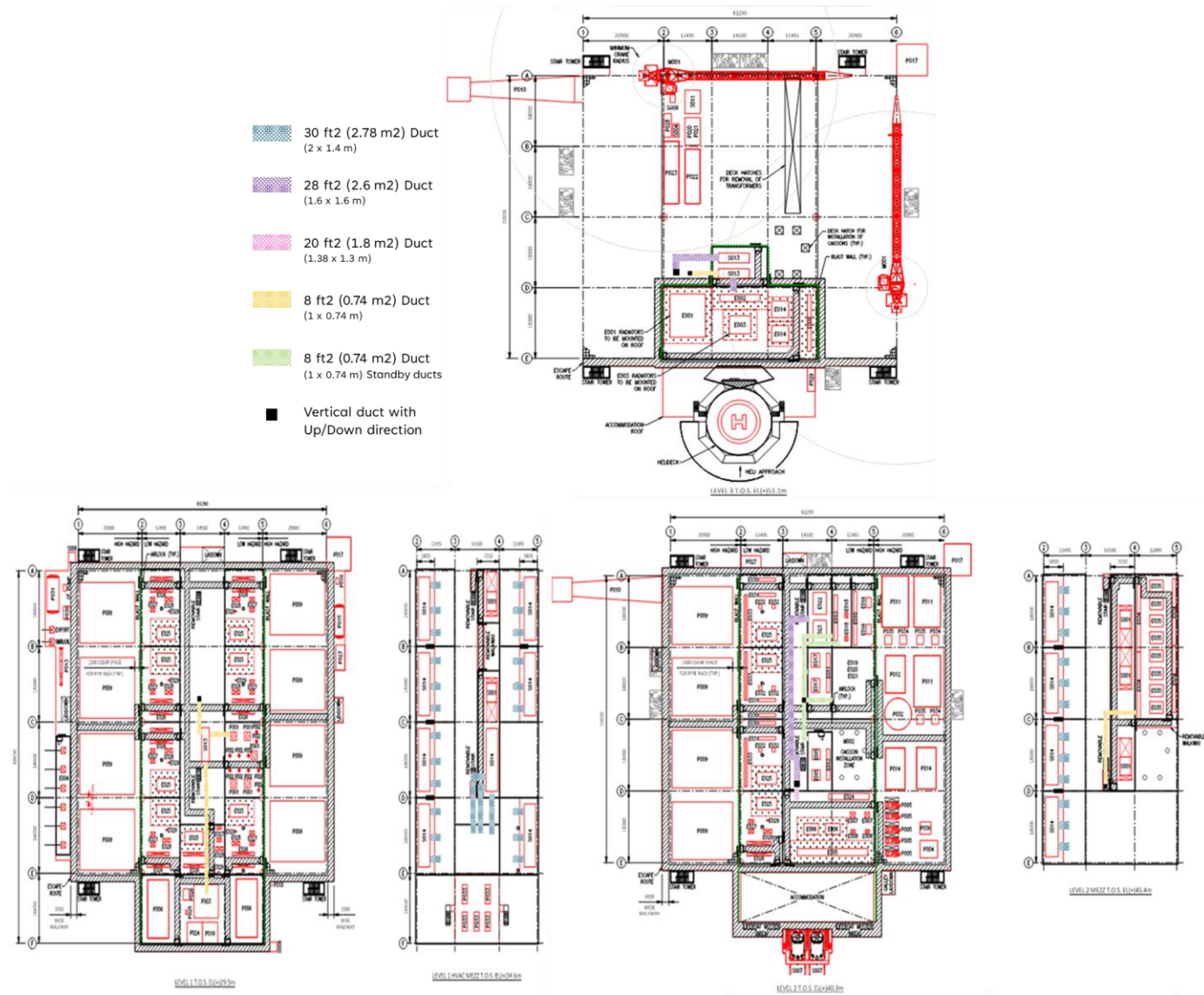


Figure 10 Duct Routing



The HVAC requirements defined in this study provide a robust thermal management solution tailored to the HOP2 facility's complex electrical systems. By combining detailed heat load assessments, airflow modelling, and equipment selection, the proposed design offers reliability, operational efficiency, and full compliance with offshore engineering standards. It ensures all critical electrical spaces are maintained within safe operating temperatures, ultimately supporting the long-term integrity of the hydrogen production infrastructure.

AHUs sizes and weights obtained from the manufacturer's catalogue include a heating module. This heating module won't be needed when the facility is running at full capacity however potential for requirement during lower capacity operation., therefore, it can be assumed that the weights and sizes for AHUs are conservative for what would be further developed at FEED stage, where the AHU will be tailored to efficiently fulfil its purpose. The location of the chillers and the AHUs can be found in the layout section below.

3.3.2 Recommendations

To reduce the HVAC demand on the platform, it is recommended to externally install radiators for the 4-winding transformers. This prevents transformer heat losses from being released into Rooms A and B, thereby significantly lowering the internal cooling load and therefore HVAC requirements. Dissipating heat externally reduces the required HVAC capacity, improves system efficiency, and helps maintain suitable ambient conditions for electrical equipment, in line with ASHRAE thermal management best practices. While also reducing the platform's total weight, and CAPEX, which might be a focus on the project's future phases.

3.4 Compression System

As part of the Phase 2 Net-Zero Technology upgrade, the selection of the H₂ compressor system was a critical aspect of this study. The compressor requirements were defined based on detailed process calculations, captured in compressor sizing within the Process Equipment List Rev A [11]. This document has subsequently been updated to Rev B incorporating vendor data [12], however, see Rev A for original reference calculations. Then, after presenting the compressor needs to different vendors and manufacturers, a compression system consisting of three high-performance hydrogen compressors was selected to support H₂ export operations. Each unit is assumed to be fully skid-mounted to allow efficient integration into the Ninian Central Platform layout. The compressor's datasheet can be found in Appendix F Compressor Datasheet.

Equipment tags A-1402A/B/C, with two-operating, one-standby configuration ensuring full capacity delivery with built-in redundancy. The vendor has quoted a delivery lead time for the package of 18 months.

Each compressor unit features six crank throws configured into two compression stages with dedicated inter-stage cooling. The casings are constructed from high-strength "Persisto" carbon steel, rated for an operating range from 29 barg at first-stage suction to 103 barg at second-stage discharge, with temperature rating of 30 °C. The compressor skids have footprint of 13m × 8m × 5.3m and are electrically driven.

In normal operation, each machine will handle approximately 10,000 kg/h of dry hydrogen—equivalent to 4,320 kg/h at 29 barg suction pressure and 30 °C inlet temperature, compressing to 103 barg..

The three-train 50% capacity configuration supports full operational flexibility, enabling planned maintenance without impacting throughput, and offering turndown control to match process demand. The non-lubricated vertical arrangement eliminates oil carry-over risk, ensuring hydrogen purity. Additionally, the integration of inter-stage cooling enhances operational reliability and contributes to the system's overall energy efficiency by boosting hydrogen from the low-pressure process header to the high-pressure export line.



3.5 Operations and Maintenance

The long-term reliability and maintainability of the offshore hydrogen production facility are critical to ensure continuous and safe operation under environmental and operational conditions. This section outlines the operations and maintenance (O&M) strategy developed to support the facility throughout its lifecycle. Emphasis is placed on early identification of potential failure modes, the mitigation of operational risks, and the optimisation of system availability. To support these objectives, a Failure Modes and Effects Analysis (FMEA) has been carried out (see Appendix G FMEA) to evaluate component-level risks and identify critical failure paths. Additionally, a Reliability, Availability, and Maintainability (RAM) study has been conducted (see Appendix H RAM Analysis) to quantify system performance, guide maintenance scheduling, and ensure alignment with production targets and safety standards.

3.5.1 FMEA

A Failure Modes and Effects Analysis (FMEA) was conducted to identify critical risks during the early-stage design. The analysis used the standard Risk Priority Number (RPN) approach, with a defined intervention threshold set at RPN = 100. Any failure mode scoring above this limit was classified as in need of corrective action. The exercise identified five key components exceeding this threshold, which together shaped the facility's initial risk profile and guided the development of targeted corrective actions (see FMEA shown in Appendix G FMEA). The table below shows the components exceeding the threshold, the actions and the revised RPN.

Table 6 FMEA summary

System	Initial RPN	Proposed actions	Revised RPN
Water treatment	175	RBI and maintenance regime	100
PEM electrolysis array	168	- RBI and maintenance regime - Dedicated sparing - Specific safety procedures	96
Oxygen vent	320	- RBI and maintenance regime - Dedicated control system	192
Flare	120	RBI and maintenance regime	80
Utilities	108	RBI and maintenance regime	54

3.5.2 RAM Study

A RAM analysis was conducted for the proposed HOP2 offshore H2 production platform (see Appendix H RAM Analysis), with the goal of quantifying the system's uptime and identifying critical bottlenecks to operational availability. Using a detailed logic-block model that accounts for both common cause failures and logistical delays, the platform's overall availability was calculated at approximately **93.39%**. This figure reflects the true "ready-to-operate" state, at the concept stage and highlights key opportunities for performance improvement. This RAM study considers the redundancy of equipment and assumes that the wind farm will normally be operating at 42% of its capacity. Appendix H shows a summary of the critical modules affecting the system's availability.



Table 7 RAM summary

Module	Module availability (%)	Critical component	Availability (%)	Observation and Recommendations
Seawater and feedwater	99.69	Sea water	99.88	- Low availability due to filter's low mean time between failures (7,000hr). - Recommend regular inspection of filters to avoid blockages - Appropriate sparing
Hydrogen and Oxygen production	95.65	PEM electrolysis array	96.08	- Low availability due to the membrane's time between failures (12,000hr) and the PEM electrolyser's mean time to repair (100hr). - Appropriate sparing. - Specialist training for regular crew for membrane changeout.
Electrical	96.65	Electrical rooms	96.65	- Low availability due to transformer's mean time to repair (100hr). - Single transformer point of failure. - Enhance monitoring of transformer

The recommendations detailed in Table 7 above, when implemented alongside a robust sparing strategy and stock management, should significantly enhance system resilience. By addressing critical failure points and reducing mean time to repair (MTTR), these measures collectively aim to improve the overall system's availability from the current 91.18%. The MTTR is highly affected by working in the offshore environment.



4 Electrical

4.1 Introduction

This section presents the secondary electrical systems design for the HOP2 Concept Definition Phase. The Primary Electrical design has been undertaken by Petrofac and accounts for the interface with the wind farm, incoming 275kV supply, power management, and supplies for the PEM Electrolysis Hydrogen equipment and any distribution for the Balance of Plant equipment. The secondary electrical design is for those systems that support HOP2 facilities operation and habitation, refer to section 1.2. Figure 3 – Concept Definition Study - Topsides Scope Overview. Power for the secondary system is also derived from the primary system.

A Load List has been prepared for the secondary electrical system [13]. The loads have also been assessed as normal or emergency/essential. This allows sizing of the electrical supplies required, and the associated switchgear, transformers and back-up / emergency generators.

Power system studies should be undertaken at the next phase of the project.

4.2 Load List

The load list was compiled using the data from the latest revisions of:

- Process PFDs and UFDs [5] [2] [3] [4]
- Process Equipment List – main compressor and pump sizing [12]
- Master Equipment List - HVAC [14]
- Historical Project data for equivalent Topsides

4.2.1 Load Summary

- Normal Operating: 25.6MVA at 0.92 power factor
- Peak: 26.2MVA at 0.92 power factor

The total load of the secondary electrical systems is shown in Table 8 below.

Table 8 Load list

	kW	kVAr	kVA	Power factor
Total normal load	23,506	10,136	25,599	0.92
Total peak load	24,111	10,371	26,248	0.92



4.2.2 Startup Load Summary

The minimum power demand on the Secondary Electrical support system is 4,600kW, increasing to 6,600kW, after starting one hydrogen compressor.

This is based on section 2.3.2: Normal Startup and Shutdown – High Level Sequence

4.3 Primary Electrical Interface

This section is based upon Petrofac's Preliminary Electrical Equipment List.

The Primary Electrical system incoming supply is 275kV, 50hz. It will then be transformed to 66kV to supply the bulk of the hydrogen production equipment. Supplies to the Secondary Electrical System will be derived from the 66kV supply.

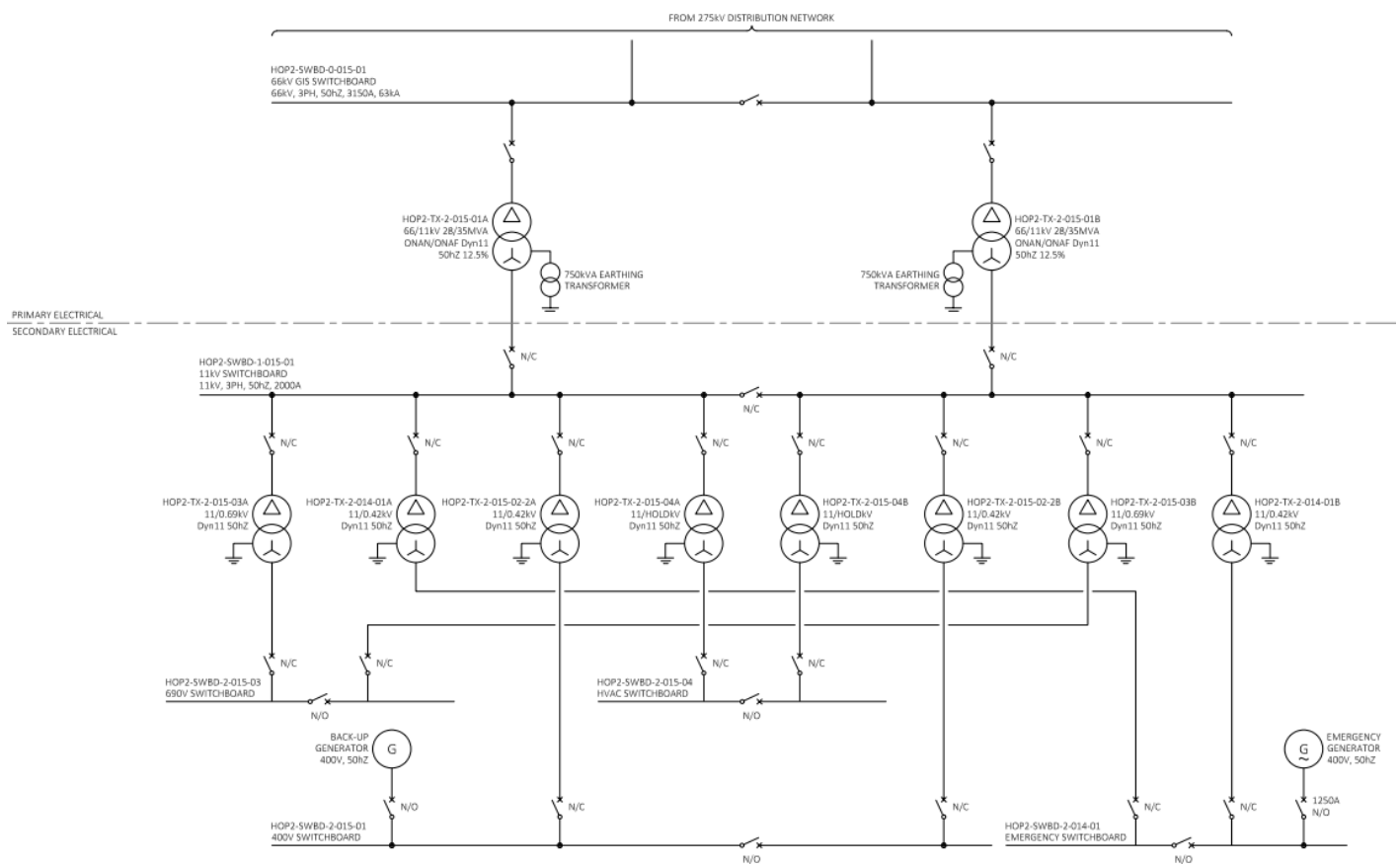


Figure 11 Primary Electrical Single Line Diagram

4.3.1 11kV Switchboard

This preliminary Primary Electrical Interface is designed with a Switchboard with two bus sections and a bus-tie switch and each bus section fed by a step-down transformer.

This will supply the largest Topsides utility loads and distribute to the low voltage switchboards

400V Switchboard

This preliminary Primary Electrical Interface is designed with a Switchboard with two bus sections and a bus-tie switch and each bus section fed by a step-down transformer.



This will supply LV Topsides utility loads and habitation supplies.

4.3.2 690V Switchboard

This preliminary Primary Electrical Interface is designed with a Switchboard with two bus sections and a bus-tie switch and each bus section fed by a step-down transformer.

This has been included by Primary Electrical Designer as a quantity of motors > 250kW were anticipated.

4.3.3 HVAC Switchboard

This preliminary Primary Electrical Interface is designed with a separate HVAC Switchboard with two bus sections and a bus-tie switch and each bus section fed by a step-down transformer – there is the option of this to be from the 66kV or 11kV systems dependant on size of the HVAC loads.

4.3.4 Emergency Switchboard

The preliminary Primary Electrical Interface is designed with the Emergency Switchboard with two bus sections and a bus-tie switch and each bus section fed by a 11/0.42kV step down transformer.

This will supply LV Topsides Emergency and Statutory utility loads and habitation supplies.



4.4 Secondary Electrical Single Line Diagram

Following compilation of the Secondary Electrical Load list an optimised Secondary electrical distribution system was developed.

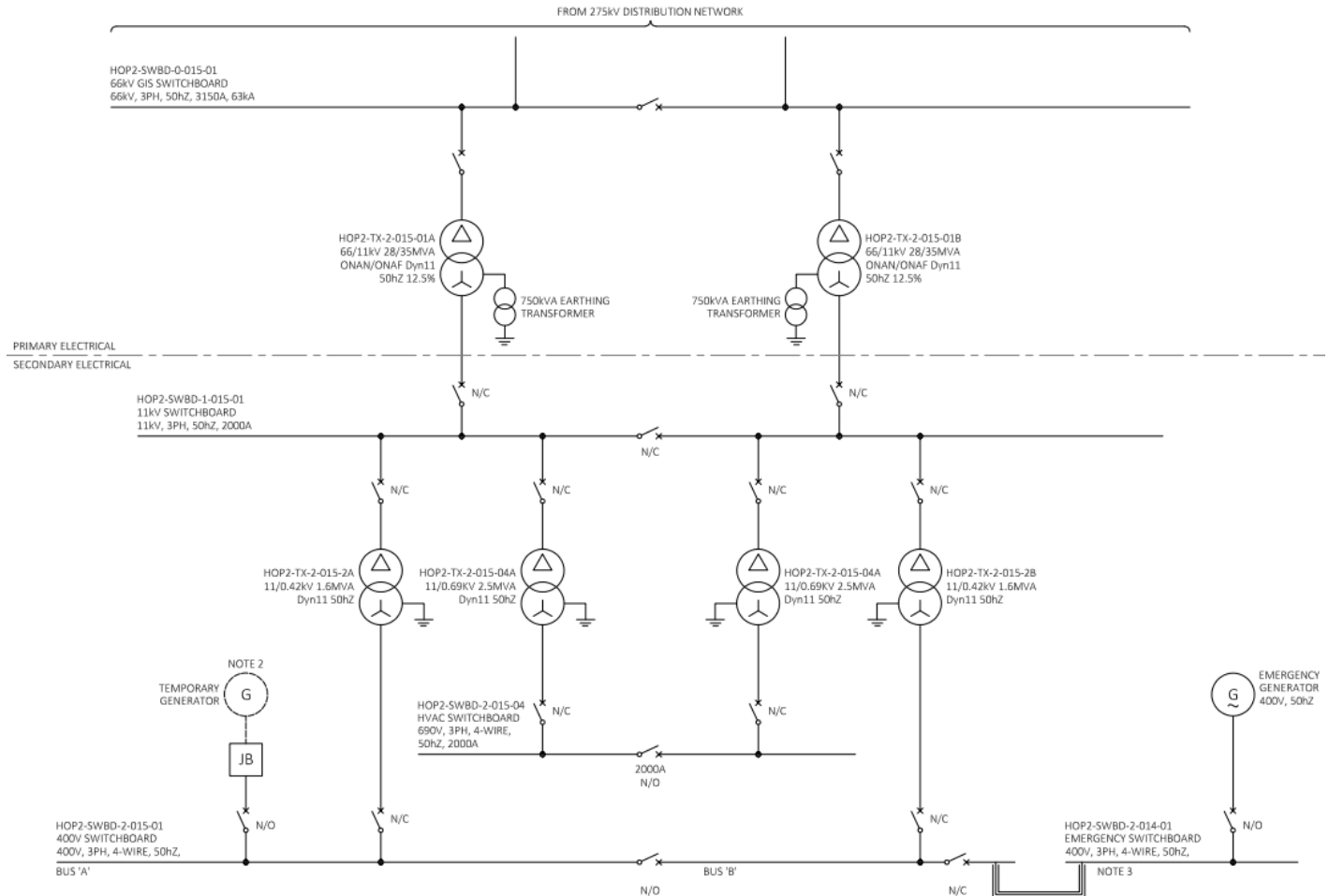


Figure 12 Secondary Electrical Single Line Diagram

4.4.1 11kV Switchboard

This will supply the largest Topsides utility loads and distribute to the low voltage switchboards

4.4.2 400V Switchboard

This will supply LV Topsides utility loads and habitation supplies.

4.4.3 690V Switchboard

As the Primary Electrical Design includes for 4 x 690V Array Auxiliary Switchboards it is felt there is no requirement for another 690V Switchboard. The largest utility motor loads will be supplied at 11kV.

Power system studies will be performed during detailed design and confirm this assumption.

4.4.4 HVAC Switchboard

With the initial concept definition design complete it is proposed that:



- a. the main chiller plant (5 off units) be supplied at 11kV
- b. the PEM electrical AHUs (12 off units) be supplied from this HVAC Switchboard at 690V
- c. the remaining AHUs (3 off units), for the Topsides Electrical/Utility areas be supplied at 400V; one of these being connected to the Emergency Switchboard.

4.4.5 Emergency Switchboard

It is proposed that the Emergency Switchboard is fed from the normal 400V switchboard, connected via a bus-tie switch and busduct. The Emergency Switchboard will be located in its own fire rated compartment. On loss of main power, the bus-tie switch would automatically open to island the emergency switchboard, and the emergency generator would automatically start and close onto the emergency switchboard.

This would remove the two emergency transformers and simplify the switchboard configuration. The increase in 400V supply transformer rating is minimal. The busbar rating of the normal and emergency switchboards would be similar.

4.5 Back-Up / Emergency / Essential Power

The base case is to provide 2 x 100% Back-Up / Emergency Generators. This is to allow for calm weather conditions which may pose a challenge in starting the primary electrical systems and therefore energising the secondary electrical equipment. It is noted that while the intention is to move to a Normally Unattended Installation it is anticipated that the early stages of running a complex installation will require permanent manning. It is therefore essential that habitation facilities are maintained. Alternative power sources other than diesel driven engines are not considered practical to provide power of the magnitude and autonomy time that would be required to support a crew of over 20 for a potentially extended period. Operating rotating equipment, such as HVAC fans, is also more practical with a diesel genset.

It is proposed that 1 x 100% permanent installed generator is installed, with the second unit being provided via a rental set. Permanent facilities would be provided to simply the hook-up of such a rental set. The benefits are: (1) no large CAPEX cost; (2) maintenance is simplified – unit can be changed out rather than complete any large services or overhauls offshore; (3) if facility moves to operating in NUI mode, the need for 2 x 100% gensets out with planned manned intervention campaigns, e.g. for maintenance, when it extended habitation is required, would not seem a definitive requirement.

One further opportunity is supply both gensets as rental or portable units to simplify maintenance burden. This would be subject to a CBA.



4.5.1 Emergency Generator Sizing

Table 9 Secondary Electrical Load List

	kW	kVAr	kVA	Power factor
TOTAL PEAK LOAD	1297	644	1448	0.9
TOTAL PEAK LOAD +25%	1621	803	1810	0.9

Table 9 above shows the overall secondary electrical load requirement for sizing the emergency and backup generator [13]. The emergency / back-up generator size (each) was calculated at 1810kVA based on 100% of the Peak connected load plus 25%, as defined in the Project Facilities Design Guide [1]. Based on commercially available units it is anticipated that an 2000kVA unit(s) would be installed. Future Safety Studies will confirm the autonomy time and hence the associated fuel tank sizing, but 12-24 hours is anticipated for emergency purposes. It is anticipated that there will be greater reliance on the Back-Up/Emergency generator(s) during periods of calm weather which may preclude start-up of the main import electrical transformers and primary electrical systems, this will further influence required diesel fuel storage capacity. The design of the primary electrical systems and mitigation to avoid excessive diesel generator usage during calm weather start-up is by others.

4.5.2 Emergency

The loads selected for connection to the Emergency Switchboard comprise:

- Nitrogen Package; note that NZTC have confirmed that there is no need for a nitrogen supply to be available to the selected PEM technology after the loss of main power. However, the FMEA concluded that nitrogen should be available for the flare.
- Instrument Air; to support the Nitrogen Package, the Instrument Air package will be connected to the Emergency Power system.
- Flare Package; for system control panel; Oxygen KO Sump Pump; to support the availability of the oxygen system.
- Emergency Lighting & Small Power Distribution Boards; 30% of the facility lighting will be classified as Emergency. While these will have integral battery packs, connecting to the emergency generator allows for some lighting to be maintained for a longer autonomy.
- 230V AC UPS & 110V DC Tripping & Closing Chargers; to maintain connected loads on mains power as long as possible, preserving battery autonomy time and facilitating black start of the facility
- Accommodation; to preserve habitation capability
- Seawater Lift Pump (one off); for start-up cooling water for the HVAC system; VSD provided for motor starting
- Emergency Generator UCP: to minimise requirement for control batteries
- HVAC; for HVAC controls and supplies to control and command areas.

4.5.3 Power

Critical, no-break supplies will be provided by UPS battery backed systems. Future Safety Studies would determine the battery autonomy time. The proposed Essential Power Supply systems are shown in Table 10 below. Note the requirement for marine and aeronautical Nav aids and marking lights on UPS is a statutory



requirement [15], [16], [17]. The statutory requirement comprises battery autonomy of 96 hours. Future studies would determine total battery autonomy time for all the UPS loads.

Table 10 Power Systems

230V AC UPS, Dual Redundant with Bypass	110V DC Tripping & Closing Dual Redundant Charger	Navais UPS – Statutory Requirement
Flare Package UCP Nitrogen Package UCP Instrument Air Package UCP F&G System Feed 1 F&G System Feed 2 ESD System Feed 1 ESD System Feed 2 DCS System Feed 1 DCS System Feed 2 PMS System Feed 1 PMS System Feed 2 L1 PEM Equipment Small Power DB L2 PEM Equipment Small Power DB L3 PEM Small Equipment DB 275kV Breaker Control 66kV Breaker Control 11kV Breaker Control HVAC Controls PAGA A PAGA B CCTV Cabinet Telephone/PABX Cabinet LAN Cabinet Telemetry/ Fibre Cabinet Back-up Satellite Cabinet SOLAS Radio Cabinet Platform Radio Cabinet	275kV Switchgear Feed No.1 275kV Switchgear Feed No.2 66kV Switchgear Feed No.1 66kV Switchgear Feed No.2 11kV Switchgear Feed No.1 11kV Switchgear Feed No.2 400V Switchboard Feed No.1 400V Switchboard Feed No.2 Emergency Switchboard Feed No.1 Emergency Switchboard Feed No.2	NAVAIDS Control Panel Helideck Lighting Control Panel Aviation Lighting DB Sea Area Lighting DB Emergency Generator(s) - Control Battery & Engine Starting Battery Lifeboats – Engine Starting Battery; Radio Battery Telecomms – SOLAS Radio Battery

4.6 Further Development

Three key areas are considered essential for further development in the next phase:

- 1 Power system studies to confirm equipment sizing and fault ratings
- 2 A primary voltage of 6.6kV for the Secondary Electrical System maybe allow the use of more compact VFD equipment.
- 3 HVAC system development to improve confidence on the electrical power requirements
- 4 Review equipment layout for optimisation of spaces .



5 Control & Instrumentation

5.1 General

The instrument and control system basis of design shall ensure compliance with current industry standards and specifications. The scope shall consider design, and engineering using standard engineering practices and will make provision for safety, reliability, ease of operation and maintenance. The scope shall ensure the instrumented, control and safety systems comprise of redundant systems, protective measures, and fail-safe mechanisms to ensure uninterrupted power supply and accident prevention.

The reliability of the instrumentation, control, safety systems, and subsystems; and network interfaces are considered critical for maintaining integrity of the operations. They shall be designed to safely operate whilst maximising the network availability and managing disturbances, without having to shut down the network.

ATEX certified equipment shall be used in hazardous areas, which are clearly marked on asset drawings. All portable electrical and electronic equipment intended for use in hazardous areas shall also be ATEX-certified in accordance with Directive 2014/34/EU and suitable for the designated zone classification. The ATEX certification and marking shall be clearly stated on the equipment and technical documentation.

As shown in Appendix J – Instrument Interface Overview Block Diagram, I&C system shall comprise of various Operational Technology (OT) systems interfacing with the ICSS.

5.2 ICSS Philosophy

The ICSS shall monitor, control and safeguard the topsides systems. It shall comprise of the following main systems while interfacing with package UCPs of topsides / subsea facility.

- PCS – Process Control System
- SIS - Safety Instrumented System
 - ESD – Emergency Shutdown System
 - FGS – Fire and Gas System

Field instrument signals shall be segregated and connected to the ICSS via marshalling cabinets. It is proposed that signals are initially terminated to Remote IO (RIO) cabinets located across selected location on the asset. These cabinets shall marshal IO from field instrumentation and communicate data between the field and ICSS controllers via agreed predefined ICSS communication protocols like Modbus or Profibus network protocols.

An internal redundant communication network shall interface the ICSS with the PCS, ESD and FGS components as well as workstations, servers and proprietary portals. Proposed system communication protocol could be based on Ethernet and TCP/IP trusted network set up as a private IP network using static addresses; supplier propriety networking routing protocol can be employed to provide robust availability optimisation. Profibus, Modbus (TCP, RTU), IEC 61850, Autronica or other efficient protocol could be considered for internal control module communication. The systems shall be continuously online, and the overall system availability of the equipment and systems shall be 98%, or better, including allowance for maintenance and verification. Where available, reliability data shall be supplied to demonstrate compliance with availability requirements.

ICSS shall be provided with a remotely accessible historian, a specialised data management system which collects, stores and retrieves time-series data. It shall also include backup storage, trending capability which monitors the process over a period, through trend traces (real time and historical as a minimum).



ICSS shall also have an Alarm Management and Rationalisation System where equipment is monitored providing real-time alerts for abnormal conditions, and ensuring timely response to protect personnel, equipment, and the environment. These shall be prioritised and displayed in accordance with ISA-18.2 and EEMUA 191.

ICSS hardware shall ensure design, engineering and manufacture of all equipment will use good engineering practices and will make provision in the design for safety, ease of operation and maintenance. The design will demonstrate the following features:

- Field-proven;
- Reliability;
- Standards-based;
- Scalability;
- Cost-effectiveness;
- Highly available;
- Uncompromised levels of protection of health, safety, security, and the environment.

Space optimisation shall be considered, and design shall comply with environmental requirements. The option of hardware virtualising should be considered.

HMI interfaces shall be designed to have access to all graphic displays and views defined in the ICSS and thus offer a fully integrated control environment with common operator interface for the whole complex (process, safety, 3rd party, asset, alarm analysis etc). Through user-defined process displays, signal tags from the PCS, ESD and F&G systems can be viewed and operated and have advanced functions for alarm handling, prioritizing and process sectioning to aid the operator in managing the process, together with standard faceplates for process objects (I/O, controller, pumps etc.). The HMI displays shall be designed according to P&IDs and PFDs, F&G layouts, ESD hierarchy diagrams, C&Es and Electrical Single Line Diagrams as well as sketches if applicable.

Refer to Appendix J for the Instrument Block Diagram for an overview of proposed ICSS sub-systems and their interfaces.

5.2.1 Process Control System (PCS)

The monitoring and control function on the asset shall be carried out within the PCS using pre-approved standardised function blocks and programmed software logic. This will be in accordance with the asset's control and operational philosophies.

5.2.2 Safety Instrumented System (SIS)

This system should comprise of SIL rated non-programmable logic solvers and controllers set in a redundant configuration to achieve SIL and operational requirements. It is anticipated the supplier shall further detail the prescribed configuration during the next phase of the scope. The Safety Instrumented Functions (SIF) should be assessed in the next phase of the project subject to a Layers of Protection Analysis (LOPA) once Piping & Instrumentation Diagrams (P&IDs) are completed.

The SIS shall be designed in accordance with IEC 61508 and IEC 61511. It shall also be designed with Critical Alarm Panels hardwired to an I/O cluster and interfaced with the ESD & FSG systems providing the most critical facilities needed to bring the plant and processes to a safe state. The panels will operate independently of the HMI display.



Emergency Shut Down (ESD) System

The Emergency Shutdown System (ESD) shall take automatic corrective action during abnormal or potentially hazardous events to prevent escalation to relief. It shall be designed to ensure timely and reliable response to safeguard personnel, environment, and equipment.

Key features shall include:

- Hardwired ESD pushbutton initiation from strategic locations
- Shutdown of process units, utility systems, and interfaces with subsea systems as defined in the ESD Cause & Effect (C&E) matrix
- Control of critical isolation valves, blowdown valves, and emergency venting systems
- SIL-rated logic implemented on non-programmable controllers
- Integration with Critical Alarm Panels providing:
 - SOS (Start-up Override Switch) / MOS (Maintenance Override Switch) functionality
 - ESD access key switch controls
 - Visual indication of system status

The ESD shall be capable of operating independently of the PCS and HMI interfaces, and all logic shall be verified against ESD hierarchy diagrams and tested during FAT/SAT.

Fire and Gas System (FGS)

The Fire and Gas System (FGS) shall be responsible for continuous detection of flammable gas, toxic gas, smoke, and fire within the facility. It shall be designed to initiate alarms, activate mitigation systems, and interface with the ESD system where appropriate to ensure safety.

Key features shall include:

- Deployment of fixed fire and gas detectors across the topsides in accordance with F&G layout drawings and hazard assessments
- Detection technologies to include (as applicable): point gas detectors, open path detectors, flame detectors, smoke detectors, and heat detectors
- Voting logic and zoning implemented within the FGS logic solver
- Interface to automatic fire suppression and extinguishing systems (e.g., deluge, inert gas)
- Manual release stations for fire extinguishing systems and visual status indicators for:
 - Fire
 - Gas
 - Protection release status

The FGS shall operate as an autonomous safety layer and be fully integrated within the ICSS. All detection, alarm, and response logic shall be validated using F&G C&E diagrams and subject to performance-based testing to meet SIL and functional requirements.

5.2.3 Package Interface

The ICSS shall interface with standalone packages UCPs primarily via serial connection (TCP/IP, Modbus) for monitoring and control functions. Field signals to package UCP shall predominantly be directly hardwired. Shutdown signals interfacing with the ICSS shall be hardwired and designed in accordance with IEC 61511.



Refer to Appendix J for the Instrument Block Diagram for an overview of anticipated UPC packages and their proposed interfaces.

5.3 Telecommunications Philosophy

The telecommunications infrastructure shall provide robust, secure, and high-availability communications infrastructure ensuring safe, efficient, and continuous operations. This includes reliable voice, data, and video communication systems that support operational, maintenance and remote access. All telecommunications systems will be designed with redundancy, cybersecurity, and scalability in mind, complying with relevant industry standards and enabling seamless integration with onshore facilities and emergency services. The architecture will support real-time data transmission, facilitate predictive maintenance, and contribute to overall asset integrity and personnel safety.

This shall comprise of the following:

Offshore Backbone Communication Link

This shall comprise various links from the asset to shore or other neighbouring assets. At this stage, one link is proposed to provide radio communication to a nearby installation(s). This could be a Line of Sight (LoS) microwave Radio Communication link as well as interfacing with Tampnet fibre optic subsea network infrastructure. This link could provide service for voice communication (giving priority to emergency calls), high speed internet access (VPN services, remote operational connections), corporate processes.

A separate link could provide VSAT satellite communication link providing interface for entertainment, personal computers and social facilities.

Offshore backbone communications links network, antenna and equipment shall be designed by specialist vendor considering proposed asset require facilities to ensure adequate bandwidth is provided. Installation locations shall be optimally selected for peak performance and maintenance.

Local Area Network (LAN)

This shall be designed to consist of redundant fibre optic backbone employing Fast Ethernet Technology providing infrastructure for both corporate Information Technology (IT), Operational Technology (OT) Networks and utility users. These networks shall be segregated as per IEC62443 requirements with each having dedicated and clearly identifiable network components. The LAN shall be designed to have high availability based on robust, modular and redundant network structure.

The LAN network provider shall make required bandwidth calculations to ensure that all systems shall have sufficient quality of Service (QoS), giving VoIP highest priority.

Public Address and General Alarm System (PAGA)

This system shall provide audible and visual alarms in all areas of the asset for General Platform Alarm (GPA) and Prepare to Abandon Platform Alarm (PAPA) in accordance with PFEER SI 1995 No743 (amended in 2005 and 2015) [18] and Health and Safety (Safety Signs and Signals) Regulations 1996 [19]. This system shall comprise of various components like access and status panels, controllers, amplifiers, beakers, sounders, etc in a redundant fully duplicated backbone infrastructure. It shall interface with asset systems like ICSS, entertainment systems, external communications systems, etc.

Closed Circuit TV (CCTV)



This shall be used to transmit video surveillance and camera control functions to the CCR and other designated points via dedicated LAN links. They shall be designed for continuous duty with the ability for troubleshooting, image search and investigations.

There shall be a CCTV Main Unit with recording capability and interface to broadcast live CCTV if required. Options for dedicated CCTV Control PC Workstations possibly located in the CCR and Temporary Refuge shall be considered. The software shall enable camera selection, video/ audio transfer to approved audited media, and data archiving. Cameras selected shall be suitable for operating in harsh offshore environment.

Telephone System, Private Automatic Branch Exchange (PABX)

An IP-based hybrid PABX exchange with facilities to connect with analogue outdoor area and emergency Ex-telephones shall be installed. This shall provide telephone facilities for cabins, offices and working areas; primarily providing means of voice communications (VoIP) between personnel and an alternate direct PAGA paging function from authorized units to initiate announcements.

For emergency communications between vital control positions independent of asset power supply, a separate sound powered telephone system shall be installed. This shall comprise of various main stations, substations, headsets, microphone, flashing beacons where applicable.

Radio System

A radio system shall be provided for normal and emergency mobile communications. Emergency communications shall be prioritized over normal communications where interface is interlocked to ensure automatic activation, disabling normal communication functions. It shall comprise of main control, base and repeater stations, ATEX approved portable radio telephones with chargers, while interfacing with the PABX and PAGA systems.

A lifeboat radio system shall be installed for each TEMPSC - a fixed Global Marine Distress Safety System (GMDSS) approved marine band VHF/DSC-Radiotelephone, a portable VHF-Radiotelephone and a Search and Rescue Transponder (SART).

A non-directional beacon and aeronautical radio system shall be installed for aviation operations.

Crane Communication System

A crane communications system shall enhance crane operator communication with the asset operations and any interfacing vessels. It shall consist of fixed VHF, UHF radio, PA loudspeakers, telephone, microphone, control panel consisting of a joystick / selector switch.

Entertainment System

An IP-based entertainment system with dedicated satellite antenna link and network shall be provided with access to radio / TV channels complete with interactive services installed in designated areas (cabins, common public rooms, etc); internet access (wireline and wireless), etc.

Master Clock System

A GPS based precision Master Clock system with UTC and local times shall be installed and distributed as per NMEA0183 serial data to ICSS and Packaged Equipment.

Meteorological System and Helicopter Management System

A Civil Aviation Authority (CAA) and UK Offshore Operators Association (UKOOA) approved system shall provide easy access to data for aviation operations. The system shall include clear displays complete with a means of



logging and storing historical data. Data shall include and not be limited to Helideck inclination, motion and wind severity index, barometric pressure, wind speed and direction, visibility and cloud height, heave, pitch, roll, surge, sway, yaw, precipitation, sea currents, local lightning monitoring.

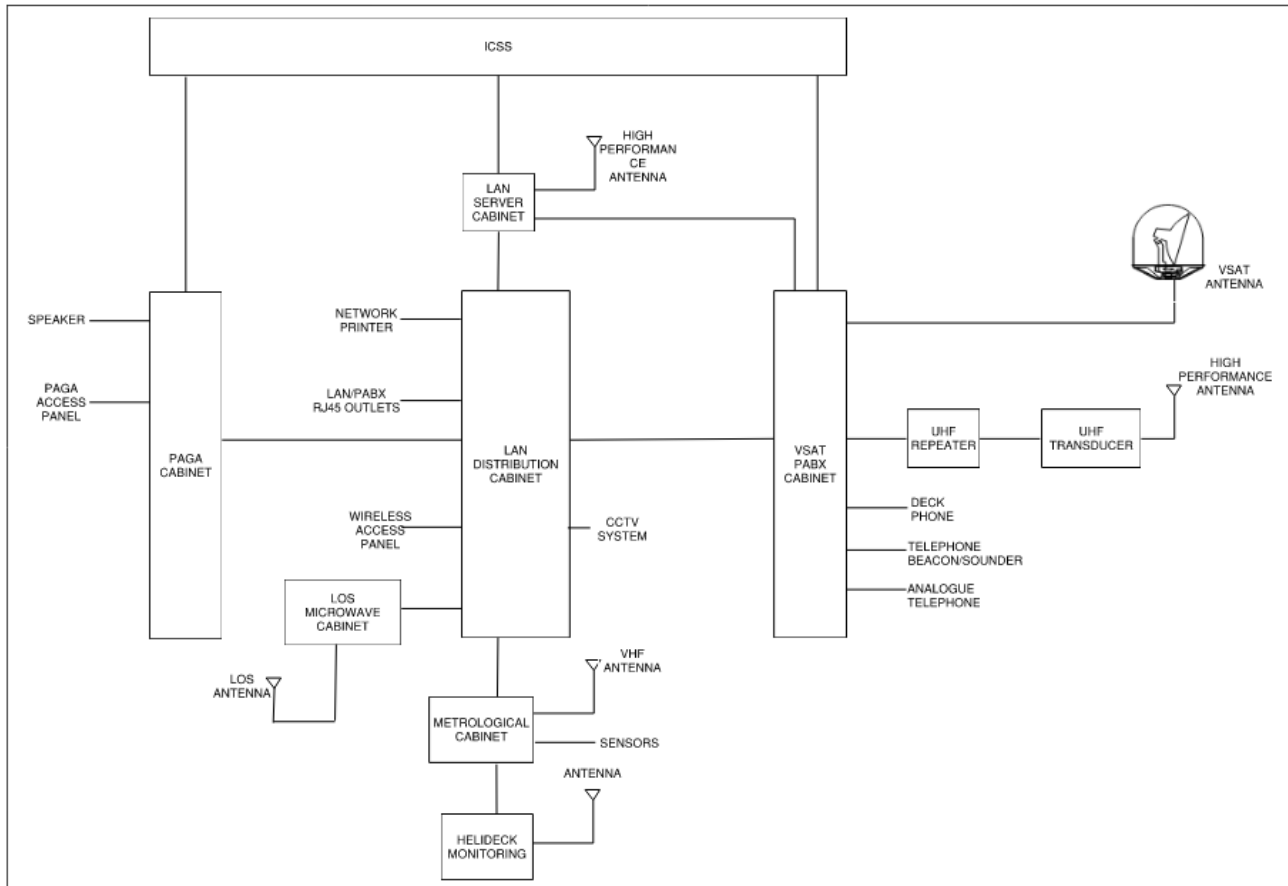


Figure 13 - Typical Telecommunications System Architecture

5.3.1 Cyber Security

The corporate IT network shall include all non-OT Network infrastructure enhancing the segregation of corporate, process, and safety networks.

The OT Network shall be further segregated into Zone and conduits as per IEC62443, NIST framework, OG86 Guidelines and client policies. OT Networks shall be initially ranked in order of highest priority and a Cyber Security Risk Assessment of proposed classifications shall be the basis for securing each critical OT network. Overall, each OT network zone shall have a dedicated network industrial firewall connecting to the OT Network Gateway Firewall. It is proposed that there shall not be any interconnectivity between OT Network zones outwith the gateway firewall interface. System components shall be partitioned to only permit processing of their own specific functions.

For remote connections, there shall be two modes proposed:

- One-way read only access via OPC Server and / or vendor proprietary interface. This shall mimic ICSS and selected OT Networks HMI displays for consistency and ease of use.
- Two-way read and write access via a secured and audited platform to permit ICSS and other selected OT Networks diagnostic and configuration ability.



An encrypted, secured, audited platform for remote read and write access shall be employed and shall utilize static permissions on applicable OT Network infrastructure. A session request structure shall be created with audited approval processes, applicable risk assessments and Permit to Work approvals. To make a remote connection, a session request shall be approved, authorised and monitored complete with session reports to ensure malicious use is discouraged.

It is envisaged that appropriate client developed policies, procedures, 3rd party vendor agreements and training shall be employed.

For physical security, all ICSS equipment shall be placed in locked cabinets with non-standard keys. Only personnel performing maintenance on the system shall be allowed access to these cabinets. This will provide physical security and prevent users from introducing unsafe media to the system. It is proposed that all physical interface units giving access to file transfer, e.g. USB, serial and parallel ports, floppy and CD drives, must be removed or disabled.

All ICSS network components and systems are required to be hardened, in accordance with pre-approved group policies. It is proposed that when standard industrial version software is used, non-relevant third-party software shall be removed or disabled before installation. A patch management solution shall be pre-approved and employed within the ICSS to ensure regular updates are installed with no bearing on operations and ICSS functions.

The ICSS is required to have backup, disaster recovery and restore capability where it creates files containing a total structured export of the system that can be stored. The system should also have a means of confirming backup validity after it is taken and prior to storage.

An antivirus / antimalware solution is required with the ICSS and should be configured to ensure it does not interfere with ICSS operations – minimising impact on performance and reaction times.

Defined user roles and permissions shall be structured within the ICSS in accordance with agreed group policies which shall be used to authenticate user access. A securely protected log of ICSS assets, address and licenses shall be maintained to input to a controlled OT Network Asset Register.

Overall, a Cyber Security Management Plan (CSMP) shall be developed to define how OT Cybersecurity requirements are established and assured during the project lifecycle including development, technical acceptance, delivery, site integration, and commissioning. At a minimum, the CSMP shall reference the following areas:

- Lifecycle stages the project shall transition.
- Input and Output documentation required for each lifecycle stage.
- The System Under Consideration (SuC)
- Roles, responsibilities, and required competencies of project personnel involved across the lifecycle stages.
- Engineering practices required of End-User (Client), contractors, and suppliers in handling and transfer of sensitive project data and information in a Cyber-Secure manner.

A High-Level Hazard and Risk Assessment shall be conducted to identify initial process and safety hazards and to determine the Security Level Target (SLT) for the system. Specific attention shall be given to systems with SIFs, ensuring that assessments are performed in accordance with IEC 61511 clause 8.2.4 and TR84.00.09.

Following this, a Cyber Security Requirements Specification (CSRS) shall be developed, which will subsequently guide the assessment of the SuC design during later stages of the project lifecycle.



At a minimum, the CSRS defines the

- required functionality of countermeasures and possible technical methods to achieve this.
- working practices and information security practices required.

Once these are produced, a Detailed Risk Assessment (DRA) shall be completed to review the design, countermeasures for each SuC and overall OT Network. Various other assessments may be proposed during project development to ensure actions from the DRA are closed out/ progressed, produced design meet CSRS requirements and incorporates any additional controls.

5.4 Metering Philosophy

The hydrogen export metering system shall measure and analyse quantities and composition of hydrogen prior to export. It is understood that operational and performance metering for hydrogen production from each electrolyser shall be achieved individually and separate from this philosophy; along with metering requirement for seawater lift, water discharge overboard, and to electrolyzers, flared gas and vented oxygen. This philosophy only covers hydrogen export fiscal flow measurements.

It is proposed that the fiscal hydrogen metering shall be based on mass measurement and achieved using a Coriolis meter installed in sufficient number of parallel metering streams with consideration for a standby meter and associated prover. This detail shall be further developed in future project design phase in agreement with the regulatory body. It is proposed that the fiscal metering system will be configured as a stand-alone skid mounted on the platform.

On-line proving facilities will be provided to allow each of the on-line meters to be individually proven without affecting the export rate. A flow computer dedicated as Prove FC is included to initiate and control the proving functions.

The metering control system will be supplied is suitable metering cabinet(s) containing supervisory computers, stream flow computers (per stream), PLC, network interface equipment (switches, printers, etc) and utilities (power supply, fans, etc). The stream flow computer is considered the core of the metering system. It is anticipated that specialist vendor proprietary software shall be configured to ensure compliance with applicable regulatory standards.

Interface to the ICSS shall be via Modbus / TCP/IP for PCS and wired connections for safety systems. See Figure 14 for a typical architecture schematic.

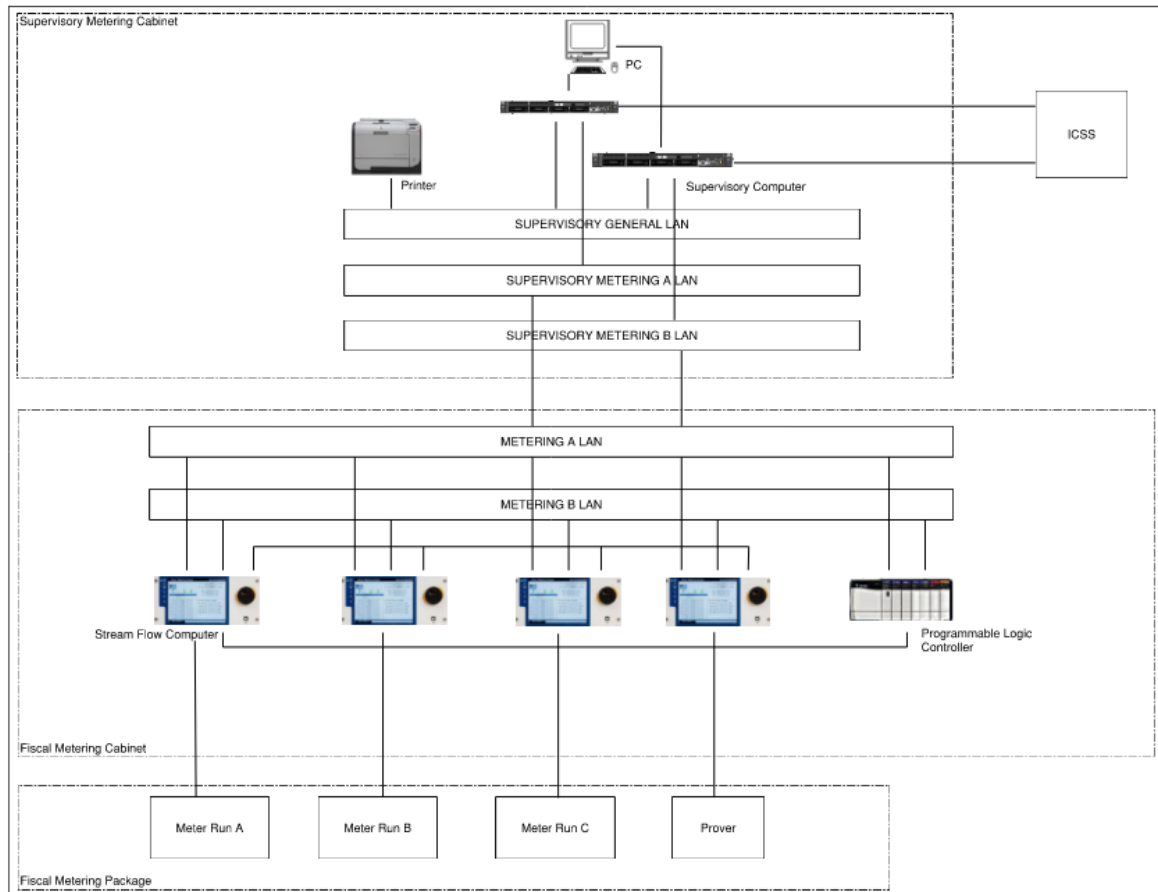


Figure 14 - Typical Metering Control Architecture

5.5 Control & Instrumentation Conclusions

A preliminary specification for the ICSS requirements has been developed. The ICSS shall monitor, control and safeguard the topsides systems. It shall comprise of the following main systems while interfacing with package UCPs of topsides / subsea facility:

- PCS – Process Control System
- SIS - Safety Instrumented System, comprising:
 - ESD – Emergency Shutdown System
 - FGS – Fire and Gas System

The ICSS shall be supported by telecommunications infrastructure which shall provide robust, secure, and high-availability communications infrastructure ensuring safe, efficient, and continuous operations. In addition, fiscal metering shall be provided for hydrogen export.



6 Structural & Construction

The following section details the development of the structural design and installation methodology for the proposed HOP2 facility, which have been advanced during the Concept Definition study. The study addressed:

- Primary framing for the new HOP2 topsides;
- Conceptual development of the interface steelwork between the new topside and the existing GBS structure of NCP;
- Conceptual design for appurtenances;
 - Electrical supply cables;
 - Hydrogen export riser;
 - Control and telecoms umbilical;
 - Seawater lift caisson/s;
 - Seawater and brine disposal caisson/s.
- Weight estimating for the new topside;
- Potential installation methods for the new topside.
 - Base case considered as single lift of integrated deck
 - Alternative modular installation method considered to assess high level impact on design.

Note, as this is a high-level concept study, no structural analysis of the proposed topside has been carried out to confirm the adequacy or estimated weight of the proposed structural framing arrangement for the topsides or interface steelwork. However, the steelwork weight broadly aligns with design norms suggesting the design is appropriate. It is expected any modifications to the design in future design phases can be accommodated without a significant impact to the overall weight of structural steelwork.

6.1 Primary Structural Framing & Interface Steelwork Development

Development of the primary framing of the topsides has been driven by two main factors, comprising:

- Interface steelwork between the new topside and existing GBS;
- Topsides layout development to suit the new larger Electrolysers and Primary Electrical systems.

6.1.1 Interface Steelwork

Development of the interface steelwork has been based upon the driving principal of maintaining the existing load paths for the topside load into the GBS. Altering these load paths significantly would present a substantial risk to the project. Any necessary requirement to modify the GBS would be a significant and costly engineering challenge. Fortunately, the existing interface between the GBS and existing NCP topside appears to lend itself to re-use for a new topside. It is therefore beneficial to base the proposed HOP2 interface upon this design.

Still images of the original NCP MSF float-over installation to the GBS are shown in Figure 15. The bearing arrangement for the NCP GBS is highlighted in Figure 17. The elastomer bearing on the Jarlin wall are shown in Figure 17 and the steel plate bearings are shown in Figure 18.



Figure 15 NCP MSF float-over installation on the GBS

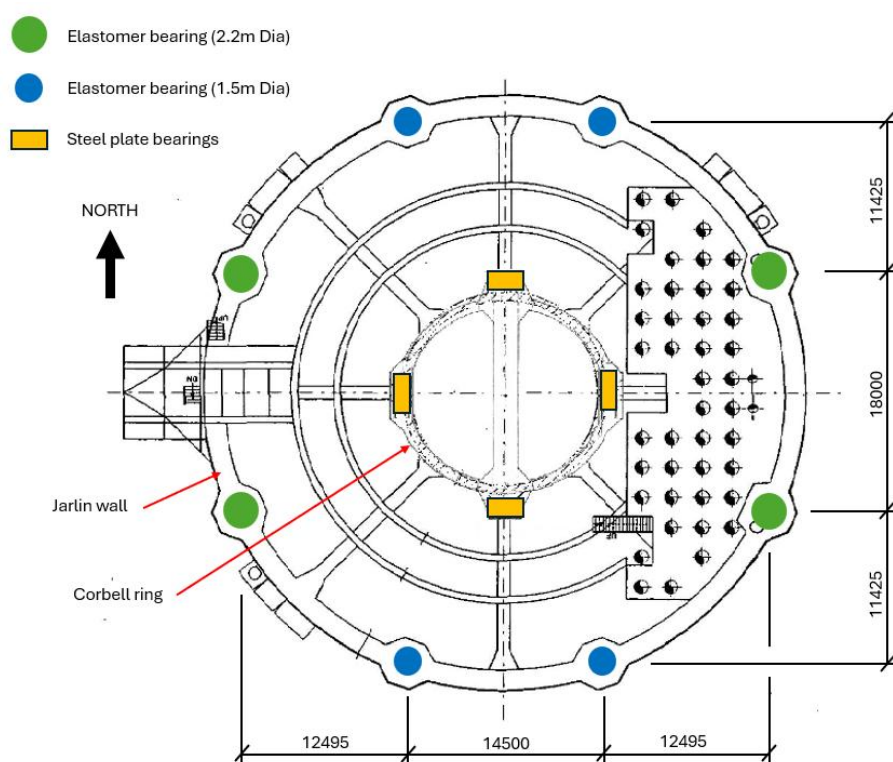


Figure 16 Existing bearing locations on GBS

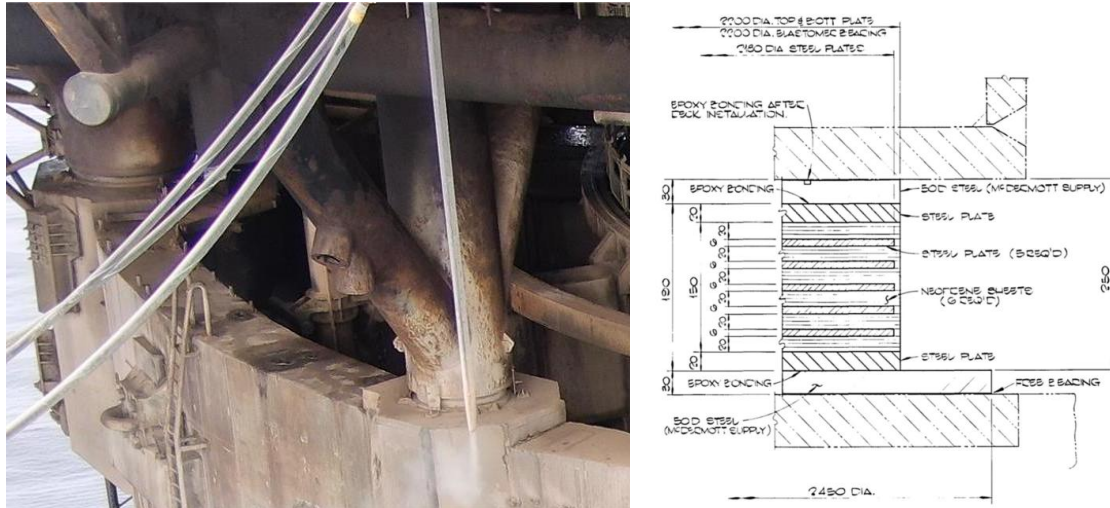


Figure 17 Elastomer bearing immediately prior to the Module Support Frame (MSF) installation

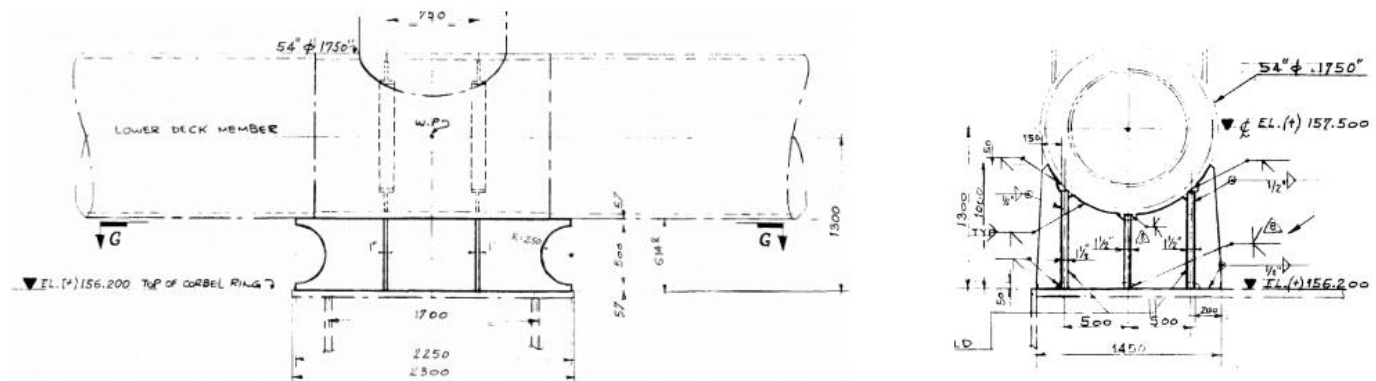


Figure 18 Steel plate bearings (typical)

Given the limited design data available for the original NCP platform, the following assumptions have been made regarding the interface between the GBS and existing NCP topsides and the associated load paths.

- 8No. Jarlin wall elastomer bearings (2.2m / 1.5m Dia)
 - Primarily intended to carry vertical axial loads (full weight of the module support frame + proportion of existing NCP topsides load based upon topsides stiffness and Centre of Gravity (CoG) position)
 - Will carry some horizontal shear force however substantially less than Corbel wall supports due to significantly lower shear stiffness.
 - Existing concrete pedestals, below the lower free bearing steel plate, can be retained (undamaged by decommissioning) and will have suitable integrity for re-use.
 - New elastomer bearings will be installed.
- 4No. Corbel wall steel plate bearings



- Assumed to have been welded in place after NCP module sub frame (MSF) was landed onto GBS elastomer bearings.
- Supports carry a proportion of the existing NCP topsides weight based upon topsides stiffness and CoG position, with no MSF weight.
- Intended to be primary restraint for horizontal forces due to environmental loading (wind and wave)
- Existing steel plates atop the Corbel ring and the Corbell ring itself can be retained (undamaged by decommissioning) and will have suitable integrity for refurbishment and re-use.

Conceptual drawings for the proposed new HOP2 interface steelwork are shown in Appendix B. A 3D model screen shot of the proposed interface steelwork design is shown in Figure 19.

It is estimated that the wave crest elevation for the 10,000yr return wave would be at around El. (+) 26.0m above LAT for the location of Ninian Central. Therefore, the bottom of steel for the lower level of the topside should be at an elevation greater than this. The top of the Corbel ring is located slightly lower than this elevation at El. (+) 23.2m, which is inconvenient for a lean interface design. Hence, a truss-like structure, similar to the original NCP MSF has been adopted to help the transfer of horizontal loading to the Corbell ring atop the central shaft and to provide stiffness for bracing the legs which will be supported by the Jarlin wall. This design has the advantage that allows for caisson guides to be installed at its lower level reducing the critical splash zone span for the caissons. The interface steel design can also be adapted to provide an actual MSF, should a modular topsides installation method be preferred.

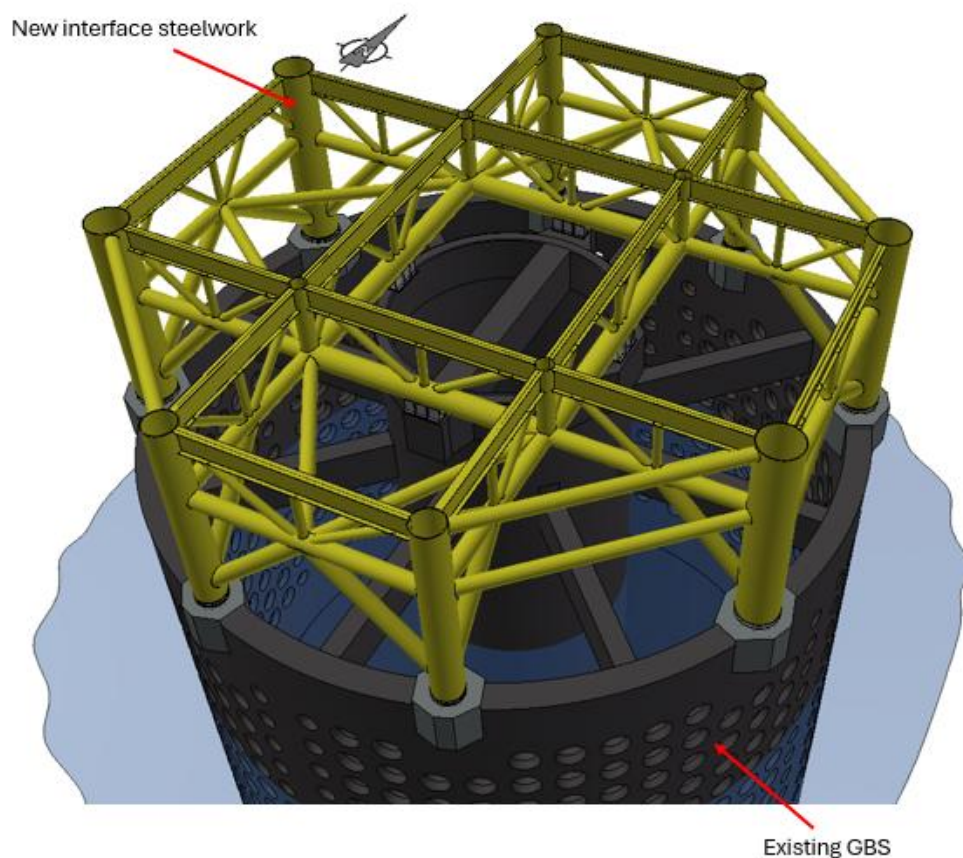


Figure 19 Proposed HOP2 topside / GBS interface steelwork



It is proposed that the existing elastomer bearings are removed and replaced with new similar items to suit the new design. It is envisaged that these will be installed to the GBS in advance of the new topsides installation. The elastomer bearing will provide a degree of shock absorption for installation loads. Similar designs are often employed for float-over installed topsides in the Persian/Arabian gulf.

The implementation of the four central steel bearings presents a more complex challenge. It is assumed that for the original NCP topsides, these would have been installed after the MSF was landed onto the GBS. Hence, the majority of the topsides load, applied after this point, would be shared between the Jarlin wall elastomer bearings and these supports in a calculated manner.

However, if this same method was employed with an integrated deck design, then the full topside load would be transmitted to the Jarlin wall supports alone. It is unclear whether this would be acceptable for the GBS design. Therefore, at this time it is proposed that a modified design is employed, where the steel bearing is welded to the interface steelwork (as a shoe). See drawing 244-025-STR-DD-0001 (Appendix A), Details 2 & 4. These would then land onto the retained steel plates atop the Corbell ring, before being welded out at site. Support heights and the stiffness of the primary structure would then need to be tuned (by adjusting bracing, framing, shim details, or other preloading adjustment) to work with the stiffness of the elastomer bearings to evenly distribute the topsides load akin to the original design distribution. It may also be possible to further modify the steel bearing design to incorporate elastomer bearings or sand-jacks to assist with load distribution and installation shock-absorption.

In any of these cases, there is a significant degree of complexity in this design which will require further thorough assessment of both the topsides/interface steelwork and the GBS to confirm the viability. Should issues arise with the installation of a full integrated deck, then it would still be possible to revert to using a module support frame (MSF) and a modular topsides installation. This would essentially allow the proven topsides installation method of the current NCP topsides to be repeated, albeit in open water at sea, instead of in an in-shore sea loch. Alternatively, it may be possible to provide a smaller MSF, similar to the steelwork shown in Figure 19, but providing 4 stab-in cones for mating with an integrated deck. The position of the stab-in cones would need to be specifically chosen to work with the topsides framing and to distribute the loading to both the Jarlin and Corbell walls, similar to the original design.

6.1.2 Topside Layout Development

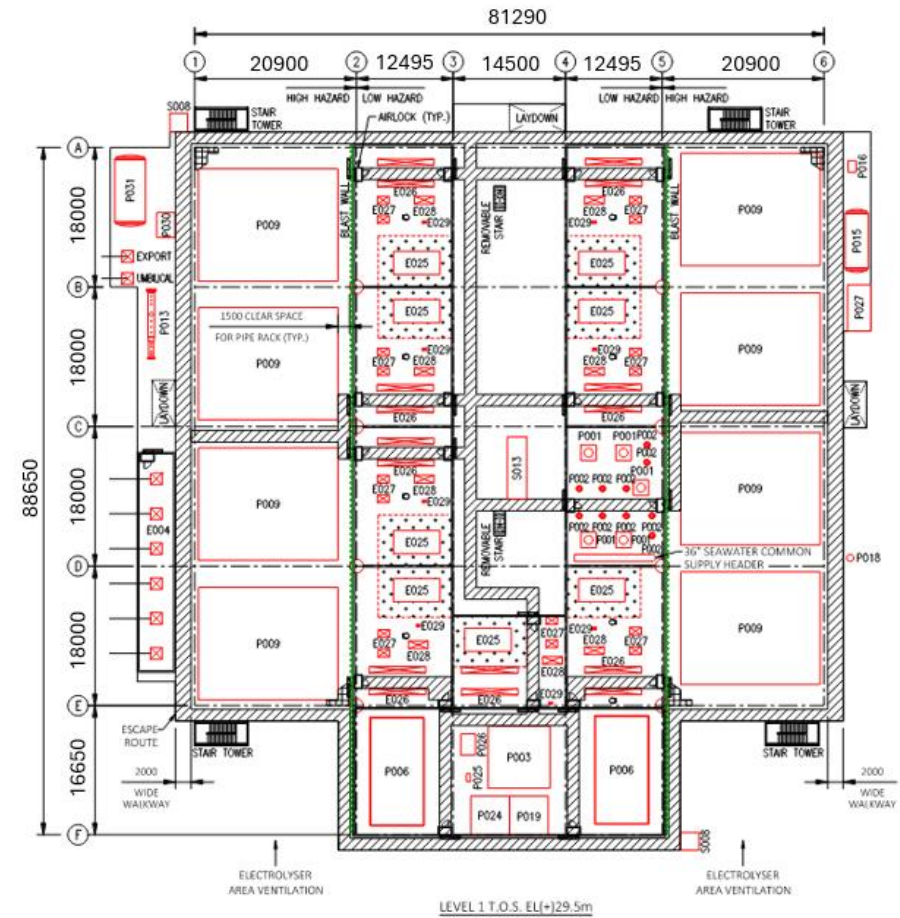
In relation to the layout development, the main changes to the proposed topside structural framing result from the increased size of the PEM Electrolyser units. At the Concept stage, there were 50No. 10MW units each sized at 12.9m x 3.5m x 3.8m (LxBxH). For Concept Development, it is intended to employ 12No. 45MW units, each sized at 18.0m x 14.5m x 7.8m (LxBxH). The significant increase in length and width necessitated extending the bay size around the units to 20.9m x 18m to provide enough space, for maintenance requirements and the 1.5m wide pipe rack running inboard of the units adjacent to the blast walls. This is illustrated in Figure 20. The 18m bay width works well with the PEM electrolyzers and also conveniently coincides with the spacing of the large legs of the interface frame.

The increased PEM Electrolyser bay length has led the overall width of the integrated deck primary frame (excluding cantilevered riser balcony to the West) to increase by ~8.4m. The utilities extension to the south of the platform has been condensed meaning the overall length of the integrated deck primary frame remains essentially unchanged at ~88.6m.

An indicative framing concept for the integrated deck, including the interface steelwork, is shown in Figure 21.



Concept: Level 1 Grid Spacing



Concept Definition: Level 1 Grid Spacing

Figure 20 Structural grid (frame) spacing changes between Concept & Concept Development

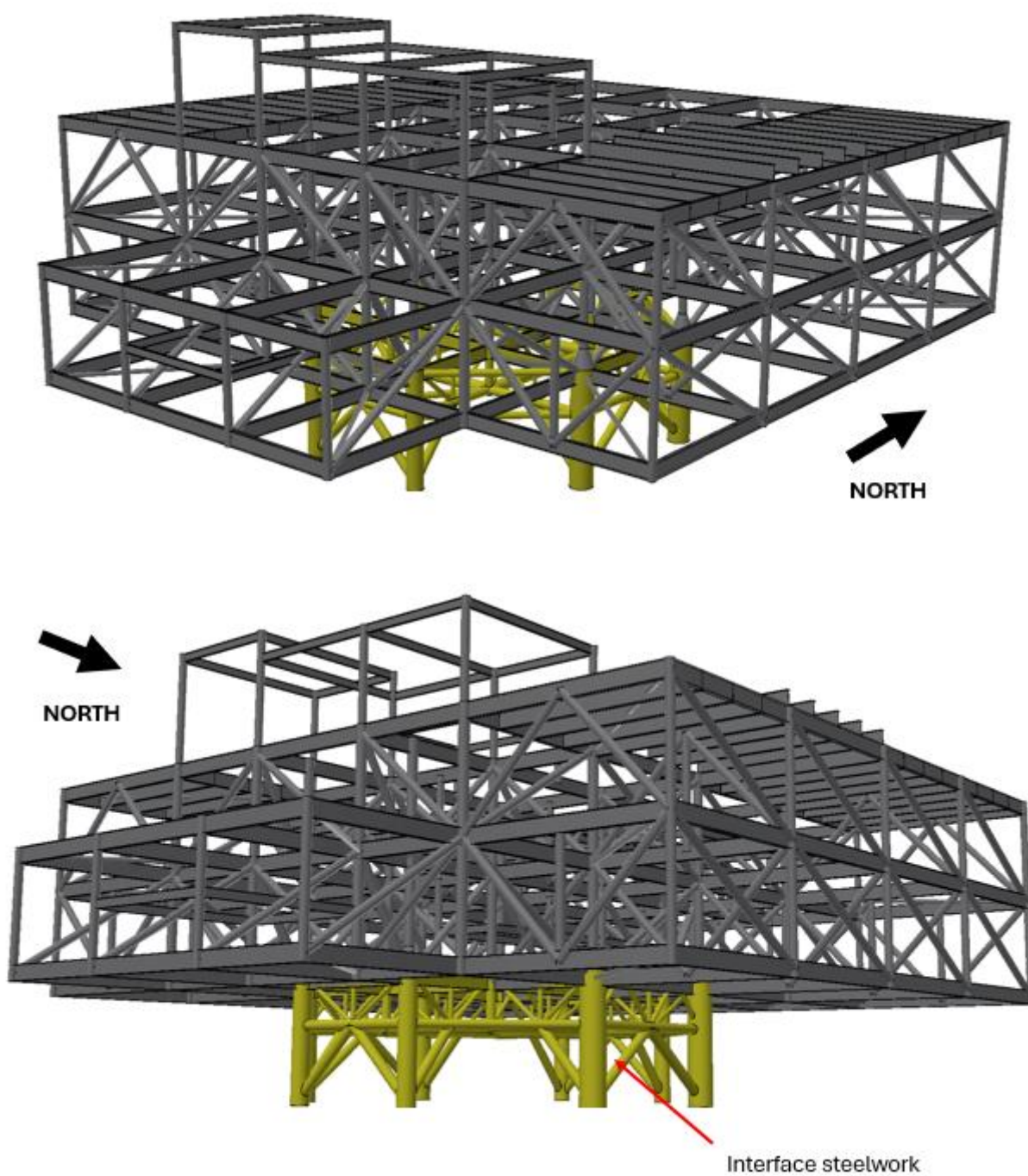


Figure 21 Indicative concept for primary framing



6.2 Conceptual Design of Appurtenances

The following section provides details of the proposed conceptual design for the required appurtenances.

The general principle for appurtenances is to employ catenary flexibles, where possible, in order to avoid any requirement to re-use existing risers/J-tubes or to make new connections to the GBS, due to the significant risk exposure these alternatives would bring to the project.

With the information available for NCP, it was not possible to identify where there are any potentially usable spare risers or J-tubes, which could be employed for the project. However, considering the age of the asset (currently 47 years old) and the challenges that would be encountered demonstrating the current integrity of the components and their supports from the GBS, as well as the ongoing challenges to inspect and maintain these items, it is deemed best to avoid these options where practical.

Making new connections to the GBS would prove to be a significant and costly undertaking. From an engineering perspective, due to the platforms age and change of ownership the availability and reliability of design drawings is likely to be a significant impediment in the development of any new appurtenance support design. Connecting to the concrete structure would entail risks of damage to existing critical structural elements of the GBS, such as pre/post tensioning cables and steel reinforcements. From the construction perspective, the use of divers inside or externally near the perforated section of the Jarlin wall is unlikely to be feasible due to the safety risks this would pose. Hydrodynamic turbulence would also be a significant factor in the efficacy of any remotely operated vehicle (ROV) operations. Due to the niche nature of this type of structure it is unlikely there are many contractors with the necessary skill set and experience to conduct this type of design and construction activity.

6.2.1 Hydrogen Export Riser, SSIV Umbilical & Power Cables

Within the Oil and Gas industry there is precedent for the use of flexibles for production risers, umbilical's, and power cables on both floating installation and fixed platforms. Therefore, it is proposed that catenary flexibles are employed for the Hydrogen Export Riser, SSIV Umbilical and Power Cables, to avoid the design and construction risks associated with fixed equivalents. From the data available it appears that there is already precedent for the use of a catenary flexible for a 10" production riser at this asset. See Figure 22. Due to the required service a bespoke Hydrogen riser and Import Power Cables are likely to be required, as opposed to off the shelf designs.

A typical hang-off for a flexible is shown in Figure 23. Similar details would be applicable for risers, umbilical's and cables.

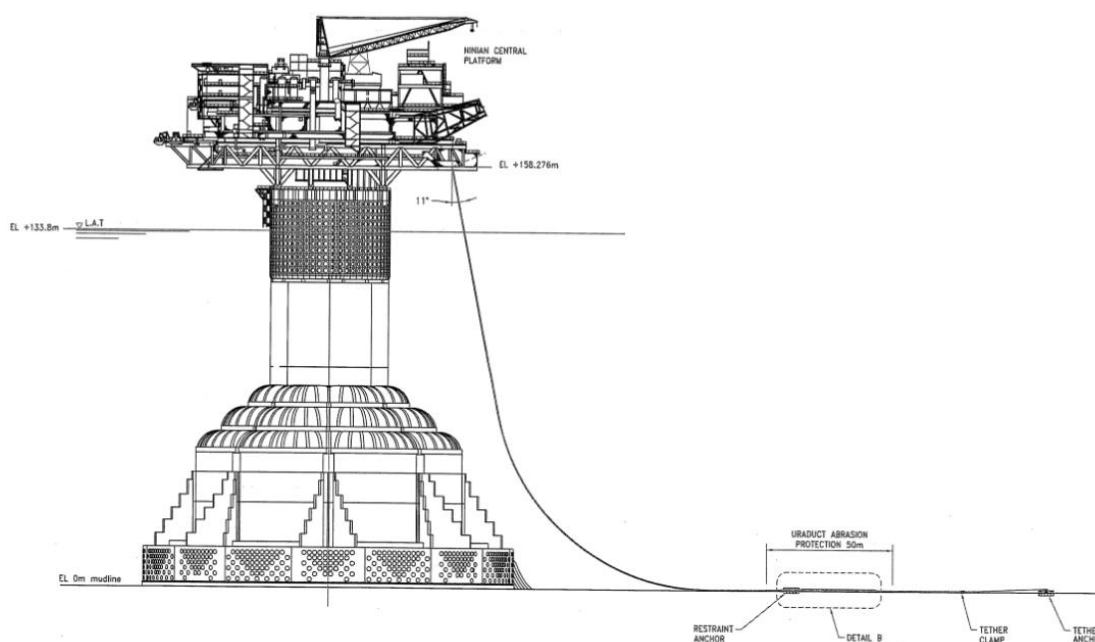


Figure 22 Existing 10" flexible production riser at NCP

As the prevailing wind is from the southwest, it is proposed that the flexibles approach the platform from the west, in order to free the north and east faces for supply vessel operations. A similar philosophy is adopted on existing oil and gas assets. A riser hang-off balcony shall be provided at the lower level to facilitate the support of the risers. See Figure 24. It is envisaged this could be a cantilever deck although it may require ties to the deck above depending upon the magnitude of the hang-off loads. The hydrogen export riser would be located to the north of this balcony to keep it at maximum distance from the accommodation and Temporary Refuge (TR), with the electrical cable hang-off being at the southern end. An enclosure around the electrical cable hang-off would be required in order to allow for the connections to topside cable (to 275kV GIS) to be made in safe area.

For riser pull-ins, it is envisaged that a winching system could be located on the cantilevered riser balcony at Level 1, although there are various options for this. For example, a temporary winching skid that can be moved between flexibles could be located on Level 3, above the Electrolysers or a specific pull-in deck could be installed at Level 2.

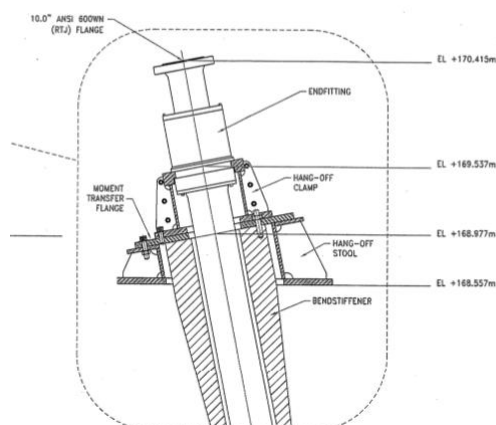


Figure 23 Typical flexible riser hang-off

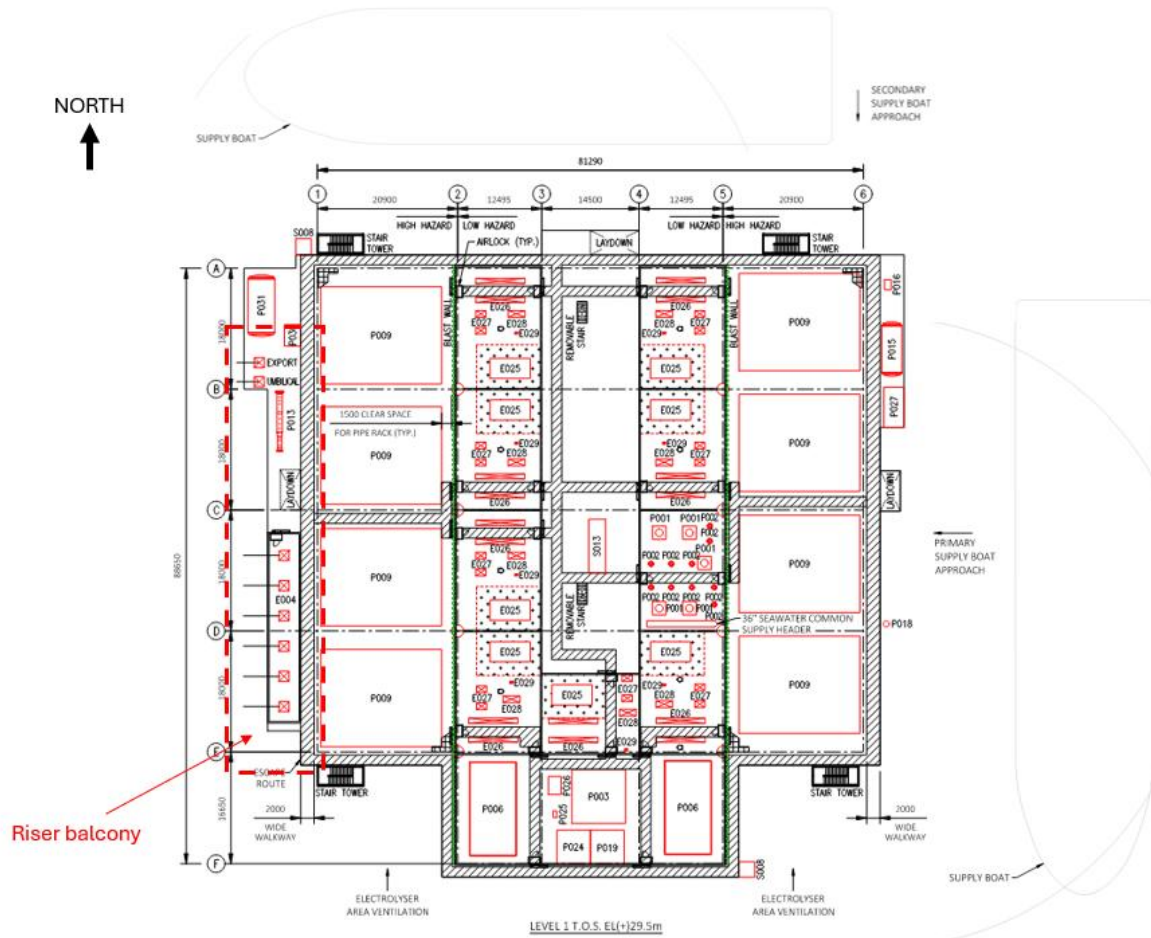


Figure 24 Location of riser balcony at Level 1

6.2.2 Seawater Lift Caissons

For the seawater lift caissons it is proposed to re-employ the existing GBS conductor guides, assuming the conductors are removed to a suitable depth (as would be expected) and the remaining guides retain good integrity.

The proposed sea water lift caissons are expected to be dead weight supported at Level 1 (El. +29.5m T.o.S), and extend down to around El. -15m to -20m below LAT. Thus, it is expected that the caissons will be around 50m in total length. The caissons would be supported by the existing conductor guides at El. +16m, El. -5m and El. -15m. A further conductor guide could be incorporated with the new interface steelwork at El. +24.5m, although this may well not be necessary.

If assuming a 762mm outer diameter and 25mm wall thickness (conservative), the caissons would each weight 22.7t. Each caisson would also require a deadweight support which would likely weight less than 1.5t.

The compartments above the caissons should be initially kept free to allow for the caissons to be installed with the platform crane. It is recommended to use the compartments above for easily clearable uses, such as the platform stores or workshop, in case future intervention is required to the caissons. For convenience it is likely beneficial for the caissons to be installed in two 25m sections joined with a mechanical connector of the type provided by GMC Limited or similar. The caissons would be provided with a stabbing type end guide to allow them to be lowered into the existing conductor guides. Once installed the internal pumps would be



lowered into the caissons in the typical fashion. It is worth noting that many existing oil and gas assets experience galvanic corrosion issues with carbon steel caissons due to the pumps typically being constructed from stainless steel, with inadequate or no isolations employed. Therefore, it is strongly recommended to provide adequate isolations and CP protections to the pump to mitigate this occurrence.

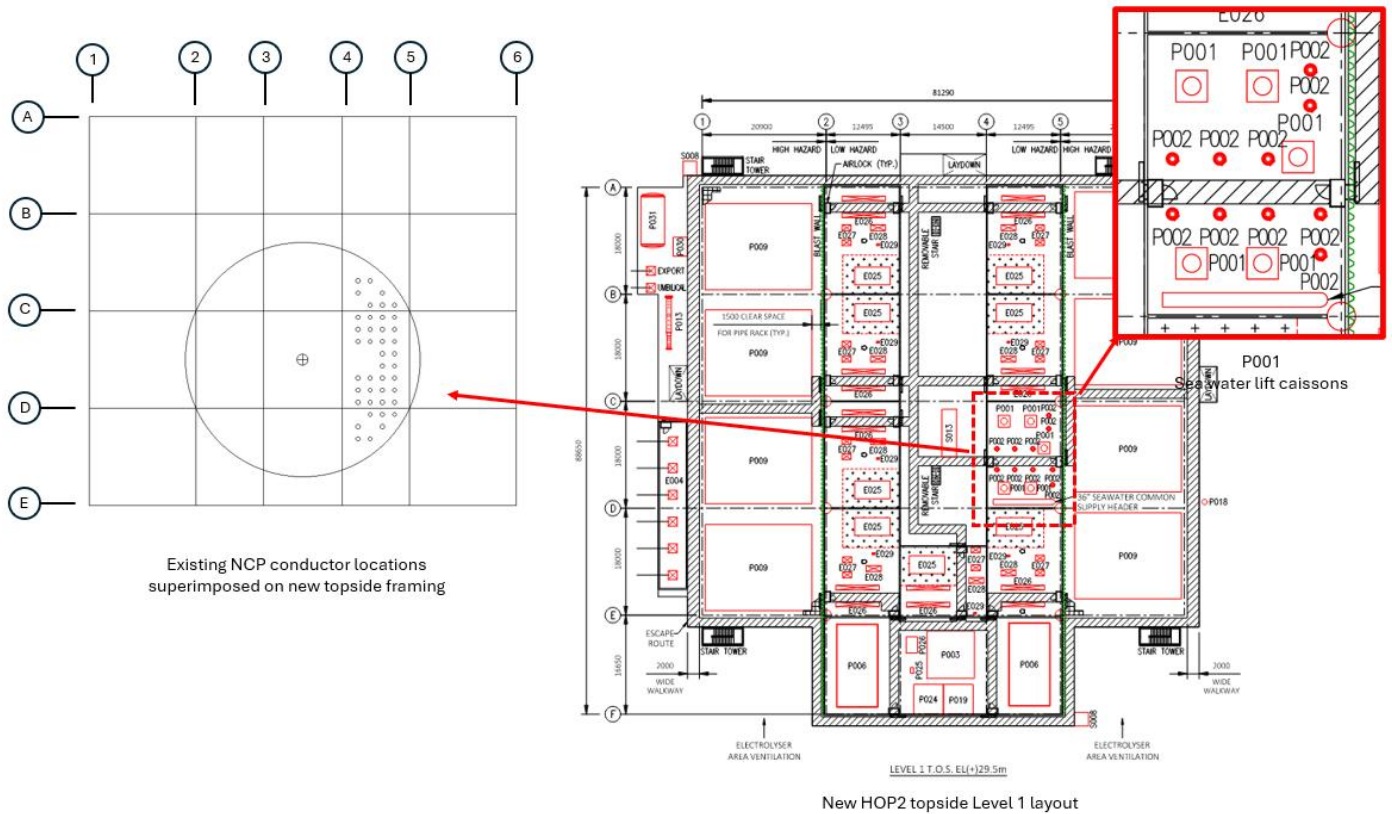


Figure 25 Location of existing conductor guides relative to new topsides & proposed sea water lift caisson locations

Although the integrity of the conductor guides is not known, the Jarlin wall of NCP provides a large degree of sheltering to the conductors and thus it is felt this is a reasonable assumption at this stage. Future loading on the guide frame would be significantly reduced due to the fewer number of caissons.

If there are integrity issues with the conductor guides, then this is likely to be limited to the frames at El. +16m and El. -5m levels where fatigue loading on the guides will be largest. In this case it is likely practicable to make repairs and reinforcements to El. +16m. The span between the El. +16m guide and the lower El. -15m would then be 31m, which is only 6m longer than the typical 20-25m 30" conductor spans employed across the North Sea meaning it is potentially viable to design the conductors to not require support at El. -5m. This increase in span could likely be compensated for with increased wall thickness.

6.2.3 Seawater Dump Caisson

A single sea water dump caisson is required for the new HOP2 topsides. It is recommended that this not be installed into the conductor guides to minimise appurtenances within the Jarlin wall and limit the associated future integrity burden. Ideally the dump caisson will extend a short distance below the Level 1 deck releasing the water to sea through the air gap. It is proposed this is located at Level 1 on the east face of the platform (Ref. Figure 25 Item P018 at Grid D/6).



6.3 Weight Estimating

Due to the early stage of the project and as per the previous stage, a volumetric approach has been adopted for weight estimating. The work carried out in Concept Definition builds upon that carried out previously, utilising the latest layout and equipment sizes and updated norms where applicable.

6.3.1 Volumetric Estimating

Table 12 gives the volumetric dry weight values that have been adopted for use in the project. These norms are applied to the volumes of relevant areas which are defined in Figure 26 to Figure 28 in order to build up a more accurate weight estimate. Where possible, Oil and Gas industry norms have been used. The norms are applied to enclosed areas only, with the weight of any cantilever deck steelwork/equipment attached to the perimeter of these areas, captured within the densities of the enclosed areas. Allowances for the Import Power Cables, Hydrogen Export Riser and Umbilical are included separately in the weight estimate (20t per hang-off). This is also the case for the Accommodation module. As per the previous stage a 1350t appliance has been included for a 68-bed living quarters and helideck, similar to that used for the Brent Charlie platform. This has been split 1250t to the accommodation and 100t to the helideck.

The Utilities, Gas treatment, and Gas compression areas adopt oil and gas norms, and are the average volumetric values for modules of these types. These are shown in Table 11. These are felt to be appropriate for the areas they have been applied to. The “HOP2” precursor identifies values that have been extrapolated and assumed based upon the oil and gas norms and engineering judgement. This is necessary due to the lack of previous projects of this nature.

Although there has been significant change in the design of the PEM Electrolysers, their “in-place” density (50kg/m³) has remained very close to that of the previous stage (48kg/m³). Hence, the 0.18t/m³ volumetric used previously for the wider electrolyser areas (HOP2 – PEM) has been retained. For the discipline weight breakdown, as shown in Table 14. This gives mechanical as having 28% of the distribution, which within the expected range. Structural was assumed to be 50% of the distribution as is typical. The remaining disciplines were given assumed values based upon engineering judgement.

The previous 0.18t/m³ volumetric density that was assumed for the areas housing the transformers and rectifier equipment (HOP2-PEM TX) was reviewed to establish if this was still appropriate. It was found that the in-place density of the equipment (35kg/m³) had dropped from the previously 42kg/m³, which corresponds to the use of fewer transformers and larger bay spacings and bay height. Other than the 55kV transformers (60t dry weight), the other electrical equipment in these locations is comparatively light (< 5t dry weight for electrical equipment & < 15t for single air handling unit). Thus, the density of these areas was pragmatically reduced to reflect this. A value of 0.15t/m³ was adopted in order to avoid underestimating the weight. This is akin to the density of a typical platform in the Arabian/Persian Gulf, where platforms typically have less densely populated topsides. There is likely some potential layout optimisation that can be employed here to better use the space. However, given the limited scope of this stage, this will need to be investigated further in subsequent stages of the project. Discipline weight distribution (Table 14) was adopted from the power generation oil and gas norm, with most of the mechanical equipment weight transferred to the electrical discipline and some added for HVAC.



Within the oil and gas volumetric norms, there is no norm which would be suitable to employ for the area which houses the 275kV/66kV transformer (HOP2 – 275kV TX). This is the only item of equipment that occupies that space and with an operating weight of 1140t, this will significantly raise the volumetric density. As it is expected that the transformer will be shipped with oil and only drained if it fails in service, the operating weight (including oil contents) is used for developing an equivalent dry volumetric weight. Assuming that the transformer makes up 65% of the area weight, this gives a volumetric of 0.672t/m³. Discipline weight distribution (Table 14) was then weighted heavily towards structural with small allowances to HVAC and piping (for locating the radiators externally).

For the remainder of the areas with electrical equipment (HOP2 – Electrical), review of the in-place equipment densities (ranging from 58-91kg/m³) showed these values fell well below the typical average equipment (mechanical - 119kg/m³) values for the power generation norm which was previously used for these areas. Thus, a reduced volumetric weight is deemed appropriate for these areas. A value of 0.26t/m³ was selected as the equipment densities broadly lay in the middle of the power generation (0.291t/m³) and utilities (0.23t/m³) norms. Discipline weight distribution (Table 14) was adopted from the power generation oil and gas norm, with mechanical equipment weight transferred to the electrical discipline.

For the maintenance corridors at Level 1 and Level 2 contain no equipment specified equipment and hence there is no suitable area type to select within the oil and gas norms. A volumetric density of 0.11t/m³ has been adopted based upon the average structural density from the various oil and gas module norms.

Table 11 Typical oil and gas module volumetric norms

Module Type	Dry High/Low and Average	Architectural	Electrical	HVAC	Instruments	Loss Control	Mechanical	Piping	Structural	Dry/Oper Weight Norm (t/m ³)
Utilities	H - Kg/m ³	14.3	21.6	11.9	14.2	8.2	60.2	24.8	145.9	0.230 0.261
	Av - Kg/m ³	11.1	13.8	7.9	6.5	4.7	42.7	16.5	127.1	
	Av - %	4.8%	6.0%	3.4%	2.8%	2.0%	18.5%	7.2%	55.2%	
	L - Kg/m ³	5.5	6.5	2.5	1.9	1.5	23.3	7.8	108.4	
Gas Treatment	H - Kg/m ³	9.9	9.0	5.1	4.6	3.0	54.9	43.4	149.7	0.194 0.225
	Av - Kg/m ³	4.7	6.1	2.7	2.4	2.7	33.8	26.1	115.8	
	Av - %	2.4%	3.1%	1.4%	1.2%	1.4%	17.4%	13.4%	59.6%	
	L - Kg/m ³	2.6	1.2	1.0	0.4	1.7	7.5	12.4	94.4	
Power Generation	H - Kg/m ³	21.8	41.1	8.3	3.0	6.1	121.9	13.6	131.8	0.291 0.316
	Av - Kg/m ³	13.6	28.8	4.1	1.4	2.7	119.3	6.9	114.2	
	Av - %	4.7%	9.9%	1.4%	0.5%	0.9%	41.0%	2.4%	39.2%	
	L - Kg/m ³	0.3	11.5	2.3	0.2	0.5	43.3	3.6	89.3	
Gas Compression	H - Kg/m ³	13.3	9.9	6.4	13.8	9.8	110.0	57.6	184.3	0.309 0.346
	Av - Kg/m ³	8.7	7.1	4.0	6.1	5.6	88.4	44.0	145.0	
	Av - %	2.8%	2.3%	1.3%	2.0%	1.8%	28.6%	14.2%	46.9%	
	L - Kg/m ³	3.4	5.9	2.4	1.3	1.7	61.2	11.1	112.6	
Living Quarters (excl. Helideck)	H - Kg/m ³	71.3	13.8	21.8	1.6	6.1	3.9	3.7	111.5	0.151 0.160
	Av - Kg/m ³	47.3	5.7	8.8	1.0	1.6	1.9	1.3	83.2	
	Av - %	31.4%	3.8%	5.8%	0.7%	1.1%	1.3%	0.9%	55.2%	
	L - Kg/m ³	22.2	2.2	2.3	0.3	0.1	0.8	0.2	55.5	
Integrated Deck (Complete Topsides)	H - %	5.2%	7.5%	1.1%	4.1%	1.0%	21.2%	20.0%	57.3%	0.226 0.300
	Av - %	3.6%	6.8%	0.8%	2.8%	0.7%	16.8%	16.9%	51.6%	
	L - %	2.4%	6.0%	0.4%	1.9%	0.4%	14.0%	15.3%	46.9%	



Table 12 Volumetric densities (dry) adopted for the project

Area	Volumetric dry density adopted (t/m ³)
Utilities	0.230
Gas treatment	0.194
Gas compression	0.309
HOP2 - PEM	0.180
HOP2 - PEM TX	0.150
HOP2 - 275kV TX	0.672
HOP2 - Electrical	0.260
HOP2 - Open	0.110

KEY

- Utilities
- Gas treatment
- Gas compression
- HOP2 - PEM
- HOP2 - PEM TX
- HOP2 - 275kV TX
- HOP2 - Electrical
- HOP2 - Open

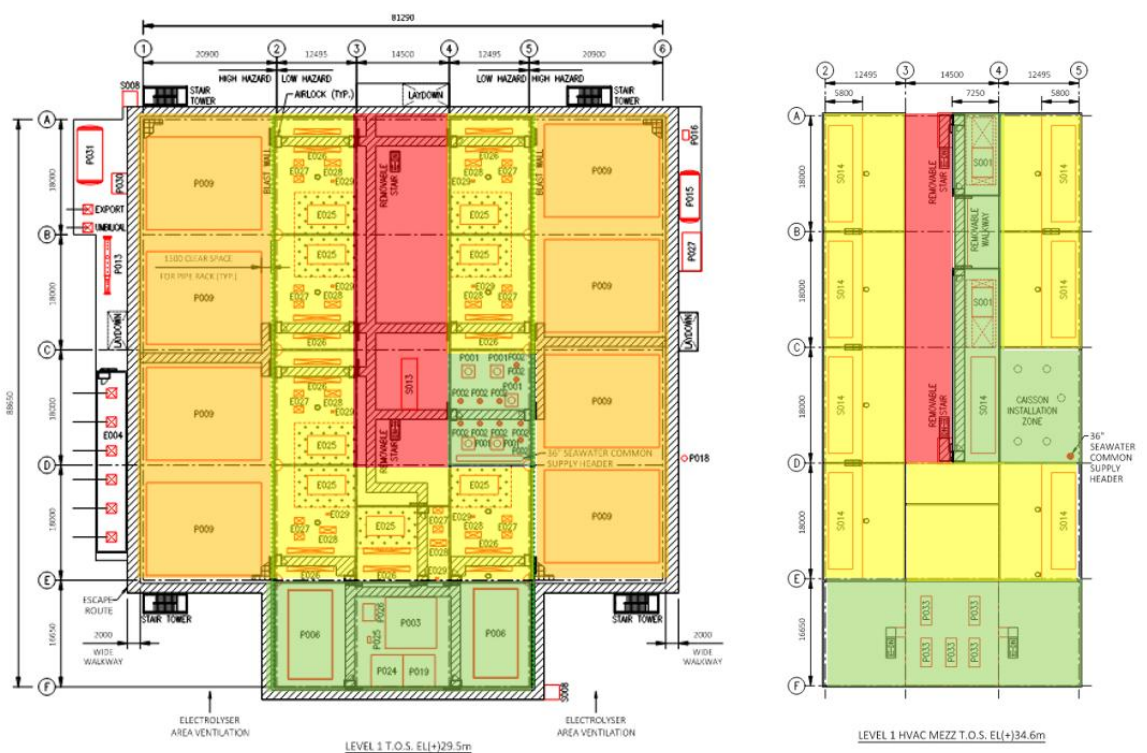


Figure 26 Level 1 highlighting areas where weight norms are applied



KEY

- Utilities
- Gas treatment
- Gas compression
- HOP2 - PEM
- HOP2 - PEM TX
- HOP2 - 275kV TX
- HOP2 - Electrical
- HOP2 - Open

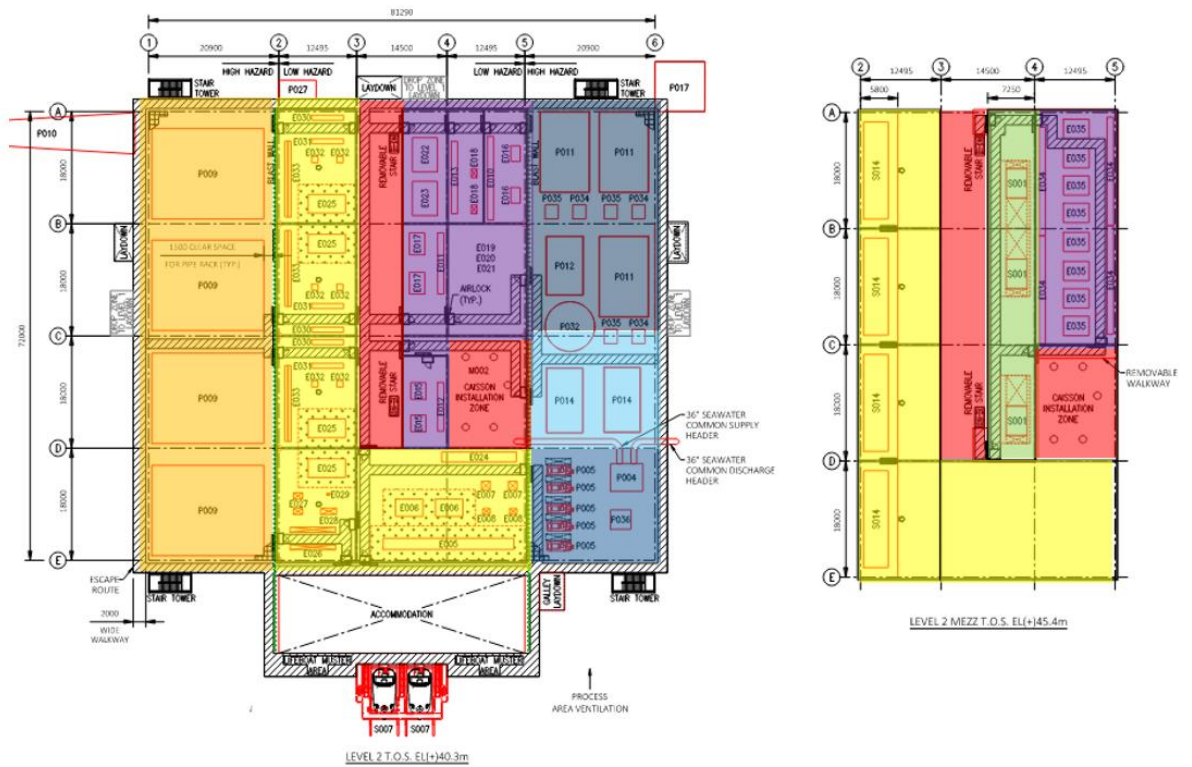


Figure 27 Level 2 highlighting where weight norms are applied

KEY

- Utilities
- Gas treatment
- Gas compression
- HOP2 - PEM
- HOP2 - PEM TX
- HOP2 - 275kV TX
- HOP2 - Electrical
- HOP2 - Open

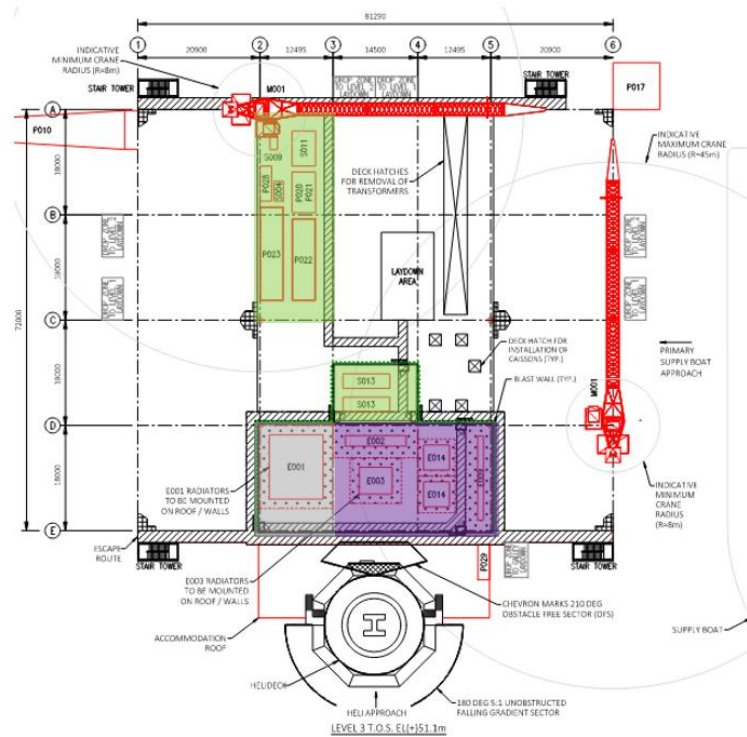


Figure 28 Level 3 highlighting where weight norms are applied



6.3.2 Weight Estimate

From the volumetric estimate a dry weight of 31,600t was calculated for the HOP2 topside, with the operating weight estimated as 35,000t (10% greater than the dry weight). These values have been rounded up to the nearest 100t to reflect this is still an early design stage estimate. This weight estimate assumes integrated deck construction and includes an allowance for interface steelwork. As per the previous stage estimate, no contingencies have been applied to the weight estimate at this time. The overall topsides volumetric density is 0.220t/m³ which compares well with the average norm for a North Sea integrated deck oil and gas platform (0.226t/m³). This provides a good degree of confidence in the validity of the estimate. The operating weight falls within the 38,000t GBS weight limit advised for the project.

The dry weight remains close to the previously estimated value (31,841t), despite a significant increase in the electrical equipment required and the addition of interface steelwork (900t) and appurtenance weighs (275t allowance). These additional loads have been counterbalanced by the reduction in weight gained from the larger PEM Electrolysers, which occupy a reduced space on the topside and a generally more efficient use of the available space (i.e. smaller central corridors and tighter equipment spacing) for the balance of equipment.

Table 13 HOP2 topsides weight estimate

Level	Area	Area Type	Volumetric (t/m3)	L (m)	W (m)	H (m)	Area (m2)	Vol (m3)	Dry Weight (t)	Operating Weight Factor	Operating Weight (t)
0	Interface steelwork								900	1.00	900
1	Utilities (below accom)	Utilities	0.230	16.65	39.5	10.8	658	7103	1634	1.15	1879
1	Utilities (caissons)	Utilities	0.230	18	12.5	10.8	225	2429	559	1.15	642
1	Electrolyser (W)	HOP2 - PEM	0.180	72	20.9	10.8	1505	16252	2925	1.15	3364
1	Electrolyser (E)	HOP2 - PEM	0.180	72	20.9	10.8	1505	16252	2925	1.15	3364
1	PEM Tx (W)	HOP2 - PEM TX	0.150	72	12.5	10.8	900	9716	1457	1.05	1530
1	PEM Tx (E)	HOP2 - PEM TX	0.150	54	12.5	10.8	675	7287	1093	1.05	1148
1	PEM Tx (S)	HOP2 - PEM TX	0.150	18	14.5	10.8	261	2819	423	1.05	444
1	Central corridor lower (open)	HOP2 - Open	0.110	54	14.5	5.7	783	4463	491	1.00	491
1	Central corridor upper (open)	HOP2 - Open	0.110	54	7.25	5.1	392	1997	220	2.00	439
1	Central corridor (HVAC)	Utilities	0.230	54	7.25	5.1	392	1997	459	1.15	528
2	Electrolyser (W)	HOP2 - PEM	0.180	72	20.9	10.8	1505	16252	2925	1.15	3364
2	PEM Tx (W)	HOP2 - PEM TX	0.150	72	12.45	10.8	896	9681	1452	1.05	1525
2	Electrical power (switchgear)	HOP2 - PEM TX	0.150	18	27	10.8	486	5248	787	1.05	827
2	Electrical power (Tx & switchgear)	HOP2 - Electrical	0.260	36	12.5	10.8	450	4858	1263	1.05	1326
2	Utilities (Workshop)	HOP2 - Open	0.110	18	12.45	10.8	224	2420	266	1.00	266
2	Gas treatment	Gas treatment	0.194	18	20.9	10.8	376	4063	788	1.15	906
2	Gas compression	Gas compression	0.309	54	20.9	10.8	1129	12189	3766	1.15	4331
2	Central corridor	HOP2 - Open	0.110	54	7.25	10.8	392	4228	465	1.00	465
2	Central corridor lower (Tx & SG)	HOP2 - Electrical	0.260	54	7.25	5.1	392	1997	519	1.05	545
2	Central corridor mezz (HVAC)	Utilities	0.230	54	7.25	5.7	392	2232	513	1.15	590
3	Utilities	Utilities	0.230	36	12.46	5	449	2243	516	1.15	593
3	Utilities	Utilities	0.230	9	14.5	5	131	653	150	1.15	173
3	Electrical power (Tx & switchgear)	HOP2 - 275kV TX	0.672	18	12.5	11.6	225	2609	1753	1.05	1841
3	Electrical power (Tx & switchgear)	HOP2 - Electrical	0.260	18	27	9.3	486	4519	1175	1.05	1234
	Accommodation								1250	1.00	1250
	Helideck								100	1.00	100
	Flare tower								125	1.00	125
	Oxy vent boom								125	1.00	125
	Cranes (x2)								200	1.00	200
	Caissons (x5 water lift)								115	1.00	115
	Hydrogen export riser								20	1.00	20
	Umbilical								20	1.00	20
	Import power cables (x6)								120	1.00	120
TOTAL								143,504	31,501	1.10	34,791



Table 13 gives highlights how the weight estimate was built up by area. The largest contributor by an individual area type is the electrolyzers (HOP2 – PEM) which have a combined dry weight of 8,776t. However, if the electrical equipment areas were taken together (HOP2 – PEM TX, HOP2 – 275kV TX and PEM2 – Electrical), these would exceed this with a combined dry weight of 9,923t. Gas compression and Gas treatment combined make up a dry weight of 4,555t with Utilities areas having a dry weight of 3,381t. The remaining 4,417t is made up with the accommodation module, maintenance corridor/store areas, interface steelwork, flare/vents, appurtenance hang-off loads and cranes.

The following tables provide a break down of the platform weight by discipline for estimating purposes.

Table 14 Discipline weight breakdown by area type

Area	Arch	Electrical	HVAC	Instr	Loss	Mech	Piping	Struct
Utilities	5%	6%	3%	3%	2%	19%	7%	55%
Gas treatment	2%	3%	1%	1%	1%	17%	13%	60%
Gas compression	3%	2%	1%	2%	2%	29%	14%	47%
HOP2 - PEM	0%	8%	0%	2%	1%	28%	12%	50%
HOP2 - PEM TX	5%	33%	9%	0%	1%	10%	2%	40%
HOP2 - 275kV TX	0%	65%	1%	0%	0%	0%	1%	33%
HOP2 - Electrical	5%	51%	1%	0%	1%	0%	2%	40%
HOP2 - Open	5%	0%	5%	0%	0%	0%	5%	85%
Living quarters	31%	4%	6%	1%	1%	1%	1%	55%

Table 15 Discipline weights by area (t)

Area	Arch	Elect	HVAC	Instr	Loss	Mech	Piping	Struct	Total
Utilities	185	230	131	108	78	710	274	2114	3831
Gas treatment	19	25	11	10	11	137	106	470	788
Gas compression	106	87	49	74	68	1078	536	1768	3766
HOP2 - PEM	0	702	0	132	44	2457	1053	4388	8776
HOP2 - PEM TX	261	1720	469	0	52	521	104	2085	5213
HOP2 - 275kV TX	0	1140	18	0	0	0	18	579	1753
HOP2 - Electrical	148	1508	30	0	30	0	59	1183	2957
HOP2 - Open	72	0	72	0	0	0	72	1226	1442
Accommodation	392	47	73	8	13	16	11	690	1250
Helideck	0	0	0	0	0	0	0	100	100
MSF	0	0	0	0	0	0	0	900	900
Flare tower	0	0	0	0	0	0	0	125	125
Oxy Vent boom	0	0	0	0	0	0	0	125	125
Cranes	0	0	0	0	0	200	0	0	200
Caissons (x5)	0	0	0	0	0	0	0	115	115
Hydrogen riser	0	0	0	0	0	20	0	0	20
Umbilical	0	0	0	0	0	20	0	0	20
Power cables (x6)	0	0	0	0	0	120	0	0	120

Total dry weight (t) = 31,501



Table 16 Topside dry weight broken down by discipline

	Arch	Elect	HVAC	Instr	Loss	Mech	Piping	Struct	Total
Topside weight (t)	1182	5458	852	332	296	5280	2234	15867	31501
% of topside weight	4%	17%	3%	1%	1%	17%	7%	50%	100%
O/all density (kg/m ³)	8	38	6	2	2	37	16	111	220

No consideration has been given to the topside CoG at this stage of the design. This is in due to the simplified volumetric weight estimate approach adopted for this high-level design. Production of a detailed weight estimate which would include CoG data was out side the scope of the study. The CoG will be important to assess as the project progresses as this can cause uneven loading to the existing GBS, which may lead to its design envelope being exceeded for a topside weight lower than the advised 38,000t limit. Although unknown, it is likely that the existing Ninian central topside CoG is close to the centre of the GBS. Should the CoG of the new HOP2 topside be found to be outside the GBS design envelope, then there are options to address this. As no structural analysis has yet been carried out, the first option to consider would be to reposition the topside so that the CoG is within the GBS envelope. This could be achieved by amending the structural framing arrangement for the interface steelwork and topside. A second option would be to amend the topside layout to better distribute the weight. This would also likely require modification to the structural framing arrangement.

6.4 Construction

6.4.1 Base Case – Integrated Deck

The base case for the platform installation is an integrated deck design, as this would prove the most efficient in terms of weight and overall cost. However, at present the only vessel that could install a topside of this weight is the Allseas Pioneering Spirit, which has a current lifting capacity of 48,000t for topsides. The HOP2 topside is within the vessel's present capability, and it is believed the Pioneering Spirit has adequate width between its hulls to straddle the existing Ninian Central GBS.

However, further engagement would be required with Allseas to develop the lifting concept and confirm the feasibility of installing an integrated deck. This would involve clarification on the clearances required and load/movement limitations of the Topsides Lift System in the context of this project; clarification on the preparatory work that may be needed on the GBS; concept development of the steelwork to interface with lifting arms; and consideration of the load out and transit conditions. Figure 29 shows the high-level installation sequence for an integrated deck type HOP2 topside.

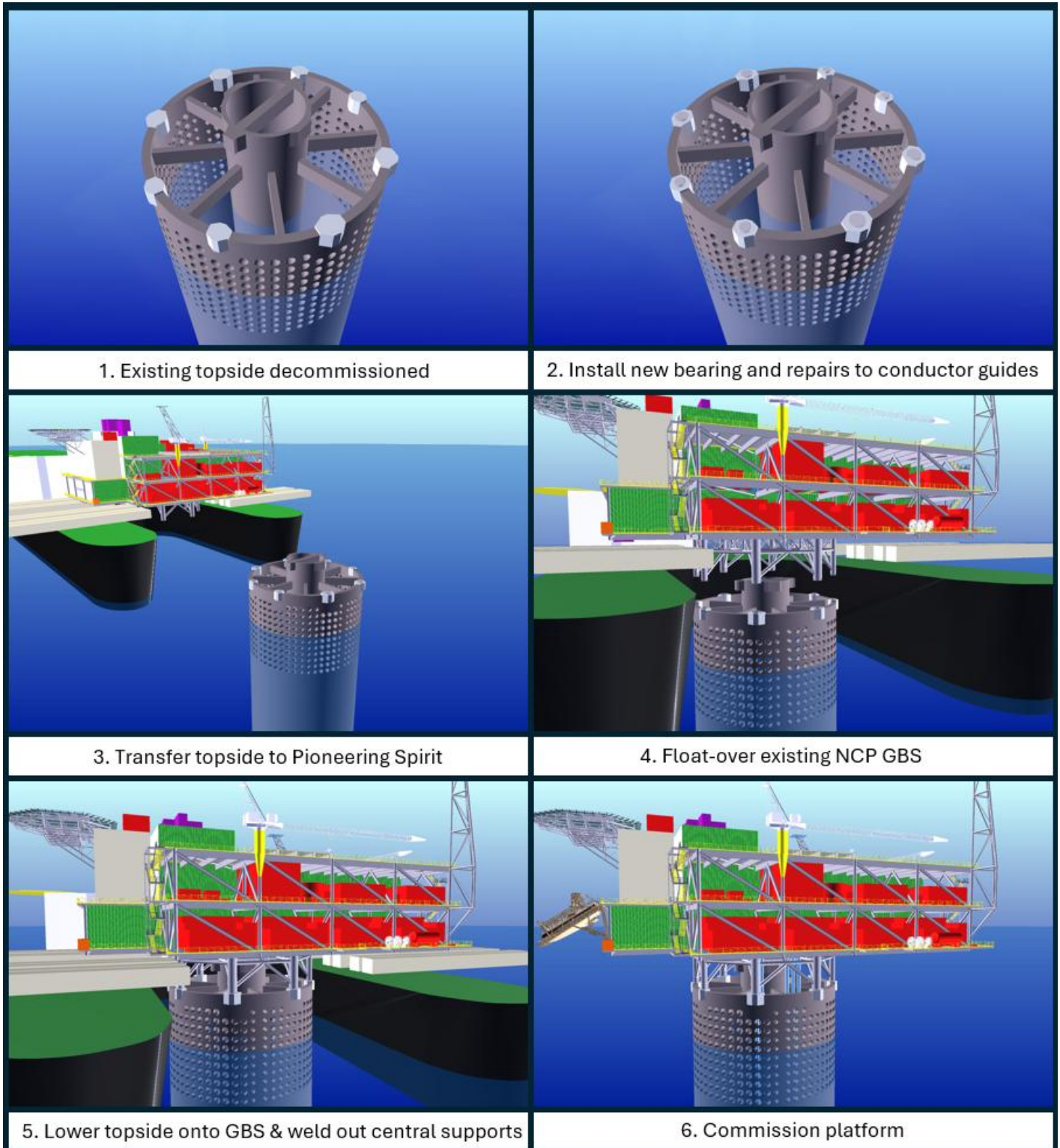


Figure 29 High level installation sequence for the installation of an integrated deck with the Pioneering Spirit



6.4.1 Modular Installation

To provide flexibility in the installation method, this study has looked at the viability of a more traditional modular installation concept. This opens up the potential to use alternative installation contractors with more common dual crane type vessels, where there is greater market availability.

It is concluded that a similar modular installation to the existing NCP topside is potentially viable. However, this would potentially push the operating weight for the platform very close to the 38,000t GBS limit provided by NZTC. This concept would first utilise a Module Support Frame (MSF) of around 1800t, which would be installed to the GBS in advance of the separate installation of several topsides modules.

Including 1800t for an MSF and assuming the modular topside design increases the main topside volume by 7,500m³ (additional 1.5m width per split line – see Figure 30) with the same volumetric density for the integrated deck, it is estimated that a modular installation methodology would increase the dry topsides weight by 2,500t to 34,100t. The operating weight increases to 37,800t (using the same 1.11 overall operating factor), which does not leave much of a margin. Weight management would play a key role in development of either installation concept, but particularly so for this option. This will require a robust FEED with a greater level of precision to weight estimating than would typically be the case. Further weight estimates should be “bottom-up” using vendor weights and discipline estimates.

The topside structure would be split into 10 modules, with the largest individual module weight likely in the region of 7,500t, which would put the installation within the range of the Saipem 7000 and Heerema’s Sleipner & Thialf vessels (the Thialf is likely to be marginal for a 7,500t module at required lift radius). The greater lifting capacity of the Sleipner (~20,000t tandem lift), it could be possible to install fewer larger modules. Conversely, smaller modules would potentially open up the scope to smaller vessels such as the Heerema’s Balder. That said, given the magnitude of the scope it would not likely be worth considering vessels smaller than the Balder with its tandem lift capacity of 6,300t, as there is a sizable step down in lifting capacity below this vessel and this would entail a less practical number of lifts. Figure 31 shows an installation sequence for a modular topsides using the Saipem 7000 vessel.

Without direct engagement with Heavy Lift Vessel contractors, which was outwith the scope for this project phase, there is limited data to use to determine lift capabilities for vessels. Saipem publish lifting curves for the S7000 online (single crane), shown in Figure 32. It is envisaged that the main hooks of both cranes will be needed for lifting the modules. The crane data has been used to perform a preliminary check of the reach and capacity for the installation of the largest module of the proposed topside (Module 1). An indicative sketch which shows the reach of the S7000 for installing the modules is shown in Figure 33. From this it appears to be feasible to install the heaviest module (Module 1 ~ 7,500t) using both cranes for a tandem lift with capacity of (x2) 4000t = 8000t @ 60m radius. The utilities cantilever could be installed as a separate module to reduce the weight if required to increase the reach.

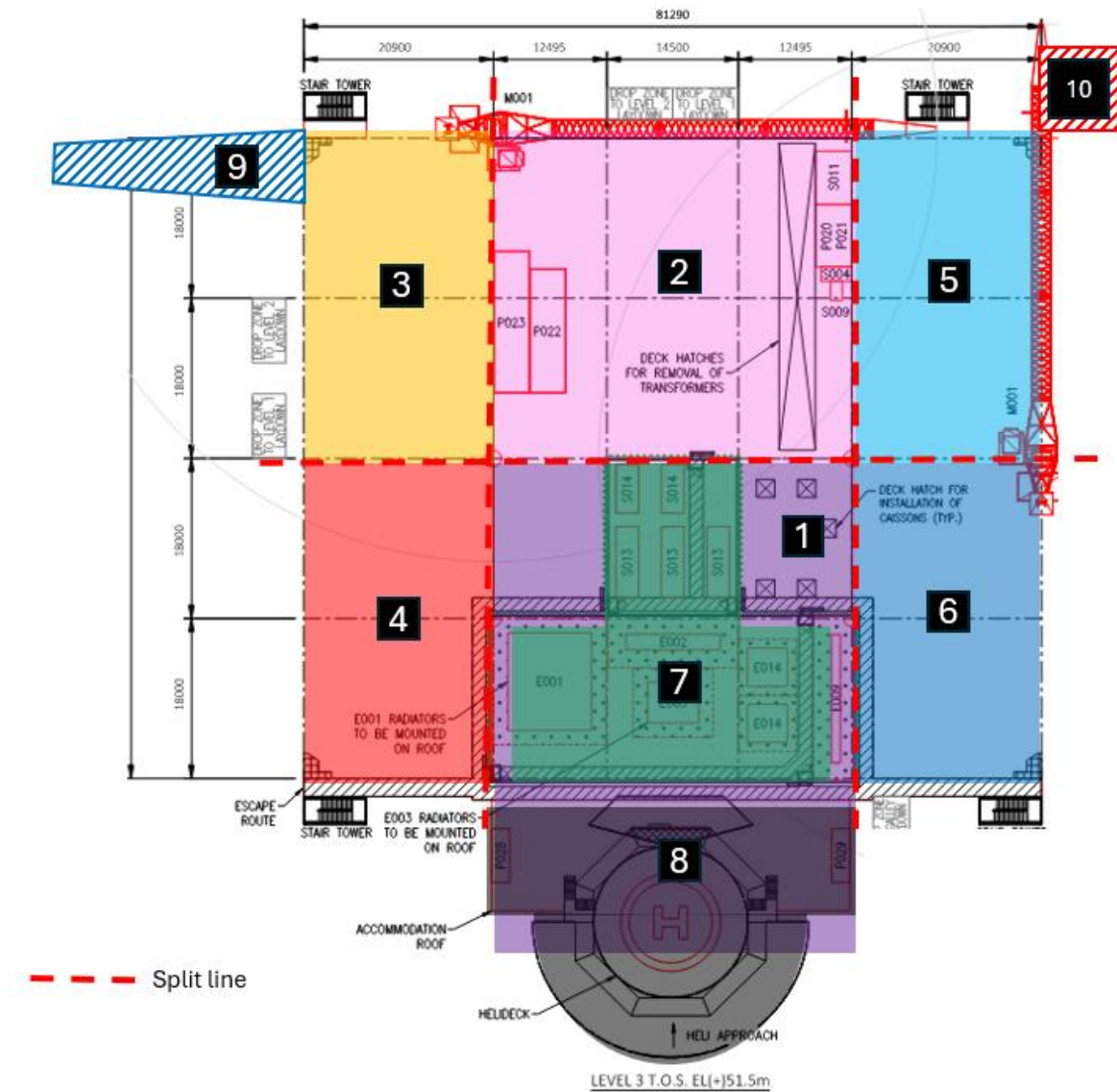


Figure 30 Proposed breakdown of topsides for modular installation

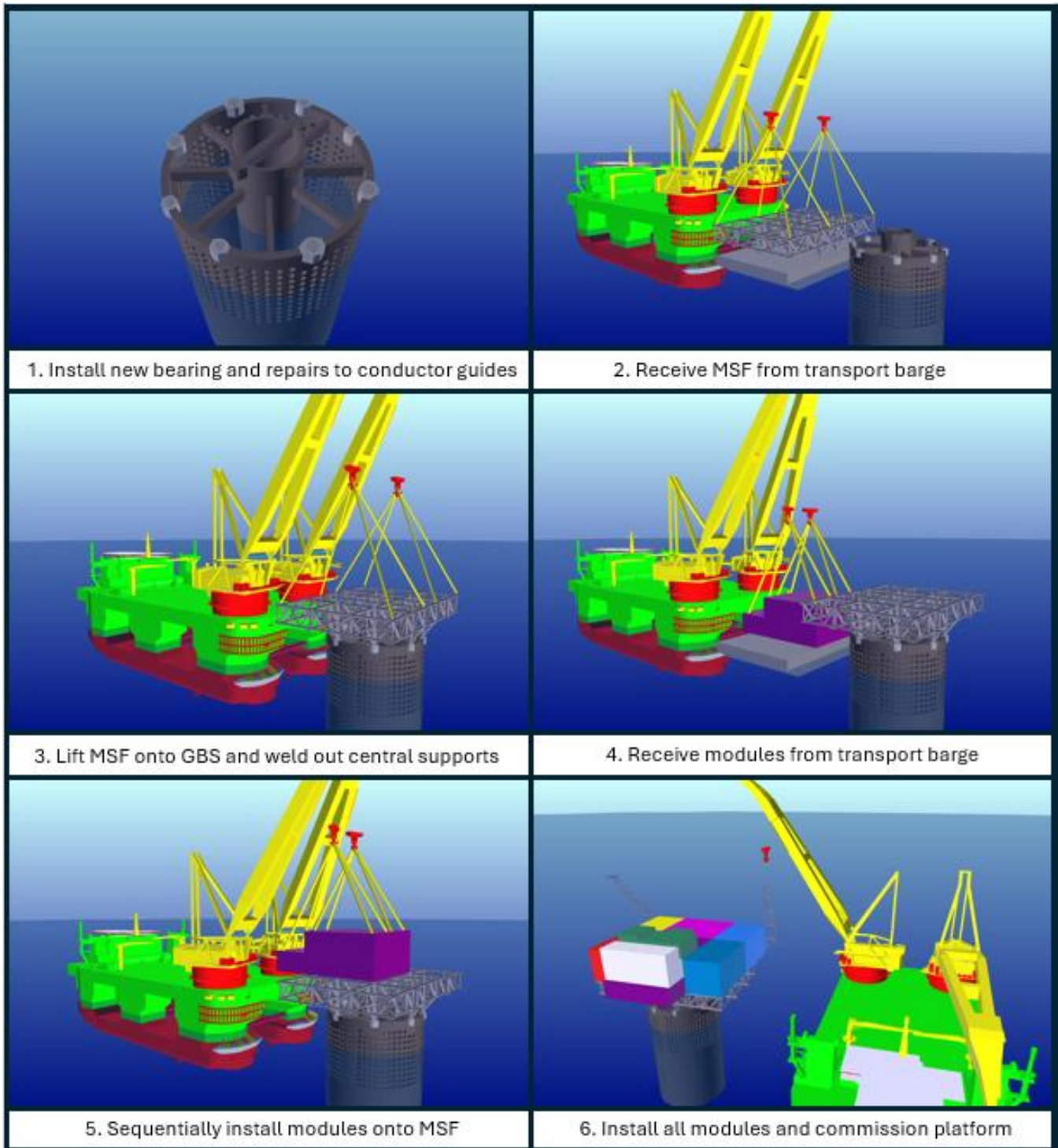


Figure 31 Installation sequence for a modular topside installation methodology by Saipem 7000

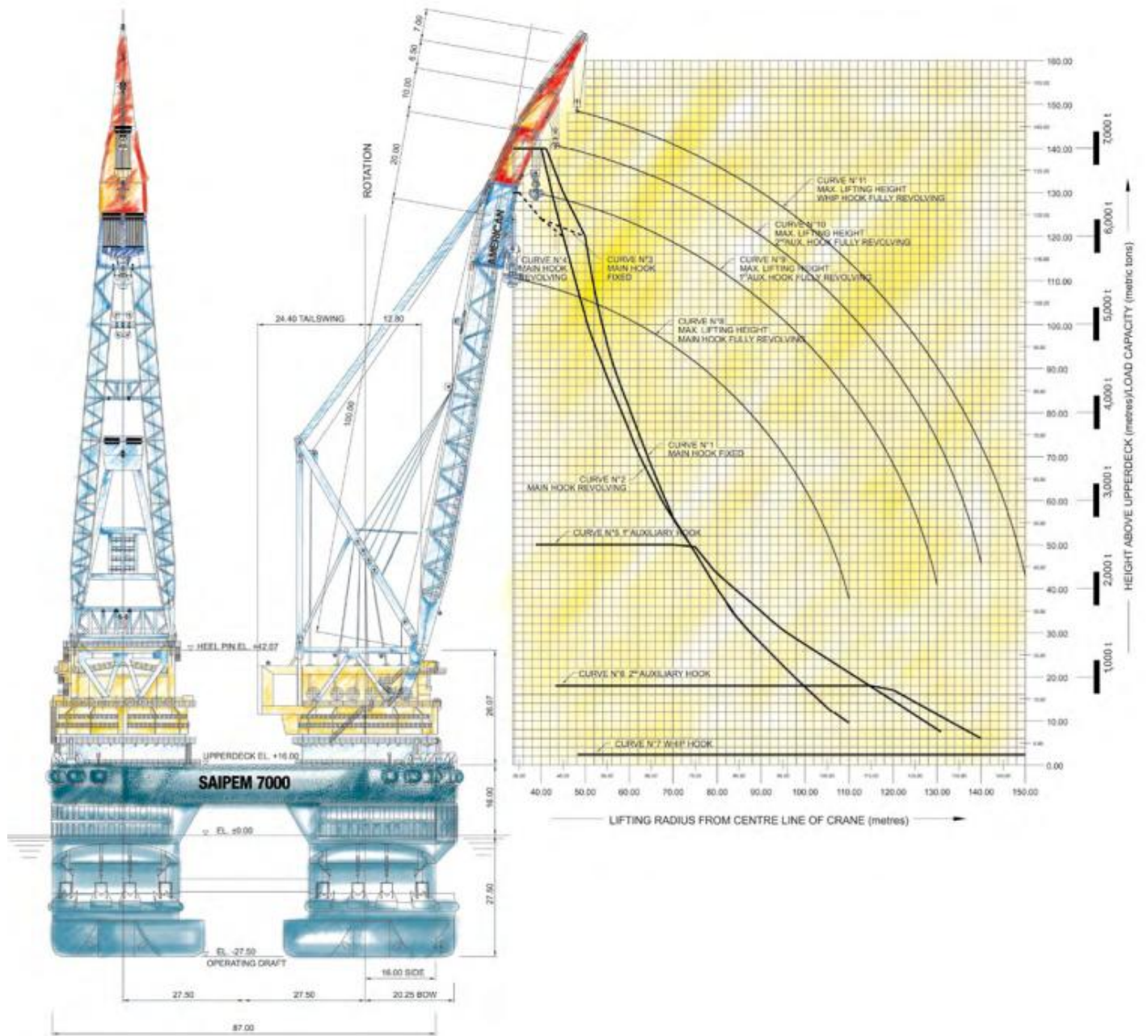


Figure 32 Saipem S7000 crane curve (single crane lift)

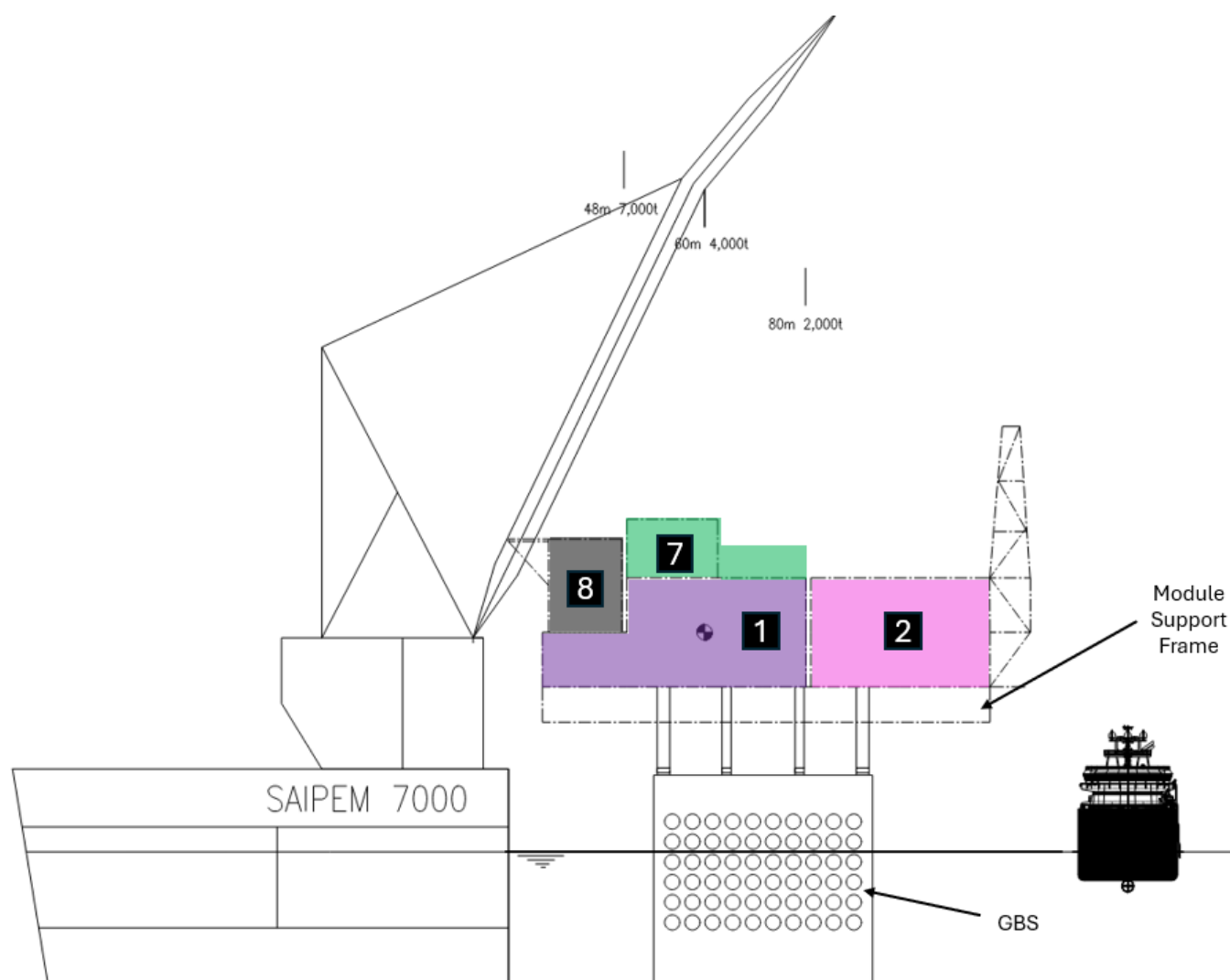


Figure 33 Indicative sketch of Saipem 7000 reach for installing modules



7 Piping and Layouts

The following section details the development of the topside layout. The layout has been developed in line with the design considerations and principles outlined in the study basis of design [10] and Facilities Design Philosophy [1].

The key aims of the layout development have been to:

- Incorporate new equipment;
 - Revised electrolyser array modules, including PEM electrolysis stacks and Balance-of-Stack equipment;
 - Now x12 45MW PEM's (18mx14.5mx7.8m – 290t each) vs previous 50x 10MW PEM's;
 - Updated process equipment including;
 - Water treatment packages – MED systems (14mx7mx7.2m – 310t operating)
 - Compression packages x3 (13mx8.0mx5.3m – 153t operating)
 - Gas conditioning packages (10.5mx5.9mx9.9m – 55t operating)
 - TEG expansion tank
 - Array Feedwater EDI packages
 - Oxygen vent KO Drum
 - Coolers
 - Primary electrical systems design;
 - Petrofac have developed a design for the primary electrical system;
 - Define sizes for components of the primary electrical system, including the 275kV/66kV Transformer (12.1mx16mx9.3m) which weights in at 1140t operating and the associated 275kV Shunt Reactor (7.0mx9.6mx7.5m) which weights in at 300t operating, which are the most significant items.
 - Updated secondary electrical systems
 - HVAC systems
 - Appurtenances
 - Import power cables x6
 - Hydrogen export riser x1
 - Umbilical x1
 - Assess impact of interface steelwork on layout
 - Minimise topsides size to reduce the weight and produce an economical design

Layout drawings for the HOP2 topside are presented in Appendix A.

For pipe routing, the study has looked at specifically at the routing for the 36" seawater common supply and discharge header lines. Additionally, a 1.5m wide space has been provided for pipe racks running adjacent and inboard of the PEM Electrolysers, for the water supply lines. The proposed 36" seawater header lines and space reserved for the electrolyser Piperack's are shown on the layout drawings.



7.1 Key Safety Principles

The layout produced is essentially an evolution of the Concept design. The key safety principles of the initial layout have been retained with a low hazard core area (housing utilities and electrical equipment) being flanked to the east and west by high hazard areas (containing the PEM Electrolysers and other process equipment). This design takes advantage of the southerly / south westerly prevailing winds in dispersing any hydrogen that may leak in the high hazard zones. High and low hazard areas will be separated with fire/blast walls. The zone demarcation is highlighted in Figure 34.

With respect to the prevailing wind directions, the accommodation module and TR are retained at the southern end of the platform in the upwind location, with cranes being located on the north and east faces to facilitate supply boat operations down wind. It is proposed that the flexible risers for the Import Power Cables and Hydrogen Export Riser and umbilical approach the platform from the west, in order to keep the north and east faces for supply vessel operations. This also keeps the southern face free for the freefall TEMPSC/lifeboats to launch. A similar separation distance from the flexible risers to supply vessel approach is found on existing oil and gas assets indicating this can be managed safely with appropriate procedures.



Figure 34 Low and high hazardous zones

Air handling units make up the majority of the HVAC equipment. Given the size of these units, it is necessary to distribute these throughout the electrical compartments, mostly at mezzanine deck level similar to the chiller units. Cooling water will be piped from the chillers to the air handling units. It is envisaged that HVAC intakes shall be located below Level 1 where possible to help negate the potential to intake any hydrogen that may be leaked. For Levels 2 and Level 3 areas it may be necessary to route intake ducts through the accommodation in order to draw in air for the southern upwind face, at as low a level as possible. Duct routing will need to be looked at further in later stages of the project, along with other service routings.

A flare tower is proposed for the hydrogen flare given its location on the northeast corner of the platform. This is favoured as it will prevent any requirement for supply boat operations under a boom which can be operationally problematic due to flare radiation and risk of collision. Given the height of the lower deck, necessitated by the interface steelwork design, there is unlikely to be any clash potential so a flare boom may be acceptable if flare radiation is not an issue. The oxygen vent is positioned at the northwest corner, ensuring a safe distance from both the flare and helicopter operations areas, thereby adhering to safety protocols and operational efficiency.



It is proposed that the free areas of the upper deck are provided with dropped object protection steelwork to mitigate against the risk of dropped objects when using the cranes. This would consist of an open grated steel deck.

Main escape routes shall be provided around the perimeter of the platform and also through the central low hazard core to allow good access back to the TR from all areas of the platform, in case of emergencies.

7.2 Maintenance Philosophy

The following maintenance philosophy has been adopted for the main items of equipment.

- PEM Electrolysers (P009)
 - The PEM Electrolysers have been offset in the bay to provide greater clearances to the face of the unit where the electrolyser membrane stacks are located. This will allow for space to use manual or powered trucks, similar to a forklift, to transport the stack units to the east or west laydown areas, along the deck plating. Since the areas around the electrolysers are grated for ventilation, it will be necessary to temporarily cover the grating with plating (over-plate) to facilitate the smooth movement of the truck near the electrolyser. Local runway beams can be provided to aid lifting the electrolyser membrane stacks from their in-situ position to the handling trucks. External walkways adjacent to the PEM units will need to be of adequate width to accommodate the trucks and provide access past these.
- Gas Treatment and Gas Compression Equipment
 - The Gas Treatment Packages, Metering Skid and Compressors, along with the associated coolers, are all located within the reach of the crane on the east face.
 - Smaller components such as cooler bundles can be lifted or trolleyed to the external walkways for transport to the east laydown area.
 - For larger and/or heavier items, the dropped object protection steelwork above these shall be designed to incorporate removable sections/hatches to facilitate any necessary maintenance of these items.
- 275kV/66kV Transformer (E001) and Shunt Reactor (E003)
 - The weights of these items significantly exceed what could be reasonably expected of a platform crane. Therefore, these items have been located on the upper level of the platform so that a Heavy Lift Vessel (HLV) could be employed to remove and replace these items in the rare event of a catastrophic failure.
 - If designing for the unlikely case of transformer failure, consideration of the installation/removal forces will be required at the design stage, for both the supporting deck and housing. Bumper/guide and set down forces will be significant given the weight of these items of equipment (1140t and 300t for the 275kV and shunt reactor respectively). The design should be developed with the guidance of a HLV contractor.
- 66kV/11kV Transformers (E014)
 - These transformers are located in the upper level of the platform adjacent to the 275kV transformer and shunt reactor. It is envisaged that these items can be removed through roof hatches or by skated or skidding them north through removable wall hatches. Suitably reinforced deck steelwork will be required along the transportation routes.



- The estimated dry weight of these transformers is 41t (55t operating). Therefore, the east crane should be suitably rated to lift these onto an attending vessel. Alternatively, a construction vessel with a suitably rated crane could be employed for this purpose, to avoid the extra costs that would be incurred procuring a suitable crane that may never have to lift this governing design load.
- Transformers (E006, E015–E018)
 - Although typically highly reliable, provisions have been made for the removal and replacement of the smaller distribution transformers as this can otherwise prove to be very challenging, or potentially unfeasible, should a failure occur in service.
 - Compartments can be designed with removable walls to allowing transformer removal whilst maintaining compartment segregation, aiding fire safety and HVAC design.
 - Central corridors between grids 3 and 4 have been provided with adequate width to allow for the transformers to be air skated or skidded to the north laydown area, where they will be accessible to the north crane. The maximum weight of any of these transformers is 12t. Suitably reinforced deck steelwork will be required along the transportation routes.
 - E016 and E018 transformers can be removed from the north of their respective compartments to the nearby north laydown area.
- 55MVA Electrolyser Transformers (E025)
 - Similar to the distribution transformers it is intended that these can be skated or skidded into the central corridors, through removable compartment walls, and then along the corridors to the north laydown area. Suitably reinforced deck steelwork will be required along the transportation routes.
 - The estimated dry weight of these transformers is 45t (60t operating). Therefore, the north crane should be suitably rated to lift these onto an attending vessel. Alternatively, a construction vessel with a suitably rated crane could be employed for this purpose, to avoid the extra costs that would be incurred procuring a suitable crane that may never have to lift its governing design load.
- Array Auxiliary Switchboard Transformers (E035)
 - These transformers which have operating weights of 12t will be located on a mezzanine deck under Level 3. Hatches can be provided on the roof of this area to allow for the transformers to be removed if necessary.
- Switchgear & Miscellaneous Small Electrical Equipment Items
 - Adequate clearances, aligning with the Facilities Design Philosophy [1], have been provided to facilitate maintenance of electrical switchgear.
 - Switch gear components do not typically require lifting equipment to facilitate their maintenance. However, there may be some instances where this is required (i.e. for removing items from mezzanine levels).
 - Doors to electrical rooms should be suitably sized to facilitate removal and replacement of switchgear components. Where necessary, suitable deck / roof hatches should be provided.
 - Decks should be suitably designed to accommodate trolleying loads for maintenance activities.
- Seawater Lift Pumps
 - There is ample height above the sea water lift pumps to allow for removable lifting beams to be installed to facilitate pulling the pumps for maintenance.



- As it is relatively common for caissons to need to be replaced due to corrosion and fatigue damage. Whilst these failure modes can be mitigated with good design, it is recommended that the compartment above the sea water lift pumps is kept free of equipment so that there is good access to remove the caissons with the platform crane, if necessary (reverse installation method). For this reason, the compartment is proposed for the platform store / workshop, as these items could be temporarily relocated to facilitate a caisson replacement, without requiring any operational downtime.
- Utilities & HVAC
 - Based upon available equipment data adequate withdrawal zones and maintenance spaces have been provided for larger equipment which needs it (i.e. HVAC chillers). Specific requirements for maintenance of air handling units should be explored further during subsequent stages of the project.



8 Technical safety – Consequence modelling

This study considers the consequences of a hydrogen loss of containment at the HOP2 facility. The impact of potential gas dispersion, explosion and jet fire following a loss of containment has been considered.

This study only considers the potential consequences of a loss of containment. No assessment has been made on the likelihood of this occurring, such as leak frequency or ignition probability.

No assessment has been made of the thermal radiation or explosion overpressures resulting from gas venting and flaring at this stage.

8.1 Consequence modelling parameters

8.1.1 Hydrogen inventories

The hydrogen inventory on the platform has been rationalised into the five separate inventories for the consequence modelling, given in Table 17. The inventory volumes are the best current estimates and may change as the plant design progresses, and the total hydrogen inventory is estimated to be approximately 1300 kg. The pressure and temperature will also vary through the process, however, the selected values are sufficiently accurate for consequences modelling at the Concept Definition stage. The location of these inventories in the overall process is indicated on the process flow diagram in Figure 35. Note, this is a previous revision of the PFD which has since been superseded, but it shows more indicative detail and is more useful for the consequence modelling. These inventories will be the total mass that could potentially be released post-shutdown, and prior to any blowdown occurring.

This gas does not contain any toxic components at any stage of the process, and is not considered a toxic hazard when released. A release may cause asphyxiation where the ambient oxygen is displaced, however, this has not been considered at this stage. A full rupture of the export pipeline and pig catcher has not been considered at this stage.

Table 17 Hydrogen inventories

Description	Pressure [barg] ¹	Temperature [°C] ¹	Inventory size	Composition [mol%]	Lower and upper explosive limits	Comment
Electrolyser Array	31	65	2.8 m ³ (62.4 kg)	12% H ₂ O 88% H ₂	LEL: 4,500 ppm (4.5%) UEL: 85,200 ppm (85.2%)	Gas volume from a single array, provided by Veolia. There are 12 arrays in total.
Gas Treatment Systems	29.5	28	11.5 m ³ (274.1 kg)	100%H ₂	LEL: 4,000 ppm (4.0%) UEL: 75,000 ppm (75.0%)	Gas volume of Tower 2, provided by Veolia.
Low pressure Electrolyser to 1 st stage compressor	30	28	8.1 m ³ (181.4 kg)	100%H ₂	LEL: 4,000 ppm (4.0%) UEL: 75,000 ppm (75.0%)	1000 L for the vessel and 1st stage suction pulsation dampener plus 100 m of 12" pipe. Preliminary estimate by Apollo.
Medium pressure	70	51	0.7 m ³ (22.4 kg)	100%H ₂	LEL: 4,000 ppm (4.0%)	600 L from Howden's offer, plus the heat exchanger volume from AICS budget



Description	Pressure [barg] ¹	Temperature [°C] ¹	Inventory size	Composition [mol%]	Lower and upper explosive limits	Comment
1 st to 2 nd stage compressor					UEL: 75,000 ppm (75.0%)	offer (~20 L), plus 10% for pipe. Preliminary estimate by Apollo.
High pressure 2 nd stage to export	105	143	1.3 m ³ (79.2 kg)	100%H ₂	LEL: 4,000 ppm (4.0%) UEL: 75,000 ppm (75.0%)	300 L + heat exchanger volume (20 L) + piping to the ESD valve (100 L). Preliminary estimate by Apollo.

¹ These will vary throughout the plant and are approximate values suitable for consequence modelling.

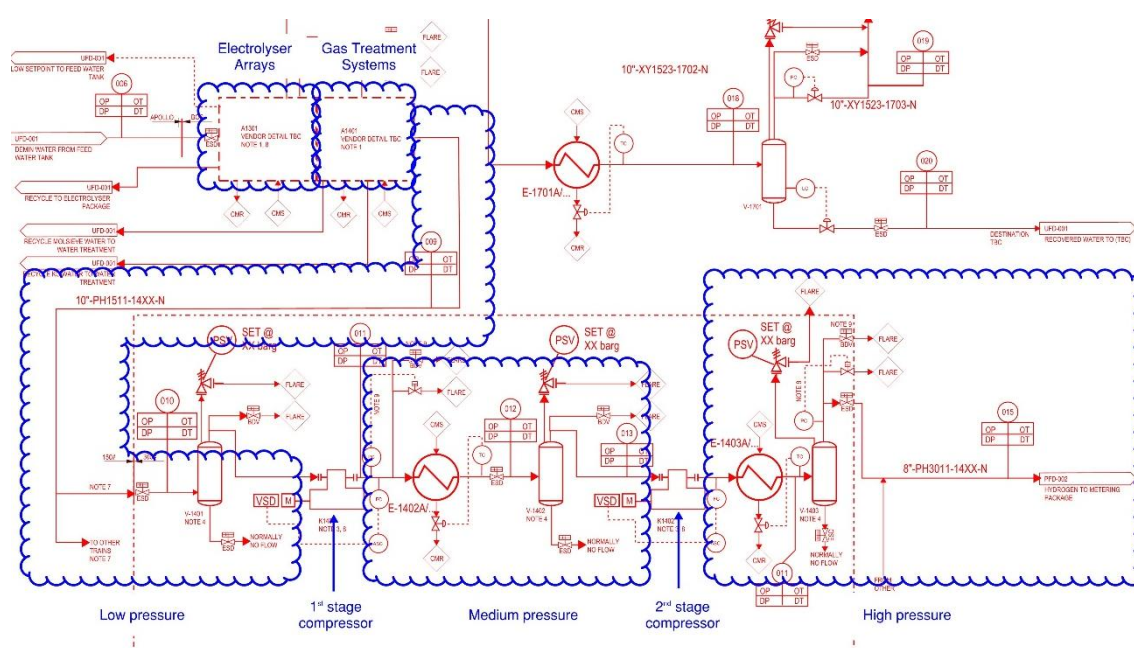


Figure 35 Hydrogen inventories marked up on process flow diagram

8.1.2 Hole sizes

This study considers three-hole sizes to represent a range of release scenarios.

- Small: 5 mm (representative of 3 mm to 10 mm).
- Medium: 25 mm (representative of 10 mm to 50 mm).
- Large: 100 mm (representative of 50 mm to rupture).

These hole sizes are typical for performing consequence analysis of offshore installations [20]

8.1.3 Release locations

Representative release locations for each inventory throughout the process modules have been assessed, where each release occurs within the process modules and is oriented into congested areas. This scenario has the potential to cause flammable gas to accumulate and find an ignition source, and is shown in Figure 36.



Releases that occur close to the platform edge and are oriented outboard will cause gas to disperse away from the platform. This scenario is unlikely to lead to an explosion as it will tend to disperse away from ignition sources and congested areas where hydrogen may accumulate. This scenario is not considered in this study.

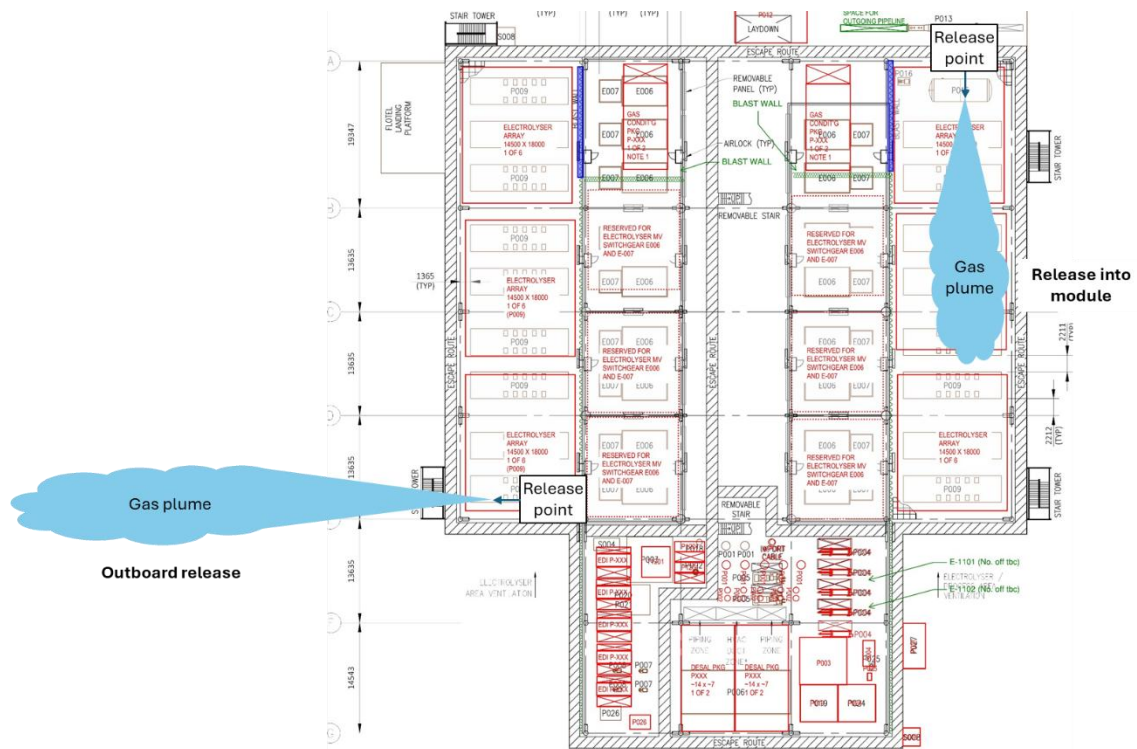


Figure 36 Release scenarios

8.1.4 Wind and stability conditions

The following wind speeds and atmospheric stabilities were considered:

- 2 m/s, stability D (2D).
- 5 m/s, stability D (5D).
- 10 m/s, stability D (10D).

A stability of D represents a neutral condition, which is a typical overcast day with little/no sun. Wind speeds of 2 m/s, 5 m/s and 10 m/s are typical for assessing release scenarios.

8.1.5 Modelling parameters analysis

All modelling has been performed using DNV Phast 7.11 software, with the support of hand calculations. Phast enables relatively high-level consequence modelling to be carried out efficiently. In contrast, a more detailed computational fluid dynamics (CFD) analysis can deliver more accurate results where the impact of platform geometry and congestion is directly modelled, but typically requires substantially more time to complete. A CFD-based analysis will likely be required at a future stage as the HOP2 design progresses.

The following parameters have been used:



- Multi-Energy method for assessing explosions. This is the DNV recommended approach that is provided in Phast and requires a blast strength to be selected to represent the congestion and confinement of the area where the explosion occurs. This parameter has a significant impact on the explosion overpressures, and varies from 1 (no congestion, open space, weak deflagration) to 10 (high congestion, high confinement, detonation). Guidance for blast strength [21] is reproduced in Figure 37. The HOP2 process modules have grated decks, but hydrogen gas could accumulate between the electrolyser modules if released. The explosion is therefore considered to be parallelly confined, and a blast strength between 5-7 is recommended. The deck congestion is assumed to be typical of an offshore process module so a blast strength of 7 has been conservatively selected for all explosion modelling. The overpressure from a typical hydrogen explosion for strengths 5, 6, and 7 is shown in Figure 38 for comparison.

Note, a lower blast strength could be justified if the decks are less confined and less congested than what has been assumed. The overpressure levels necessary to cause injury are typically defined as a function of peak overpressure, without regard to exposure time.

- The explosion is modelled as occurring within a uniform congested space. This is appropriate as the flammable mass of the gas cloud can be contained entirely within the process module volumes.
- This blast analysis has only considered deflagration explosion and not detonation. Detonation develops from a shock wave that causes compression and auto-ignition of the fuel ahead of the flame front. Detonation is typically not considered when assessing natural gas on an offshore platform, because the required ignition energy is very high, the transition to detonation is not well understood, and there is no historic precedent for it to be included. When compared to natural gas, the ignition energy required for hydrogen direct detonation is lower, and the deflagration-to-detonation transition is more likely. However, detonation has been considered unlikely for this application and is not assessed here. Note, this is an area of continuing research, and these assumptions should be reviewed at later stages.
- The total flammable mass is determined as the mass of gas between the lower and upper flammability concentrations in the gas plume.
- The flammable cloud finds a low-energy ignition source (such as a spark) at 10 m from the release point. The use of a further or closer ignition point does not significantly affect the explosion overpressures, only the location of the explosion source.
- Releases are modelled as continuous until the inventory is emptied. This is a conservative approach as in practice, a release would depressurise and the rate would gradually decline over time.
- The release is horizontal and occurs at an elevation of 34 m above the sea surface. This is approximately the elevation in the middle of level 1.



Ignition energy		Obstruction			Parallel plane confinement	Multi-Energy Unconfined	Class
Low	High	High	Low	No			
(L)	(H)	(H)	(L)	(N)	(C)	(U)	
	H	H			C		7-10
	H	H				U	7-10
L		H			C		5-7
	H		L		C		5-7
	H		L			U	4-6
	H			N	C		4-6
L		H				U	4-5
	H			N			4-5
L			L		C		3-5
L			L			U	2-3
L				N	C		1-2
L				N		U	1

Figure 37 Blast strength guidance [21], the current scenario is highlighted in red.

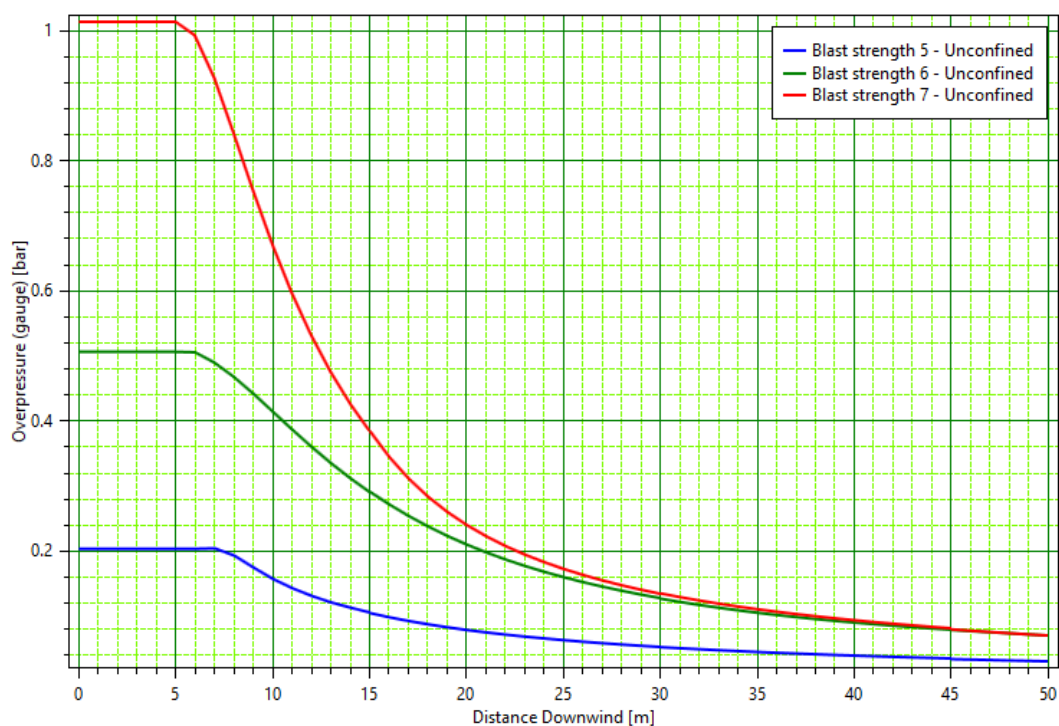


Figure 38 Overpressures for blast strengths 5, 6 and 7, 2 kg hydrogen explosion.
Strength 7 has been used for this study.

8.1.6 Explosion overpressures

The explosion overpressures have been assessed against the blast criteria given in Table 18, which is taken from industry guidance.



Table 18 Overpressure impact

Overpressure [bar]	Impact on personnel [22]	Impact on equipment/structure [20]
0.02	-	10% of window glass is broken
0.21	20% probability of fatality to personnel inside, 0% probability of fatality in the open	-
0.35	50% probability of fatality inside 15% probability of fatality in open	Heavy damage to buildings and pressure equipment. Lifeboats, temporary refuge and escape routes impacted.
0.5 – 1.0	50% fatality for personnel outside the TR	-

8.2 Consequence modelling results

8.2.1 Discharge and gas dispersion

The resultant gas plumes for a 5 mm, 25 mm and 100 mm hole size for the ‘Low pressure’ inventory are shown in Figure 39, where a side view of 100%LEL gas concentration is given. The flammable plume shape is typical for all scenarios assessed in this study. Note, for a 100 mm release, a full steady plume does not develop before the inventory is depleted. Wind speed does not have a significant impact on the extent and size of a 100%LEL plume, as shown in Figure 40.

The discharge rates for each release scenario are summarised in Table 19. For each scenario, the extent of a 100%LEL plume at the 34 m release elevation is provided. The plume extents are similar for each inventory but change significantly for each hole size. All hole sizes cause a significant flammable gas cloud to form on the platform.

The dispersion extent of a 20%LEL plume is provided in Table 19. This is typically the gas concentration that platform gas detectors are calibrated to for a first alarm level. These results show that even for the smallest release assessed, the resultant gas cloud will cover a large area of the platform and likely trigger multiple alarms.

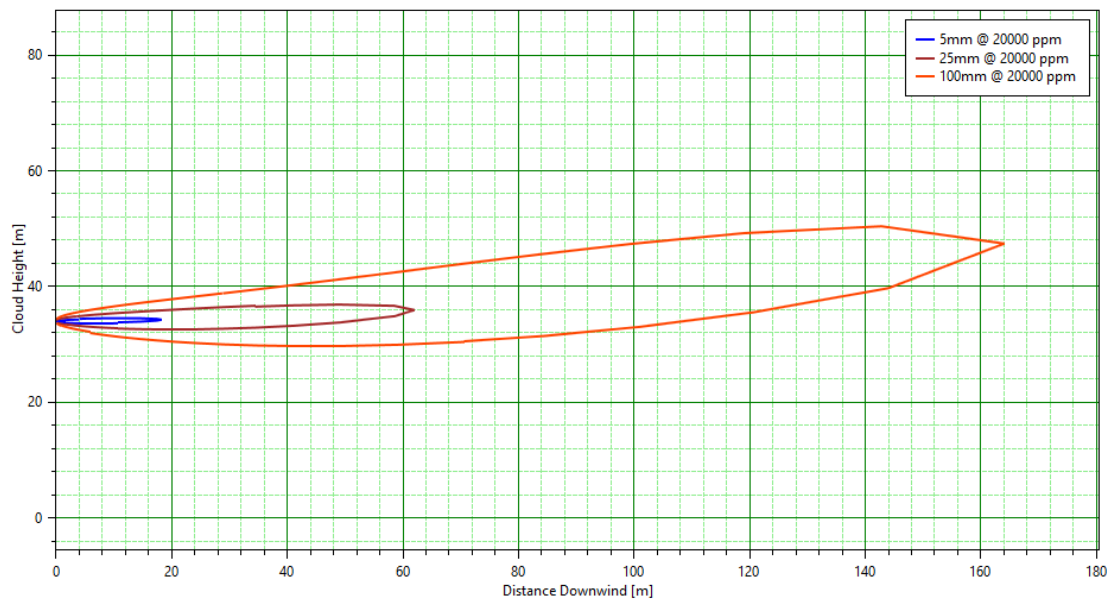


Figure 39 100%LEL gas plume for 5 mm, 25 mm and 100 mm hole sizes, wind 10D, low pressure inventory.

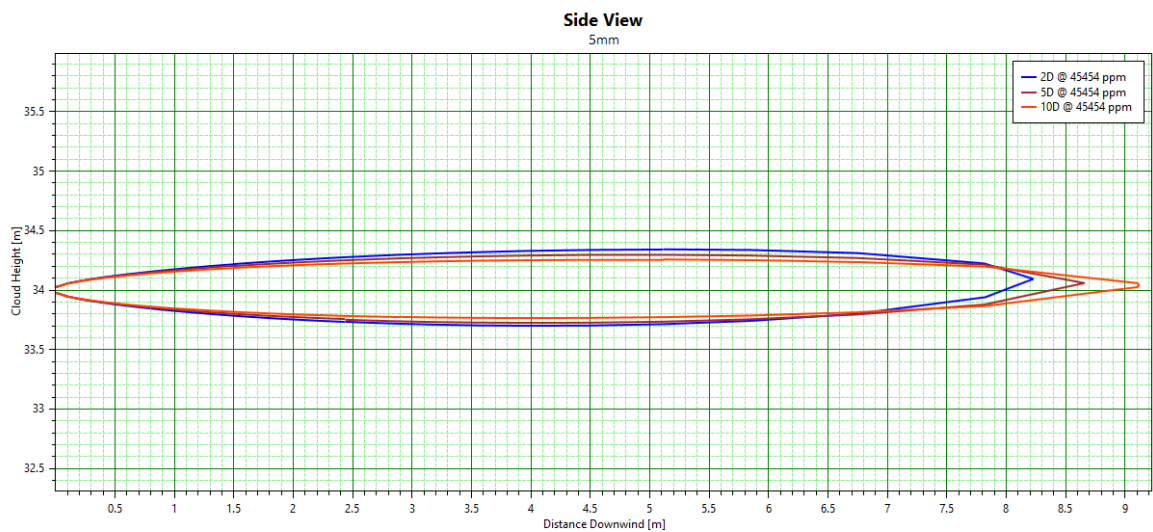


Figure 40 Dispersion extent, 5 mm hole size, wind speed of 2D, 5D and 10D.



Table 19 Release rates and dispersion extents, 100%LEL

Inventory	Hole size [mm]	Release rate [kg/s]	Downstream 100%LEL extent [m]		
			2D	5D	10D
Electrolyser Arrays	5	0.1	8.1	8.6	9.1
	25	2.4	32.2	34.1	36.1
	100	38.3	77.9	85.9	97.2
Gas Treatment Systems	5	0.0	8.0	8.7	9.4
	25	0.8	26.8	29.8	33.2
	100	12.0	62.9	70.9	81.1
Low pressure	5	0.0	8.2	8.9	9.7
	25	0.8	27.4	30.6	34.0
	100	12.0	66.1	75.4	82.8
Medium pressure	5	0.0	9.1	9.9	10.6
	25	1.2	29.5	32.7	36.4
	100	19.3	49.6	55.6	64.9
High pressure	5	0.1	11.4	12.4	13.5
	25	2.3	35.2	39.0	43.7
	100	36.5	63.0	69.8	80.5

Table 20 Release rates and dispersion extents, 20%LEL

Inventory	Hole size [mm]	Release rate [kg/s]	Downstream 20%LEL extent [m]		
			2D	5D	10D
Electrolyser Arrays	5	0.1	14.7	16.3	17.6
	25	2.4	46.4	52.3	58.7
	100	38.3	97.8	112.7	136.0
Gas Treatment Systems	5	0.0	12.9	15.1	17.3
	25	0.8	35.4	42.3	51.2
	100	12.0	79.1	91.8	111.0
Low pressure	5	0.0	13.2	15.5	17.7
	25	0.8	36.5	43.4	52.4
	100	12.0	82.7	98.8	126.8
Medium pressure	5	0.0	14.2	16.6	19.2
	25	1.2	39.0	45.4	54.6
	100	19.3	59.5	68.7	84.7
High pressure	5	0.1	17.1	19.9	23.2
	25	2.3	45.5	53.0	63.5
	100	36.5	75.1	85.2	103.1



8.2.2 Explosion

For each leak scenario summarised in section 8.2.1 the resultant explosion following an ignition was assessed. This was performed by igniting the flammable mass in the gas plume with the ignition point set at 10 m from the release source. The flammable mass is defined as the hydrogen mass between the lower and upper flammability concentration of the plume.

For each leak scenario, the blast radii of 0.02, 0.21 and 0.35 bar overpressures are given in Table 21. These levels correspond to the impact criteria given in Table 18. The flammable mass and subsequent blast radii do not vary significantly for the assessed wind speeds, shown in Figure 41. For clarity, only the results for the 2D wind condition are presented in Table 21.

The overpressure radii for all scenarios are similar, where the medium pressure and high-pressure inventories produce increasingly larger blast radii. The blast extents for a high-pressure inventory release are marked up on a lower deck plan in Figure 42. The lower pressure limit of 0.02 bar, which will cause limited damage such as broken windows, covers the entire platform. The higher pressures of 0.2 bar and 0.35 bar, which can cause significant injuries, fatalities and equipment damage, are confined to the immediate areas surrounding the ignition point.

Note, the impact of the blast wall is not accounted for with this analysis. These will provide some protection from the blast overpressures, depending on their blast rating. No escalation following the initial explosion has been considered here.

Table 21 Blast overpressure radii, 2D wind

Inventory	Hole size [mm]	Initial release rate [kg/s]	Overpressure radius [m]		
			0.02 bar	0.21 bar	0.35 bar
Electrolyser Arrays	5	0.1	12.9	1.8	1.3
	25	2.4	37.1	5.2	3.8
	100	38.3	69.2	9.7	7.0
Gas Treatment Systems	5	0.0	13.1	1.8	1.3
	25	0.8	37.3	5.2	3.8
	100	12.0	69.4	9.7	7.1
Low pressure	5	0.0	13.5	1.9	1.4
	25	0.8	37.9	5.3	3.9
	100	12.0	70.4	9.9	7.2
Medium pressure	5	0.0	15.6	2.2	1.6
	25	1.2	41.1	5.8	4.2
	100	19.3	76.4	10.7	7.8
High pressure	5	0.1	20.0	2.8	2.0
	25	2.3	17.4	6.6	4.8
	100	36.5	87.7	12.3	8.9

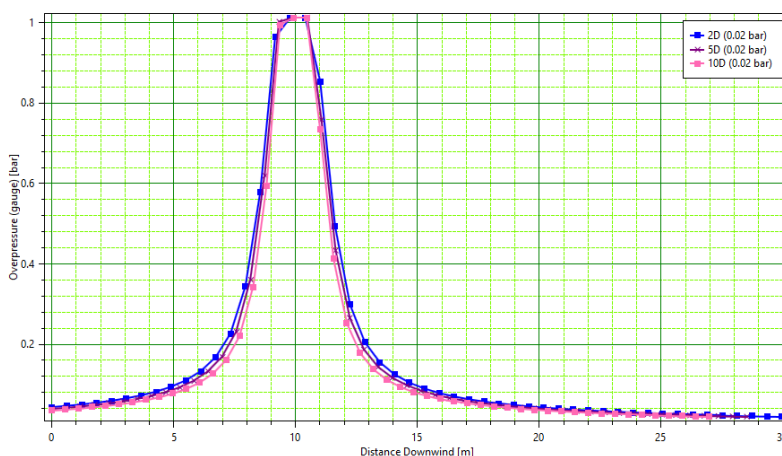


Figure 41 Overpressure extent, 100 mm hole size, winds 2D, 5D and 10D.

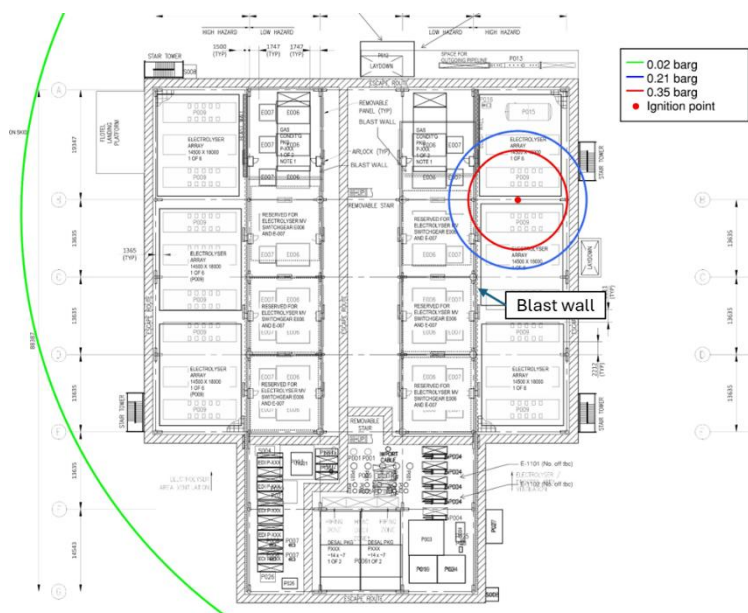


Figure 42 Blast radius from a 100 mm high pressure releases, 2D wind.
Note, Phast cannot account for the blast wall shielding.

8.2.3 Jet fire

The jet fire lengths were determined by Phast and are summarised in Table 22. The flame size is proportional to the release rate and increases significantly as the hole size increases. The wind speed or stability does not meaningfully impact the jet fire size.

The flame lengths are similar for all the inventories assessed, where the high-pressure inventory causes the largest flame lengths. This is shown in Figure 43 where the flame lengths are overlaid on the platform lower deck plan. The small 5 mm hole size results in a flame length of approximately 4 m for the assessed inventories, which will have a limited impact on the local area. The medium and large hole sizes produce flames which are over 14 m, which can impact a significant area of the platform.



Jet fires are considered to cause fatalities to any personnel in the immediate area. Significant thermal radiation is also generated, requiring personnel with a direct line of sight to the fire to shelter. Any equipment impacted by the jet fire, such as piping and pressure vessels, can be significantly damaged, potentially leading to further escalation.

Generally, jet flame impingement for more than 5 minutes is expected to cause failure of steel piping/equipment, and 1 minute will cause failure of steel plates/beams [20]. Releases from the 100 mm and some 25 mm hole sizes cause a jet fire with a duration that is not sufficiently long to damage steel equipment. However, small 5 mm releases can last longer than 5 minutes, producing flames 3 to 5 m in length. This is large enough and sustained for long enough to cause surrounding piping or structural beams to fail, potentially triggering further escalation. This assessment does not account for the effect of mitigation measures, such as blowdown or active/passive fire protection.



Table 22 Jet fire length

Inventory	Hole size [mm]	Initial release rate [kg/s]	Jet fire length [m]	Duration [mins]
Electrolyser Arrays	5	0.1	4.8	10.9
	25	2.4	21.5	0.4
	100	38.3	64.4	Less than 10 s
Gas Treatment Systems	5	0.0	3.3	151.9
	25	0.8	14.1	6.1
	100	12.0	51.7	0.4
Low pressure	5	0.0	3.4	93.8
	25	0.8	14.6	3.8
	100	12.0	53.3	0.2
Medium pressure	5	0.0	3.9	7.7
	25	1.2	16.8	0.3
	100	19.3	61.1	Less than 10 s
High pressure	5	0.1	5.2	14.5
	25	2.3	22.4	0.6
	100	36.5	79.6	Less than 10 s

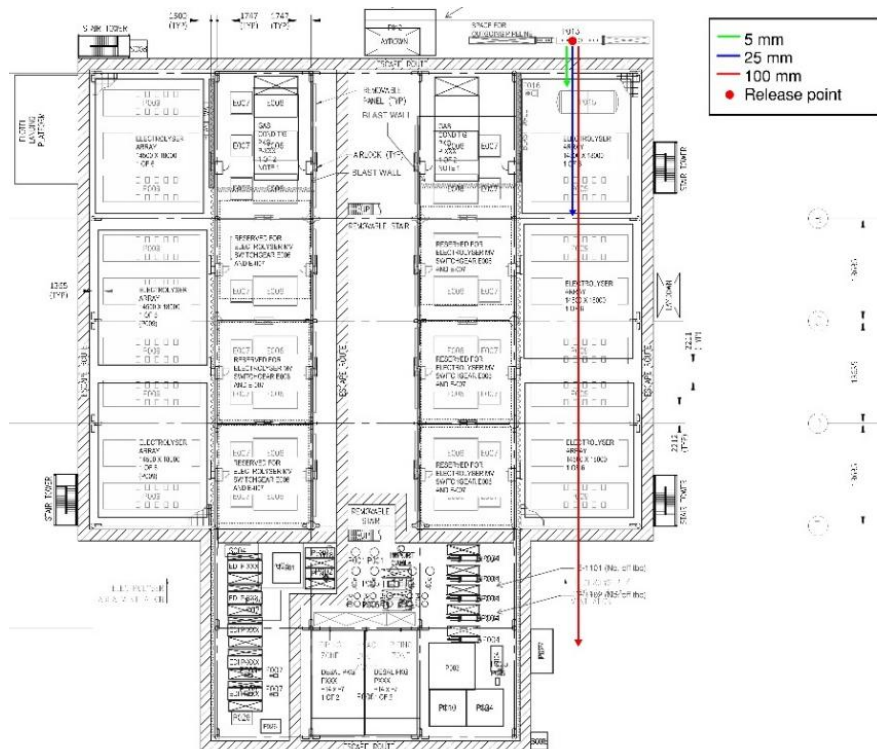


Figure 43 Jet fire from the high-pressure inventory



8.3 Summary

This study considered a range of leak scenarios of the HOP2 platform, where high-level consequence modelling was performed. The impact of gas dispersion, explosion and jet fire has been assessed following a loss of containment.

This study was limited to assessing the potential impact of a gas release, and the probability of these events occurring has not been considered. The estimated total mass of gas on the platform is 1,300 kg, which is less than a typical North Sea platform producing natural gas. The release frequency, release size, and potential escalation risk are therefore likely to be lower when compared to a typical natural gas platform. However, hydrogen has a larger flammability range and requires lower ignition energy when compared to natural gas, and its high diffusivity and low molecular size make it prone to leaking. To fully understand the risk, a quantitative risk assessment (QRA) is recommended at a future stage of the project development. This will determine if the risk of the events considered here is tolerable or if further risk reduction is required.

The following is concluded:

Gas dispersion

- The release rate and flammable plume extent have been provided for a range of hole sizes (5 mm, 25 mm, 100 mm), wind speeds (2D, 5D, 10D), and HOP2 inventories. All release cases considered were found to be capable of producing a significant flammable cloud on the platform.
- Wind speed does not have a significant impact on the size of a flammable gas plume within the scope of the scenarios modelled, where the highest speed assessed of 10 m/s causes a similar flammable plume size to the lowest wind speed of 2 m/s.
- The extent of 20%LEL gas plume has been provided, a typical concentration that gas detectors are calibrated to on offshore platforms. The HOP2 gas detector layout has not been designed yet. However, for each release case considered, multiple detectors would likely be alarmed due to the gas dispersion extent within the process modules, providing detection of potential leaks.
- The total inventory of hydrogen on the platform is estimated to be approximately 1300kg.

Explosion

- Explosion impacts were assessed for various hydrogen leak scenarios upon ignition 10 meters from the release point. The flammable mass of hydrogen (between lower and upper flammability limits) and resulting blast radii at overpressures of 0.02, 0.21, and 0.35 bar were calculated.
- Wind speed was found to have a small impact on the flammable mass and blast radius.
- The overpressure radii for all scenarios are similar, where the medium pressure and high pressure inventories produce increasingly larger blast radii. For each release scenario assessed, the following overpressures were determined:
 - 0.02 bar (low damage such as breaking windows)
 - 0.21 bar (20% probability of fatality to personnel inside, 0% probability of fatality in the open)
 - 0.35 bar (50% probability of fatality inside, 15% probability of fatality in open. Heavy damage to buildings and pressure equipment. Lifeboats, temporary refuge and escape routes impacted.)
- The analysis did not include the mitigating effects of blast walls, which may provide shielding of the explosion overpressure. This will be depended on the blast wall rating.



- Due to the propensity of hydrogen to leak and its low ignition energy, the risk from explosion overpressure may potentially not be tolerable. This should be considered further in a risk assessment at a later stage in the project.

Jet fire

- Jet fire flame lengths for each release scenario were calculated using Phast and summarised in Table 22. The jet flame length was found to increase significantly with hole size due to higher release rates. Wind speed and atmospheric stability have little effect on flame size.
- High-pressure inventories produce the longest jet fires, and flame lengths are similar across assessed inventories.
- Small hole (5 mm) results in ~4 m flame, with limited local impact. Medium and large holes (25 mm, 100 mm) result in flames exceeding 14 m, affecting a significant area of the platform.
- Jet fires pose fatal risks to personnel in the immediate area and generate intense thermal radiation.
- Jet fires can severely damage equipment, potentially escalating incidents, where flame impingement lasting over 5 minutes may lead to steel equipment failure, and 1 minute will cause failure of steel plates/beams. For all 100 mm and some 25 mm leaks assessed, jet fire durations were not long enough to cause steel failure. However, small 5 mm releases can last longer than 5 minutes, producing flames 3 to 5 m in length. This is large enough and sustained for long enough to cause surrounding piping or structural beams to fail, potentially triggering further escalation. Note, inventory depressurisation through blowdown and any mitigation measures (such as active/ passive fire protection) have not been considered, and will limit the impact of jet fires.

Recommendations

Future work should undertake a comprehensive risk review with a full Quantified Risk Assessment (QRA) to determine whether all measures necessary have been taken to reduce the risk to As Low As Reasonably Practicable (ALARP). Particularly, the limited mitigation provided by deploying blast walls to protect against hydrogen explosions should be considered. Further, the impact of depressuring and/or catastrophic full rupture of the export pipeline should be considered in a comprehensive risk review, supported by Functional Safety studies such as LOPA.



9 Environmental

9.1 Environmental and Consenting Risk Assessment

This section outlines the key environmental and consenting risks associated with HOP2 based on the current, high-level concept design. Specifically, the objectives of this document are to:

- Undertake an initial review of the local receiving marine environment of HOP2 on the Ninian Central Platform including environmental and socioeconomic values;
- Identify anticipated environmental risks and undertake an initial assessment of potential impacts to the marine environment as a result of planning, construction, operation and decommissioning of HOP2;
- Assess potential mitigation and management options for environmental risk; and
- Present an overview of expected regulatory compliance, permitting and consenting requirements associated with HOP2 to inform decision-making for the next phase of development.

9.1.1 Data Review

To evaluate environmental risk associated with the HOP2, an initial data review has been undertaken to summarise baseline environmental values.

Environmental information has been collated and analysed using publicly available sources including, but not limited to:

- Spatial data including marine protected areas (MPAs) and other areas of sensitive ecological significance;
- Species records and habitat distribution focusing specifically on mammals, seabirds and fish;
- Fisheries landings and effort data;
- Information pertaining to other potential users of the area; and
- Any previous environmental surveys available undertaken within and adjacent to the investigation area if available.

9.1.2 Legislative and Planning Summary

Table 23 below provides a summary of likely permitting requirements related to HOP2. Note this is an indicative summary based on current legislation requirements and anticipated trends. HOP2 will need to be reviewed as the project progresses to ensure alignment with the latest legislation and planning requirements

Table 23 Summary of Expected Permitting Requirements

Overarching Legislation	Administering Authority	Relevance to HOP2
Marine and Coastal Access Act 2009 Marine (Scotland) Act 2010	DESNZ Marine Directorate	Marine Licence may be required for works within Scottish waters.
Energy Act 2008	DESNZ	Variations to existing Ninian Central Consent to Locate may be required for change in use of facility from oil and gas production to hydrogen production.



		New Consent to Locate may be required for the installation of additional offshore infrastructure
Offshore Chemical Regulations 2002 (as amended)	OPRED	A Chemical Permit may be required for the release of any chemicals at sea.
Offshore Oil and Gas Exploration, Production, Unloading and Storage (Environmental Impact Assessment) Regulations 2020	DESNZ NSTA	HOP2 requires the undertaking of an EIA and ES.
Petroleum Act 1998	NSTA	A Pipeline Works Authorisation (PWA) will be needed to permit changes to the function of the export pipeline
Gas Act 1986	NSTA	A licence is required to ship, transport or supply hydrogen

9.1.3 Environmental Sensitivities Summary

Table 24 provides a summary of environmental sensitivities for the HOP2 area.

Table 24 Environmental sensitivities

Aspect	Detail
Offshore conservation interests	
Protected areas	There are no protected areas in the vicinity of HOP2. The closest, Pobie Bank Reef SAC, is located 74 km west of HOP2. The Fetlar to Haroldswick NCMPA is situated 123 km west of HOP2.
Annex I habitats	There are no known Annex I habitats in the vicinity of HOP2.
Annex II species	The only Annex II species sighted within the area is the harbour porpoise, sighted in very high numbers in February and July and in low to moderate numbers during the rest of the year (Reid et al., 2003; UKDMAP 1998).
Physical and chemical characteristics	
	Depth within the vicinity of HOP2 development ranges from approximately 140 to 146 m (Fugro ERT, 2011). Tidal currents in the location of HOP2 are typical of the NNS, with relatively weak surface current velocities and mean spring tides ranging from 0.11 to 0.25 m/s and neap tides below 0.11 m/s (ABPmer, 2016). Annual wave heights range between 2.51 and 2.75 m.
	Though no specific chemical assessment has been undertaken at the HOP2 area, Sediment properties from the Ninian Northen Platform Survey (Fugro ERT, 2011) indicated THC levels between 8.0 µg/g and



	1,390 µg/g, PAHs between 0.035 to 0.342 µg/g heavy metals including lead, mercury, and cadmium exceeding background concentration values.
Environmental characteristics and sensitivities	
Plankton	The plankton in the HOP2 area is typical of the northern North Sea. Peak productivity occurs in spring and summer (BEIS, 2022).
Habitat Characterisation and Benthic fauna	HOP2 lies in an area of the NNS where sediment is composed of fines and coarse sand (Künitzer et al., 1992). Surveys around the Ninian Northern Platform and proposed HOP2 ranged poorly sorted very fine sand to a lesser degree fine sands (Fugro ERT, 2011). EUNIS Biotopes within UKCS Block 3/3 are characterised by Atlantic offshore circalittoral sand (MD52) and Atlantic offshore circalittoral coarse sediment (MD32) (EMODnet Seabed Habitats, 2024). Benthic communities in the HOP2 area are similar to those found throughout a large surrounding area of the northern North Sea (BEIS, 2022).
Fish spawning areas	HOP2 is located in low intensity spawning grounds for cod, Norway pout and saith (Jan to Apr), sandeels (Nov to Feb) and whiting (Feb to Jun) (Coull et al., 1998; Ellis et al., 2010).
Fish nursery areas	HOP2 is located in nursery grounds for herring, ling, mackerel, spurdog, haddock, Norway pout, blue whiting, sandeels, whiting, monkfish and European hake (throughout the year) (Coull et al., 1998; Ellis et al., 2010).
Marine mammals	Marine mammals sighted in and around the HOP2 area include minke whales, long finned pilot whale, killer whale, white beaked dolphins, and harbour porpoises. Peak sightings predominantly occur in the summer months (Reid et al., 2003; UKDMAP1998; Gilles et al., 2023). Grey seals have been recorded undertaking foraging trips of up to 150 km. While such occurrences are uncommon, individuals may still be present in the vicinity of HOP2.
Seabirds	The most abundant bird species found in the area throughout the year are the northern fulmar great black-backed gull, lesser black-backed gull, common guillemot, Atlantic puffin, razorbill, northern gannet, herring and black-legged kittiwakes (Kober et al., 2010). There are no seabird hotpots within proximity to HOP2.
Societal characteristics and sensitivities	
Fisheries	Total annual value in ICES rectangle 50F1 was £8,470,359 in 2023. Of the total commercial catch in 2023, 4,415 tonnes of pelagic species, 2,073 tonnes of demersal species, and only 10 tonnes of shellfish species were caught (Scottish Government, 2024).
Shipping	Shipping density in the vicinity of the HOP2 (UKCS Block 3/3) is classified as “moderate” (NSTA, 2016; EMODnet, 2024).



Oil and gas industry	HOP2 lies within an area of high oil and gas intensity. There are 12 surface infrastructure located within a 40 km radius of HOP2.
Other users of the sea	In the vicinity of the HOP2 there are no recorded military activities or offshore renewable developments. The nearest cable is over 73 km west beyond the UKCS Median Line (DTI, 2001; Kis-Orca, 2023). There are 77 identified shipwrecks within a 40 km radius of HOP2.

9.1.4 Summary of potential impacts

The following sections outlines the potential impacts associated with the construction and operation of HOP2. Note as HOP2 is still in the early design phases, this is a preliminary overview based on likely impacts associated with hydrogen production facilities.

Seabed Disturbance

Seabed disturbance may occur during the installation and removal of infrastructure and protective material. Seabed disturbance can result in habitat loss, disturbance to seabed communities or smothering resulting from plumes of displaced sediment, with potential impacts on protected sites and the habitats and the species supported by them.

HOP2 will predominately consist of remodifying the existing substructure of the Ninian Central Platform accompanied with new-build topsides. This will include reconfiguration of subsea telecommunication and electricity cables, hydrogen export pipeline and seawater lift. Seabed disturbance may take the form of temporary disturbance (e.g. smothering of marine organisms from sediment displacement) or longer-term impacts including permanent habitat change. Repurposing existing subsea infrastructure is expected to omit the need for activities such as pile driving or drilling which may cause greater damage to the seabed and benthic habitat.

Permanent Habitat Change

Long term impacts may occur through the introduction of permanent features to the benthic environment. As such, the addition of new infrastructure, or protection materials, may lead to direct loss of benthic species and communities or loss of natural habitat. Specifically, localised impacts to epifauna and infauna due to direct physical disturbance to the seabed through crushing, physical abrasion and burial. Smothering of animals may also lead to direct mortality of sessile seabed organisms that cannot move away from the contact area. Seabed infrastructure will alter the physical characteristics of the seabed, transforming natural sandy benthic habitats into a stable, hard substrate. Over time, this newly created hard substrate, with limited sand cover, will be colonised by different species through a sequence of changes in the composition and structure of a community over time, known as ecological succession, leading to the establishment of a new benthic community.

The installation and operational activities of HOP2 may impact fish and shellfish species through burial, smothering and habitat alteration due to the introduction of new materials. These activities can displace or result in the mortality of mobile fish species and potentially affect spawning grounds. However, given that fish are highly mobile organisms, they are likely to avoid areas with re-suspended sediments and turbulence caused by the activities, although spawning and nursery grounds may be affected. Nephrops, herring and sandeels, which have identified spawning areas within the wider northern North Sea region, are demersal spawners and are therefore more susceptible to impacts from benthic disturbance (BEIS, 2022).



Temporary Disturbance

Wider indirect disturbance to the benthic environment may occur through the suspension and re-settlement of sediments. This would cause localised mortality of benthic organisms due to increased turbidity and smothering. Sessile benthic and epibenthic fauna are at particular risk of smothering effects and changes in oxygen availability, with some species being able to tolerate small sediment layers, while others cannot withstand any covering (Gubbay, 2003). Though smothering from suspension of sediment is expected to be localised and temporary. Evidence has shown that, re-colonisation may occur within one to two years following cessation of seabed disturbance activities (e.g. piling) and that benthic infauna and epifauna can recover relatively quickly in deep water communities (Neff, 2010; Jones et al., 2012).

Temporary deposits on the seabed (e.g. anchors) may also cause temporary impacts to benthic communities. Though, natural processes of sediment transportation and biological settlement are expected to restore the seabed once the temporary infrastructure is removed. As well as this, indirect impacts may occur from the potential release of contaminants from disturbed sediments, which can impact the early life stages of some fish species.

Management and Mitigation

The design of the project should consider seabed impacts and aim to minimise disturbance where possible. In particular, minimising the introduction of new substrate, such as protective rock, will reduce the area of permanent habitat loss. The strategy of re-purposing existing oil and gas infrastructure would be expected to minimise the seabed disturbance resulting from HOP2.

All necessary permitting and consenting will be submitted to the Regulator in line with current expectations.

HOP2 is not located within existing protected sites or sensitive seabed habitats.

Discharges to Sea

Discharges to sea refers to any planned contaminants released to the marine environment as a result of the proposed activities associated with HOP2. Discharges to sea may also occur as an accidental event. Marine discharges have the potential to impact the following receptor groups: water quality; benthos; plankton; fish and shellfish; and protected habitat and species, with the toxicity of certain products potentially harmful at high concentrations.

The exact chemicals and quantities to be used and discharged will be determined during the detailed design. However, the main contaminants are likely to be attributed to structure and pipeline commissioning, and discharge of cooling water which is likely to be mixed with brine and other cleaning chemicals (Witteveen+Bos, 2024). Prior to any discharge, and if required following discussion with the Regulator, an appropriate discharge permit will be obtained through the UK Energy Portal Environmental Tracking System (PETS) in accordance with the Offshore Chemical Regulations 2002 or other appropriate regulations.

Benthic fauna are susceptible to smothering from marine discharges. Discharges that settle on the seabed have the potential to smother benthic organisms and communities and release pollutants into sediments. In the short-term, smothering would cause localised mortality of benthic organisms and a change in sediment composition. Though there may be temporary disturbance through localised smothering and changes in sediment composition, impacts would be expected to reduce over time with most of the discharged material is expected to settle on the seabed in close proximity to the discharge point.

Fish and shellfish that live in close contact with sediments, or which are demersal spawners, may be susceptible to smothering by discharged solids and physical disturbance of the seabed. However, due to the small volume



of contaminants produced the area will largely be contained and impacts to highly mobile pelagic fish and shellfish is limited.

Operations at HOP2 will use desalination of seawater to produce water that is suitable for electrolysis. As a result of this process, brine will be discharged into the marine environment via a density plume that sinks to the seafloor (Fernández-Torquemada et al., 2019). This may cause impacts to water quality due to increased salinity. Heavily concentrated brine has the potential to cause mortality in sessile benthic marine organisms that are unable to move away from the plume and are particularly sensitive to changes in marine salinity. Research has indicated changes in the community composition of soft-bottom benthic communities such as Polychaeta and Amphipoda that affect their diversity, abundance, and richness (Sola et al., 2024). Pelagic fish species may be vulnerable due to surface dispersal of hypersaline water mass at the discharge site (Fernández-Torquemada et al., 2019).

Table 25 below shows a summary of the chemicals and quantities to be discharged to sea.

Table 25 - summary of the chemicals and quantities to be discharged to sea

Property	Value
Seawater flowrate overboard	7,510,948 kg/hr
Hypochlorite in seawater	2 mg/L continuous, up to 5 mg/L shock based on seawater overboard flowrate
Seawater discharge temperature	25°C
Brine discharge flowrate	12,960 kg/hr

Management and Mitigation

The impacts of discharge to the marine environment may be mitigated by careful selection of chemical products, to minimise the use and discharge of those with Substitution warnings, or with Offshore Chemical Notification Scheme (OCNS) or hazard quotient (HQ) groupings higher than hazard level E or Gold. Carrying out full risk assessments, in which toxicity, biodegradability and bioaccumulation potential of products, along with obtaining all necessary permits required for the use and discharge of products offshore will be necessary.

Considering alternative options to product discharge, such as the shipping of chemical waste to shore will further reduce impacts on the marine environment. Moreover, the design may be refined in the planning stages to ensure minimal brine water discharge is released to the environment and to avoid discharging high concentrations of brine in proximity to sensitive benthic marine habitat.

Atmospheric Emissions

Although HOP2 is a project that aims to reduce overall atmospheric emissions as part of the push for renewable energies, there are several activities associated with the development that will release gases into the atmosphere which have the potential to affect air quality at a local level and contribute to global GHG emissions. Installations may have controlled or uncontrolled gas emissions of hydrogen (H₂), oxygen (O₂) and nitrogen (N₂) during construction and operation such as through pipeline rupturing (Witteveen+Bos, 2024). CO₂ and carbon monoxide (CO) emissions would largely be associated with construction and service vessels. Combustion emissions have the potential to reduce the local air quality through the introduction of contaminants such as nitric oxide (NO) and nitrogen dioxide (NO₂) (NO_X), volatile organic compounds (VOCs) and particulates which contribute to the formation of local low-level ozone and photochemical smog. Environmental receptors present in the immediate vicinity of the operations tend to be sparsely distributed



and/or mobile in their distribution, for example, marine mammals and seabirds. Local impacts are further mitigated by the open and dispersive nature of the offshore environment. Impacts at this level are likely to be difficult to measure and distinguish from naturally variable background levels. On this basis, localised impacts from combustion emissions during HOP2 installation and operations are anticipated to be negligible.

On a larger scale, emissions derived from the different phases of HOP2 will contribute to cumulative worldwide environmental impacts such as global climate change, noting hydrogen may have an estimated GWP of 11 (+/-5) times greater than carbon dioxide (Warwick et al., 2022). However, the direct impact will be difficult to assess as these emissions will only form a very small part of the overall global air emissions.

Management and Mitigation

As a renewable energy project, HOP2 should be designed and constructed with the intent to minimise and reduce emissions to the extent that is practicably feasible (e.g. by considering the use of renewable energy sources or biodiesel to power generators). The strategy of repurposing existing oil and gas infrastructure and utilising a nearby offshore wind platform will ultimately reduce the overall emissions required for newly manufactured equipment. Careful consideration in engineering design can minimise risk of pipeline ruptures and the accidental release of hydrogen emissions. Ongoing monitoring of atmospheric emissions should be undertaken at HOP2 to determine any exceedances or impacts to air quality. Considered management of vessel plans to increase the efficiency of offshore operations will minimise operational emissions.

Underwater Noise

Noise may be produced by several sources in all lifecycle phases. The main sources for noise would be continuous noise from vessel activity and subsea engineering works during construction and operation. Should any seabed surveys, using equipment such as sub-bottom profilers (sparkers or pingers) be required prior to installation there would be impulsive noise disturbance. Note at this stage of the development, piling activities are not anticipated as part of HOP2.

Marine mammals are highly adept at receiving and interpreting information within the marine environment using sound. Cetaceans use the sound for navigation, communication and prey detection. Anthropogenic underwater noise has the potential to impact marine mammals (JNCC, 2010; Southall et al., 2007). Animals have been reported to display a range of reactions from ignoring the vessel noise to avoiding the noise, leading to temporary displacement from an area and more severe effects including permanent hearing loss. Several species of cetacean have been recorded as present within the HOP2 area including the minke whale, common dolphin, white-beaked dolphin, Atlantic white-sided dolphin, long-finned pilot whale, bottlenose dolphin and harbour porpoise (Reid et al., 2003). Harbour porpoises are particularly sensitive to impulsive underwater noise. For example: the high-intensity sound waves produced during an activity such as piling or seismic survey can cause temporary or permanent hearing loss, leading to disorientation and difficulty in navigating their environment.

Fish species have varying behavioural responses to sound due to differences in anatomy, physiology and ecology. At high sound levels, there may be temporary or partial loss of hearing or potential injury to fish species, fish eggs and larvae (Popper et al., 2014). However, given the relatively small disturbance area compared to the large spawning grounds in the North Sea, it is not expected that the operations associated with HOP2 will have a significant adverse effect. Marine invertebrates (e.g. cephalopods) may also be susceptible to impulsive noises such as from piling operations, triggering behavioural and physiological responses, although it is not expected that noise disturbance from the activities at HOP2 will be as significant as that resulting from piling. However, research on underwater noise impacts to marine invertebrates is limited.



Management and Mitigation

Appropriate mitigation measures may be implemented where practicably feasible to mitigate the impacts of underwater noise to cetaceans including soft starts, the use of dampers on noise-generating equipment, the implementation of Marine Mammal Observers (MMOs) during operations and reduction of vessel movements where possible. Where practically feasible, works may be undertaken seasonally to avoid peak periods where marine mammals and other sensitive species may be particularly abundant in the HOP2 area, acknowledging that summer months will be peak periods for marine mammal abundance and also the safest and most practical time of year for engineering work at sea. If noise disturbance is expected to be significant (e.g. through use of impulsive survey techniques), risk assessment including noise modelling may be appropriate.

Physical Presence and Protected Sites and Species

There are no protected sites within 40 km of the HOP2 area, and as such significant impacts are deemed unlikely. However, protected species, particularly cetaceans and seabirds, are present in the area. Potential impacts on these species have been considered elsewhere in this section.

The physical presence of offshore infrastructure may provide opportunity for nesting sites for protected seabird species. Evidence has shown that black-legged kittiwakes have been recorded breeding on at least 26 offshore platforms in UK waters and are present across many more (GoBe, 2024). Other species known to colonise offshore platforms within UK waters include guillemot and razorbills which have also been recorded within the HOP2 area (Kober et al., 2010). Research indicates that platforms enable a suitable alternative for population recruitment with productivity higher than averages at natural colonies. It is possible protected seabirds may utilise HOP2 area and associated Ninian Central Platform as a nesting site. This may pose a challenge when the time comes for decommissioning of the installation, as the disturbance of nesting birds is a criminal offence.

Management and Mitigation

Bird deterrent measures should be considered to minimise the chance of birds nesting on the platform. At the point of decommissioning, scheduling platform removal for a period outside the nesting season will reduce the risk of encountering nesting birds. Bird activity should be monitored through the lifespan of the installation so risks are understood and can be properly prepared for.

Socioeconomic Features and Other Sea Users

HOP2 has the potential to physically interact with other stakeholders of the sea, including shipping, fisheries, commercial vessels, wind farms, and oil and gas activities. For example, a temporary increase in vessel traffic may increase vessel collision risk and the establishment of any new temporary or permanent exclusion zones if required could result in loss of access to fishing grounds. A detailed project EIA would assess the potential impact on other stakeholders of the sea.

There will be physical presence of infrastructure and other vessels during installation and the operational phases of HOP2, thus temporarily increasing vessel activity in the area. This increased activity may have potential impact on commercial fishing, shipping and other users of the sea. Throughout the operational life of HOP2, service vessels will also be required to maintain infrastructure. However, it is anticipated overall vessel traffic will be low compared to standard oil and gas activities.

The physical presence of infrastructure (e.g. cables) also have the potential to increase snagging risk and result in loss of access to fishing grounds. In terms of fisheries, ICES Rectangle 50F1 represent less than 1% of the UK's total fishing landings values for 2023. Therefore, the sensitivity of commercial fisheries to the proposed operations can be considered low.



There are several oil and gas installations and 77 identified shipwrecks within a 40 km radius of HOP2. Appropriate measures will be put in place to ensure there are no interferences with existing oil and gas operations or shipwrecks within the area. There is no other infrastructure expected to interact within a 40 km radius of HOP2.

Management and Mitigation

Extensive and ongoing engagement and consultation with key marine stakeholders and other sea users prior to the commencement of HOP2 would mitigate impact on other users. Ensuring all necessary maritime notifications and consents (e.g. Consent to Locate) are issued to aid navigation of vessels through the project area.

Accidental Events

Accidental events refer to the potential worst-case unplanned events that may result in consequential impacts to the receiving marine environment due to activities undertaken during HOP2. At a high-level the following accidental events have been identified for an offshore hydrogen production facility:

- Unplanned release of chemicals or other contaminants into the marine environment (e.g. fuels from vessel collision and exceedance of water quality objectives;
- Pipeline leaks or ruptures leading to release of atmospheric emissions (e.g. H₂, CH₄, CO₂);
- Metal hydrogen embrittlement;
- Vessel strike; and
- Objects dropped into the sea.

Vessel collision may lead to a loss of diesel inventory. While this could lead to local impacts on surface fauna (primarily seabirds), diesel is a light fuel and would be expected to evaporate and disperse quickly. Due to the distance involved, there would be little chance of diesel reaching the shoreline or impacting protected sites.

Accidental damage to existing pipelines or offshore structures during installation or operational activities could potentially lead to a release of hydrocarbons. Only limited quantities of oil will be present, used in the cooling and lubrication of equipment and subject to containment to prevent leakage. In the event of a spill of oil, planktonic organisms living near the sea surface would be at high risk of floating hydrocarbons, experiencing high mortality and reduction in overall plankton biomass (Buskey et al., 2016; Ozhan et al., 2014). Seabirds would be susceptible to fuel pollution on the sea surface as they utilise these areas as feeding grounds. Fouling of feathers and the toxic effects of ingesting hydrocarbons can lead to seabird fatalities. The effects will depend on species presence, their abundance and the time of year. The Seabird Oil Sensitivity Index (Webb et al., 2016) indicates sensitivity ranges between low and moderate for the HOP2 area. Cetaceans are considered more likely to be able to deal with the effects of fuel spill due to a thicker body covering that is less susceptible to loss of waterproofing; however, they will be at risk if they ingest prey contaminated with hydrocarbons (Helm et al., 2014). Offshore fish populations remain relatively unaffected by hydrocarbon pollution as hydrocarbon concentrations below the surface slick are generally low, but it may cause disruption to migration or spawning patterns due to avoidance behaviour. Benthic communities would be susceptible to impacts from hydrocarbons that reach the seabed. Hydrocarbon spills may also cause indirect impacts on the commercial fishing industry if fish and shellfish exposed to fuels may become tainted and unsuitable for commercial use. Should the oil reach shore, there would be impacts on protected areas and sensitive coastal habitats and species.



Current research on the environmental implications of unplanned hydrogen releases remains limited, highlighting the need for further investigation to fully understand the associated risks. However, several key safety and environmental concerns can already be identified based on hydrogen's physical and chemical properties. Hydrogen is an odourless, flammable and colourless gas, which may pose significant safety concerns. Its lack of sensory indicators makes leak detection difficult, and in confined environments, accumulated hydrogen can ignite, leading to potentially severe explosions (Osman et al., 2022). From an environmental standpoint, while hydrogen itself is not a direct greenhouse gas, the interactions with other atmospheric constituents from unplanned releases should be considered. For example, hydrogen can react with atmospheric oxidants such as hydroxyl radicals (OH), reducing their availability. This depletion may slow the atmospheric breakdown of methane leading to indirect impacts on overall greenhouse gas emissions.

Finally, unplanned hydrogen release can lead to material degradation through a process known as metal hydrogen embrittlement. The small molecular size of hydrogen enables it to pass through materials such as pipelines, weakening the metal's internal structure. This makes the material more prone to cracking or rupture, which can compromise asset integrity. The risk is even greater in aquatic environments, where the process tends to accelerate (Osman et al., 2022). As noted previously, a detailed assessment on environmental impact of hydrogen releases will require further investigation.

Management and Mitigation

Extensive construction and design planning will be required to minimise the risk of accidental events and unplanned release. For unplanned hydrogen release specifically, such measures may include pressure relief systems, double-lined piping for transport of gas and leak detection systems where possible to identify and respond to leaks quickly. Regular inspection and ongoing maintenance of infrastructure including pipelines should be undertaken to identify and address any defects such as stress-induced cracking, ruptures, changes in surface texture or any other signs of material degradation.

More generally, the compliance of operators and all contractors with all safety requirements, the reporting of accidents in line with best practice and the appropriate training of personnel will minimise the risk of accidental events. The ongoing engagement with stakeholders and ensuring that all necessary maritime notifications and consents are issued will ensure potential risks are identified early and can be mitigated against.

For the full environmental & Consenting risk assessment see appendix I.



10 Cost Estimate

10.1 Basis of Estimate

10.1.1 Scope

The Class 4 estimate (+50% / -30%) has been raised to cover the costs associated with the engineering, design, procurement, fabrication, site construction and third-party vendors required to execute the Engineering Contractor scope according to Figure 3. Note the below major exclusions from Apollo's estimate:

- Electrolyser packages
- Demineralisation packages and EDI packages
- Gas purification packages
- Primary electrical systems

It is assumed that the costs for the excluded items (including engineering, design, procurement, fabrication, site construction and third-party vendors) are By Others.

10.1.2 Allowances

- Growth has been applied to the estimate keeping within standard guidelines for a Class 4 estimate
- 4% markup applied on materials, fabrication and vendors
- Client costs based on 20% of estimated costs (including hire of heavy lift vessel)
- 20% contingency on bottom line
- Where budget quotes have been received in Euro, exchange rate of 0.85 has been applied
- Insurance and bonds have been excluded



10.2 CAPEX Estimate Summary

Table 26 Capital Cost Estimate Summary

Cost Element	Estimated Base Costs (£)	Growth Allowance (%)	Mark-up (%)	Total Estimated Cost (£)
Management & Project Services (FEED)	£1,566,844.82	25%	0%	£1,958,556
Engineering & Design (FEED)	£6,267,379.30	25%	0%	£7,834,224
Management & Project Services (Detailed Design)	£10,967,913.77	25%	0%	£13,709,892
Engineering & Design (Detailed Design)	£31,336,896.49	25%	0%	£39,171,121
Follow-on Engineering	£1,566,844.82	25%	0%	£1,958,556
Close-out	£2,350,267.24	25%	0%	£2,937,834
Commissioning (site)	£9,269,102.07	25%	0%	£11,586,378
Miscellaneous costs	£5,500,000.00	25%	0%	£6,875,000
Site implementation	£37,076,408.28	25%	0%	£46,345,510
Plant & equipment	£3,707,640.83	25%	0%	£4,635,551
Materials	£137,556,475.00	25%	4%	£178,823,418
Fabrication	£161,112,617.19	25%	4%	£209,446,402
Third party vendors	£	47,131,027.4725%	4%	£61,270,336
Facilities Management / Scaffolding	£9,269,102.07	25%	0%	£11,586,378
Sub-total				£598,138,155
<i>Client costs</i>	20%			£119,627,631
<i>Client contingency</i>	20%			£143,553,157
Total Estimate Value				£861,318,943

11 Implementation Schedule

An approximately 5-year implementation schedule has been estimated based on the integrated deck concept, see Figure 44 below for the Level 2 schedule.



Year	Year 1				Year 2				Year 3				Year 4				Year 5			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Design activities																				
FEED																				
Detailed Design																				
Procurement																				
Procure Long Lead Items																				
Down-select yard																				
Procure packages and sub-contracts																				
Construction																				
Structural steelwork fabrication																				
Deck assembly and stacking																				
Commissioning																				
Cold commissioning																				
Hot commissioning																				
Transport to site																				
Installation and hook-up																				
Site commissioning																				
Test run																				
Operation																				

Figure 44 Level 2 Schedule



12 Conclusions and Recommendations

The Concept Definition study for the HOP2 project comprised multi-disciplinary design of new topsides for the Ninian Central Platform (NCP) based on revised concepts for the electrolysis, water treatment, hydrogen purification and primary electrical systems. The Concept Definition study was undertaken by a multi-disciplinary team comprising:

- Process
- Mechanical (including Heating, Ventilation & Air Conditioning (HVAC), as well as Operations & Maintenance (O&M))
- Electrical
- Structural (including Piping, Layout and Construction)
- Controls & Instrumentation
- Technical Safety
- Environmental
- Estimating (cost and schedule)

Figure 45 below shows the overall outputs from the study.

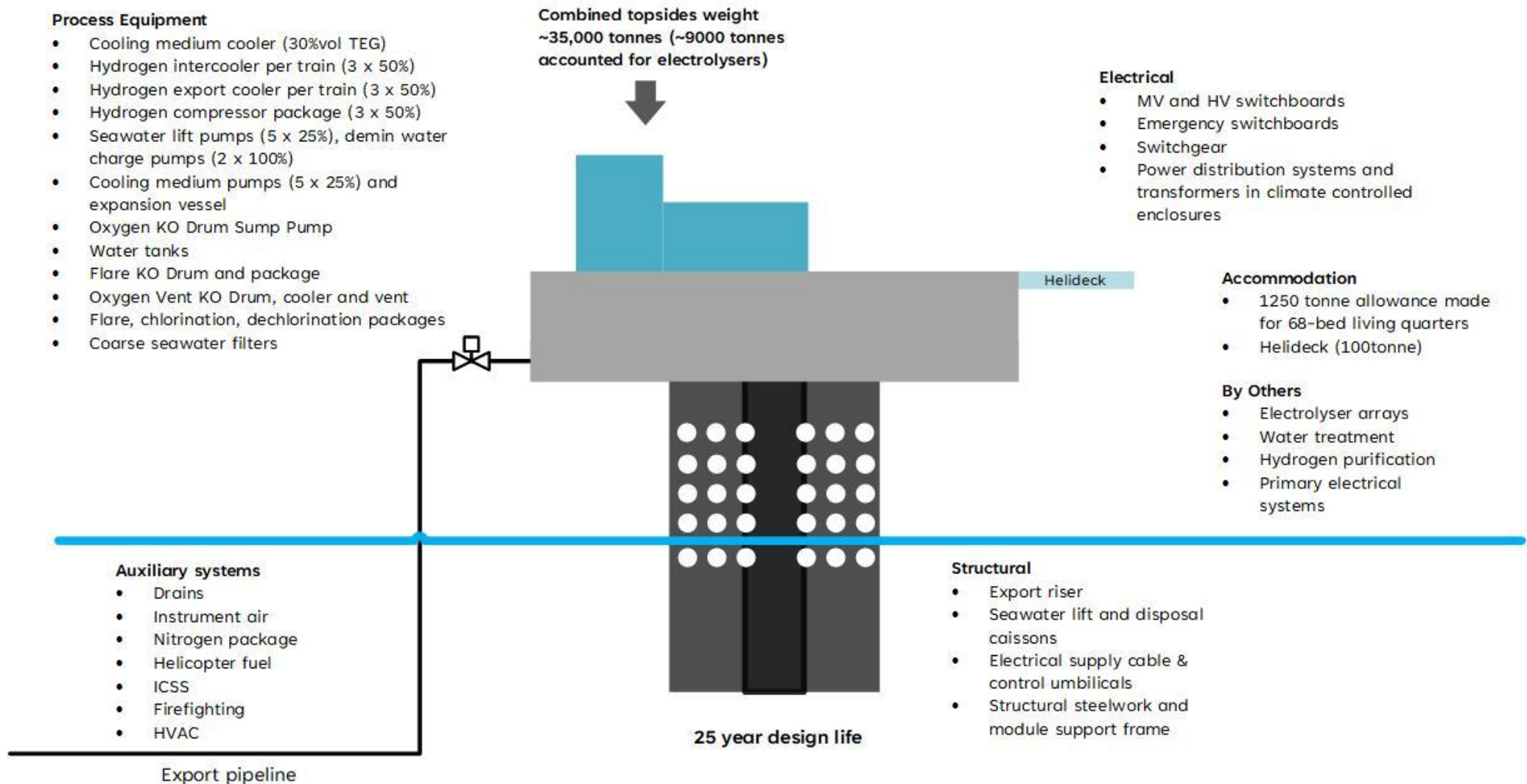


Figure 45 Key Design data for HOP2 project



12.1 Process Conclusions

12.1.1 Hydrogen Vent and Flare Philosophy

Four options were considered to process the low-pressure vent streams from the electrolyser arrays (<5kg/hr total at 0.5 barg). Dedicated cold vents (1 per array) were recommended as the other options would not be feasible. The array low pressure hydrogen vents will be required to be directed away from sources of ignition.

Other flare users – which would operate at a higher pressure – were connected to a HP flare header, knock-out drum and flare stack lit by a continuously sparking ignitor to ensure combustion of nitrogen. The flare stack would be continuously purged with nitrogen along its whole length to prevent the ingress of air. The purge rate would be minimised by deploying a molecular seal within the flare tip.

12.1.2 Selection of Variable Speed Drives

Variable Speed Drives (VSD) have been recommended for two pumps:

- P-1101A-E: Recommended to be controlled by VSD due to variation in suction head because of tidal range as well as ability to minimise starting currents for large motors.
- P-1201A/B: Recommended to be controlled by VSD due to variation in discharge head requirements: at part load the static head requirement may be decreased if only the lower level of electrolyser arrays is operating. In addition, the reduction of frictional losses in the lines at part load (potentially as low as 10%) would encourage the use of VSD to minimise wasted pump head.

12.1.3 Segregation of Hazardous and Non-Hazardous Cooling Users

The study has provided indirect TEG closed loop cooling for hazardous areas of the plant rather than cooling with seawater directly. The selection of an indirect TEG loop enables the detection of leaks and compartmentalises the potential for a leak of hydrogen (or oxygen) to transfer to equipment and areas that would not normally be in a hazardous area. In addition, heating seawater to 60°C for the heat integration between electrolyzers and desalination plant would pose significant additional material challenges and is not recommended.

HOP2 is recommended to proceed with direct seawater cooling for the HVAC system as titanium options are readily available for chillers, and the disbenefits of additional head and pipework have been minimised as far as practicable during the development of the process layout.

12.1.4 Key Process Data

Seawater lift

The total seawater lift flowrate was determined to be approximately 10,571,000 kg/hr at End-of-Life conditions, comprising approximately 7,511,000 kg/hr (71%) for cooling and the remaining 21% for desalination. The seawater lift pumps require approximately 525 kW absorbed power each (2.1 MW total) to meet the head and flow requirements at full load.

Cooling

The total cooling provided by the seawater lift was calculated as approximately 83 MW.th, comprising approximately 49MW.th process users (60%) and 34 MW.th seawater cooling of HVAC equipment [2]. Cooling for the process users was specified as an indirect closed loop of 30 vol% TEG, with total circulation rate calculated as 7,238,000 kg/hr, of which 6,750,000 kg/hr (93%) would be used for the electrolyser and desalination main loop, and remaining 7% sent to cool the hydrogen and oxygen equipment.



12.2 Mechanical Conclusions

The mechanical scope of the HOP2 Concept Definition successfully outlines a comprehensive study of key mechanical systems. Such as cranes, HVAC, compression, and operability and maintenance, which have been specified with careful consideration of operational demands, safety, and efficiency.

The crane system, featuring two high-capacity pedestal cranes, is engineered for offshore reliability and is fully compliant with API and DNV lifting standards. Having a lifting capacity of 50 tonnes at its 45m radius, enabling it to safely handle the maximum expected lift of a 45-tonne transformer at full range.

The HVAC system has been developed to manage the significant thermal loads generated by high-capacity electrical equipment, such as transformers, rectifiers, and harmonic filters. The design is based on detailed thermal load assessments and airflow modelling, with performance benchmarks aligned to ASHRAE guidelines and vendor specifications. A total cooling load of 6,651 tons has been identified under realistic operating conditions, supported by five 1,500-ton chillers and a network of high-capacity air handling units. Modular ducting strategies, airflow optimisation, and the recommendation to externally install transformer radiators further enhance optimal HVAC design. This significantly reduces HVAC demand and contributes to lowering the platform's weight and CAPEX.

The specified compression solution comprises three vertical, non-lubricated reciprocating compressors, delivered as fully skid-mounted units for streamlined integration. Designed for high-pressure hydrogen service, the system provides full process capacity through a 3x50% configuration, ensuring built-in redundancy and operational flexibility. This arrangement enhances maintainability, maximises uptime, and ensures compliance with stringent hydrogen purity and performance requirements.

Finally, a proactive O&M strategy is supported by a detailed FMEA and RAM analysis. These analyses identified high-priority risks, such as oxygen venting failures and PEM electrolyser vulnerabilities, and proposed targeted mitigation measures. The RAM study quantified the system availability at 93.39%, highlighting areas for future improvement, particularly in upstream power and electrolyser systems.

Overall, the mechanical design aligns with offshore engineering best practices and provides a solid foundation for the facility's future FEED and execution phases.

12.3 Electrical Conclusions

The design of the Secondary Electrical System is readily achievable using standard commercially available and proven equipment. The total loads for the secondary systems comprised:

- MV Utilities: 13MW
- HVAC: 9MW
- Topsides: 1.1MW

The HVAC load is significant at 40% of the overall Topsides power requirements and should be a focus to improve definition at any next project phase.

VSD's have been selected for much of the main process utility equipment for system control and operability reasons, but this will also assist with motor starting capability. Power System Studies should be conducted at the next phase of the project.

The initial project basis is on providing both a back-up and an emergency generator, i.e. 2 x100% units. There are various ways to configure these, and two generators have been incorporated into the design but with



options for rental unit(s) discussed. The philosophy around the use and need for back-up power should be developed further. If calm weather days are likely to be significant it may be that sizing of the back-up power includes more than typical emergency and basic habitation load; one option is to run both units in such a scenario. Liquid fuel back-up generation is recommended. This is because of the likely extended run times for back-up generation and starting requirements for the nature of some of the connected load.

12.4 Control and Instrumentation Conclusions

A preliminary specification for the ICSS requirements has been developed. The ICSS shall monitor, control and safeguard the topsides systems. It shall comprise of the following main systems while interfacing with package UCPs of topsides / subsea facility:

- PCS – Process Control System
- SIS - Safety Instrumented System, comprising:
 - ESD – Emergency Shutdown System
 - FGS – Fire and Gas System

The ICSS shall be supported by telecommunications infrastructure which shall provide robust, secure, and high-availability communications infrastructure ensuring safe, efficient, and continuous operations. In addition, fiscal metering shall be provided for hydrogen export.

12.5 Structural, Layout, Construction Conclusions

A revised layout has been produced for the HOP2 topsides based upon the updated Master Equipment List (MEL). The layout is an evolution of the design proposed at the previous Concept Stage. The layout has been essentially condensed down to two main levels, with a smaller area of the third level housing the key components of the primary electrical system, HVAC handling units and smaller utilities. As this is a high-level concept study, no structural analysis of the proposed topside has been carried out to confirm the adequacy or estimated weight of the proposed structural framing arrangement for the topsides or interface steelwork.

From the volumetric estimate carried out, a dry weight of 31,600t was found for the latest HOP2 topside design. The operating weight is estimated as 35,000t (11% greater than the dry weight). This weight estimate assumes integrated deck construction and includes an allowance for interface steelwork. The overall topsides volumetric density was found to be 0.221t/m³ which compares well with the average norm for a North Sea integrated deck oil and gas platform (0.226t/m³). The dry weight remains close to the previously estimated 31,841t from “Concept”, despite a significant increase in the electrical equipment required and the addition of interface steelwork (900t) and appurtenance weighs (275t allowance). These additional loads have been counterbalanced by the reduction in weight gained from the larger PEM Electrolysers, which are a more efficient use of the available space. No consideration has been given to topsides CoG at this stage of the design.

Given the volumetric weight estimating technique adopted, no contingencies have been included in the weight estimates. The estimated 35,000t topside operating weight constitutes 92% of the advised 38,000t topside weight limit for the existing Ninian Central GBS, leaving a 1.09 growth factor to account for future project growth or inaccuracy in the volumetric norms. Should the 38,000t topside weight limit be exceeded then this would need to be addressed by reducing the topsides production capacity.

The base case for the platform installation is considered to be an integrated deck design, as this would prove the most efficient in terms of topside weight and overall cost for the topsides (procurement & fabrication). However, at present the only vessel that could install a topside of this weight is the Allseas Pioneering Spirit.



The Pioneering Spirit has a current topside lifting capacity of 48,000t, therefore the HOP2 topside is within the vessel's capability. The width between the two hulls is believed to be wide enough to straddle the existing Ninian Central GBS. However, further engagement would be required with Allseas to develop the lifting concept and confirm the feasibility of installing HOP2 as an integrated deck.

To provide flexibility in the installation method, this study looked at the viability of a more traditional modular installation methodology concept. This opens up the potential to use alternative installation contractors with crane vessels, where there is greater market availability.

It is concluded that a similar modular installation to the existing NCP topside is potentially viable. However, this would potentially push the operating weight for the platform close to the 38,000t GBS limit. Including 1800t for an MSF and assuming the modular topside design increases the main topside volume by 7,500m³ (additional 1.5m width per split line – see Figure 30) with the same volumetric density for the integrated deck, it is estimated that a modular installation methodology would increase the dry topsides weight by 2,500t to 34,100t, with the operating weight increasing to 37,800t (using the same 1.11 overall operating factor), which does not leave much of a margin.

This concept would first utilise a Module Support Frame (MSF) which would be installed to the GBS in advance of the installation of several topsides modules. The rest of the topside structure would be split into 10 modules, the largest individual module weight would likely be in the region of 7,500t, which would put the installation within the range of the Saipem 7000 and Heerema's Sleipner & Thialf vessels (Thialf likely to be marginal for 7,500t module). Smaller modules could be installed with smaller HLV's such as Heerema's Balder.

To mitigate against the complexity and costs of making connections to the existing GBS, it is proposed that appurtenances should be flexible catenaries, where possible. This applies to the Import Power Cables, Hydrogen Export Riser and Umbilical. For the Seawater Lift Caissons, it will likely be more practical to utilise the existing conductor guides, subject to review of their integrity. It is proposed that the Seawater Lift Caissons are installed after the topsides using the east platform crane.

12.6 Technical Safety Conclusions

This study considered a range of leak scenarios of the HOP2, and high-level consequence modelling was performed. The impact of gas dispersion, explosion and jet fire has been assessed following a loss of containment. The conclusions comprise:

12.6.1 Gas dispersion

The release rate and flammable plume extent have been provided for a range of hole sizes (5 mm, 25 mm, 100 mm), wind speeds (2D, 5D, 10D), and HOP2 inventories. All release cases considered were found to be capable of producing a significant flammable cloud on the platform. Wind speed was not found to have a significant impact on the size of a flammable gas plume within the scope of the scenarios modelled, where the highest speed assessed of 10 m/s causes a similar flammable plume size to the lowest wind speed of 2 m/s. The extent of a 20%LEL gas plume has been provided, a typical concentration that gas detectors are calibrated to on offshore platforms. The HOP2 gas detector layout has not been designed yet. However, for each release case considered, multiple detectors would likely be alarmed due to the gas dispersion extent within the process modules, providing detection of potential leaks.



12.6.2 Explosions

Explosion impacts were assessed for various hydrogen leak scenarios upon ignition 10 meters from the release point. The flammable mass of hydrogen (between lower and upper flammability limits) and resulting blast radii at overpressures of 0.02, 0.21, and 0.35 bar were calculated. Wind speed was found to have a small impact on the flammable mass and blast radius. The overpressure radii for all scenarios were found to be similar, where the medium pressure and high-pressure inventories produce increasingly larger blast radii. For each release scenario assessed, the following overpressure distances were determined:

- 0.02 bar (low damage such as breaking windows), dependent on inventory: 12m – 90m
- 0.21 bar (20% probability of fatality to personnel inside, 0% probability of fatality in the open), dependent on inventory: 2m – 12m
- 0.35 bar (50% probability of fatality inside, 15% probability of fatality in open. Heavy damage to buildings and pressure equipment. Lifeboats, temporary refuge and escape routes impacted.), dependent on inventory: 2m – 9m

The analysis did not include the mitigating effects of blast walls, which may provide some shielding of the explosion overpressure, which would be dependent on the blast wall rating.

Due to the propensity of hydrogen to leak and its low ignition energy, the risk from explosion overpressure may potentially not be tolerable. This should be considered further in a risk assessment at a later stage in the project.

12.6.3 Jet fires

Jet fire flame lengths for each release scenario were calculated using Phast. The jet flame length was found to increase significantly with hole size due to higher release rates. Wind speed and atmospheric stability were found to have little effect on flame size. High-pressure inventories produced the longest jet fires, and flame lengths were similar across inventories. Small holes (5 mm) resulted in approximately 4 m flames, with limited local impact. Medium and large holes (25 mm, 100 mm) resulted in flames exceeding 14 m, affecting a significant area of the platform. Jet fires pose fatal risks to personnel in the immediate area and generate intense thermal radiation. Jet fires can severely damage equipment, potentially escalating incidents, where flame impingement lasting over 5 minutes may lead to steel equipment failure. For all 100 mm and some 25 mm leaks assessed, jet fire durations were not long enough to cause steel failure. However, small 5 mm releases can last longer than 5 minutes, producing flames 3 to 5 m in length. This is large enough and sustained for long enough to cause surrounding piping or structural beams to fail, potentially triggering further escalation. Note, inventory depressurisation through blowdown and any mitigation measures (such as active/ passive fire protection) have not been considered, and will limit the impact of jet fires.

12.7 Environmental Conclusions

HOP2 aims to repurpose existing oil and gas assets within the UK Continental Shelf for offshore green hydrogen production, focusing on the Ninian Central Platform in the NNS. This environmental and consenting risk assessment outlines the project's potential impacts and likely associated regulatory requirements based on information provided to date. Environmental regulatory and consenting requirements may need to be revisited as HOP2 develops.

The environment around HOP2 is typical of the wider region, with a characteristic range of benthic, fish, marine mammals and bird species present. There are no designated conservation areas within the vicinity of HOP2.



Socioeconomic considerations highlight evidence of commercial fishing activity, moderate vessel traffic primarily from service vessels, and proximity to several oil and gas platforms.

Potential impacts from the construction and operation of HOP2 identified include seabed disturbance, discharge to sea, atmospheric emissions, underwater noise, and accidental events such as chemical spills and vessel strikes. These impacts could affect water quality, benthic organisms, fish, marine mammals, seabirds and other sea users. The consideration of potential impacts in project design, along with early engagement with other users, stakeholders and regulators will help to mitigate these risks. Moreover, HOP2 has been designed to repurpose existing oil and gas subsea infrastructure and to utilise a nearby offshore wind platform as the power source, thereby reducing the need for subsea infrastructure and installation activities. The ultimate end use of HOP2 will reduce overall carbon emissions and impacts to environmental sensitivities in comparison to historic oil and gas use within the North Sea.

As project design is further developed, scoping, Environmental Risk Identification (ENVID) and EIA will allow a more detailed appraisal of environmental impact and risks.

12.8 Cost Estimate

A Class 4 cost estimate (+50% / -30%) has been raised to cover the costs associated with the engineering, design, procurement, fabrication, site construction and third-party vendors required to execute the Apollo's scope for the HOP2 project. Note the below major exclusions from Apollo's estimate:

- Electrolyser packages
- Demineralisation packages and EDI packages
- Gas purification packages
- Primary electrical systems

It is assumed that the costs for the excluded items (including engineering, design, procurement, fabrication, site construction and third-party vendors) are By Others. The total cost for Apollo's scope was estimated at approximately £861 million.

12.9 Next Phase Recommendations

Moving forward in the feasibility assessment of offshore hydrogen production platforms, the subsequent phase demands a more comprehensive examination of various critical aspects. While this report has touched upon certain elements, several key factors remain unexplored due to the predefined scope of work. The future studies and assessments should delve deeper into the following area to ensure a thorough and exhaustive evaluation:

- **Topsides Installation Method:** The topsides installation method heavily influences the platform weight and overall costs. It will be necessary to commit to either integrated deck or modular topsides installation prior to commencing FEED. In order to allow an informed choice to be made the following key activities are recommended:
 - Engagement with HLV suppliers to perform high-level installation studies for both options and to gain availability and cost data for each.
 - Additional structural studies to look in more detail at the interaction between the topsides and GBS and to further develop the interface steelwork and topsides design for both options.



- Given the large size of the topside and the necessary height of the interface steelwork, to match with the existing GBS structure, it would be prudent to have early engagement with topside fabricators to confirm the constructability of the integrated deck topsides.
- **Topsides Structural Design:** Topside design models should be developed for in-place, lift and transport scenarios to better understand the structural weight and primary framing requirements impact on layouts. Focus should be applied to the centre of gravity (CoG) and interface steelwork design in order to distribute loading into the GBS in as similar as manner as possible to the existing topside. Whilst similar to the existing Ninian topside, the proposed HOP2 design has large cantilevers which will need to be given consideration in the analysis, with the effects of deflections considered for the vent and flare. The interface steelwork design depends heavily upon the chosen installation methodology and should be included in the analysis.
- **GBS Structural Assessment:** For the re-use of the GBS it will be necessary to conduct a full integrity review and strength/fatigue appraisal of the existing structure to ensure it can be relied upon for the lifespan of HOP2. This should be carried out by specialist consultants with knowledge of the structure and its design. This assessment should also include for strength and fatigue appraisal of the existing conductor guide frame for the future support of the five seawater lift caissons.
- **Weight management;** Future stages of project development should develop “bottom-up” weight estimates based upon vendor weight data and discipline weight estimates in order to develop a more robust and accurate appraisal of the topsides weight. Volumetric weight estimating (benchmarking) is acceptable for conceptual design, but a more reliable estimate will be required for FEED. This can only be achieved by a “bottom-up” approach. Weight management will be a critical activity as the project progresses, but particularly so if a modular installation method is selected, given the operating weight is predicted to come very close to the GBS weight limit. Due consideration of the platform CoG will also be critical for distribution of loading to the GBS.
- **Appurtenances:** It is proposed that catenary flexibles are employed for the power cables, export riser and control umbilical. Due to the required service a bespoke Hydrogen riser and Import Power Cables are likely to be required, as opposed to off the shelf designs. Thus, to de-risk the project these proposals should be investigated early in the next phase to confirm the viability of this option;
- **Vendor engagement:** Further engagement with specialist vendors (equipment vendors, heavy lift vessel providers etc.) will help to size the equipment accurately, helping to firm up the layout and also providing the valuable weight and cost data required. Vendor engagement will also be key to confirm the viability of the flexible appurtenances, particularly for the Hydrogen Export Riser and Power Cables;
- **Optimisation of electrical equipment technology / arrangements:** Investigate options for reducing quantity of rectifiers/transformers, the overall sizes, maintenance zones and maintenance lifting requirements;
- **Layout Review:** Comprehensive review and optimization of the platform's plot plan to enhance overall efficiency and functionality should continue at subsequent phases as more reliable vendor data and greater understanding of maintenance requirements become available;
- **HAZID Analysis:** A more detailed examination of Hazard Identification (HAZID) to identify safety critical elements (SCE) so outline performance standards can be developed;
- **HAZOP:** Hazards around hydrogen equipment to further define MEL and platform layout requirements;
- **Fire and Blast Analysis:** Detailed analysis focusing on fire and blast scenarios to ensure robust safety measures are in place and assess the impact on layouts and structural design;



- **Heat Radiation Analysis:** Evaluation of heat radiation factors to assess potential impacts and implement necessary mitigations;
- **Hydrogen flare radiation and gas dispersion study:** To optimise the height of the flare; Constructability Study: A comprehensive study to assess the constructability of the proposed platform design, emphasizing feasibility during the construction phase;
- **Quantified Risk Assessment and ALARP Demonstration:** to determine risk to personnel has been reduced to ALARP.
- **Mechanical Handling Study:** A more detailed exploration of mechanical handling requirements, considering every aspect of maintenance needs and operational efficiency;
- **Temporary Refuge, Escape, Evacuation and Rescue Assessment (TREERA) Study:** In-depth assessment of escape, evacuation, and rescue procedures to ensure the safety and well-being of personnel in emergency situations;
- **Dropped Object Protection Study:** Analysis and implementation of measures to protect against dropped objects, emphasizing safety and asset integrity.
- **Power System Studies:** Validation, and better definition of electrical equipment sizing through load flow, short circuit and motor starting studies
- **HVAC system development:** To improve confidence on the electrical power requirements
- **Materials:** Review the materials selected for hydrogen service to identify potential long term degradation mechanism risks.



13 References

- [1] Facilities Design Philosophy - Hydrogen Offshore Production Project (HOP2).
- [2] Apollo, "244-025-PRO-PFD-0001 Seawater and Feed Water Rev B".
- [3] Apollo, "244-025-PRO-PFD-0002 Hydrogen System Rev B".
- [4] Apollo, "244-025-PRO-PFD-0002 Cooling System Rev B".
- [5] Apollo, "244-025-PRO-PFD-0001 Auxiliary Systems Rev B".
- [6] NZTC, "Apollo_PFD&UFD_CRS Rev A".
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- [10] 244-025-GLR-BOD-0001-B HOP2 Concept Basis of Design.
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- [12] Apollo, "244-025-PRO-PEL-0001-B Process Equipment List Rev B".
- [13] Apollo, "244-025-ELE-RPT-0001 Secondary Electrical Load List Rev B".
- [14] Apollo, "244-025-GRL-GEN-0001A Master Equipment list".
- [15] UK CAA, "Guidance for offshore helicopter landing areas," in *CAP 437, 9th Ed*, 2023.
- [16] IALA, "Guideline G1162 The Marking of Offshore Man-made Structures Edition 1.1," Dec 2021.
- [17] UK Government, "SI 2022: No. 146 The International Organisation for Marine Aids to Navigation (Legal Capacities) Order".
- [18] HSE, "Prevention of fire and explosion, and emergency response on offshore installations," 1995. [Online]. Available: <https://www.hse.gov.uk/pubns/books/l65.htm>.
- [19] HSE, "Safety signs and signals. The Health and Safety Regulations," 1996. [Online]. Available: <https://www.hse.gov.uk/pubns/books/l64.htm>.
- [20] J. Spouge, Guide to Quantitative Risk Assessment for Offshore Installations.
- [21] Publicatiereeks Gevaarlijke Stoffen 2, Methods for the calculation of physical effects (Yellow Book).
- [22] HSE, Methods of approximation and determination of human vulnerability for offshore major accident hazard assessment.



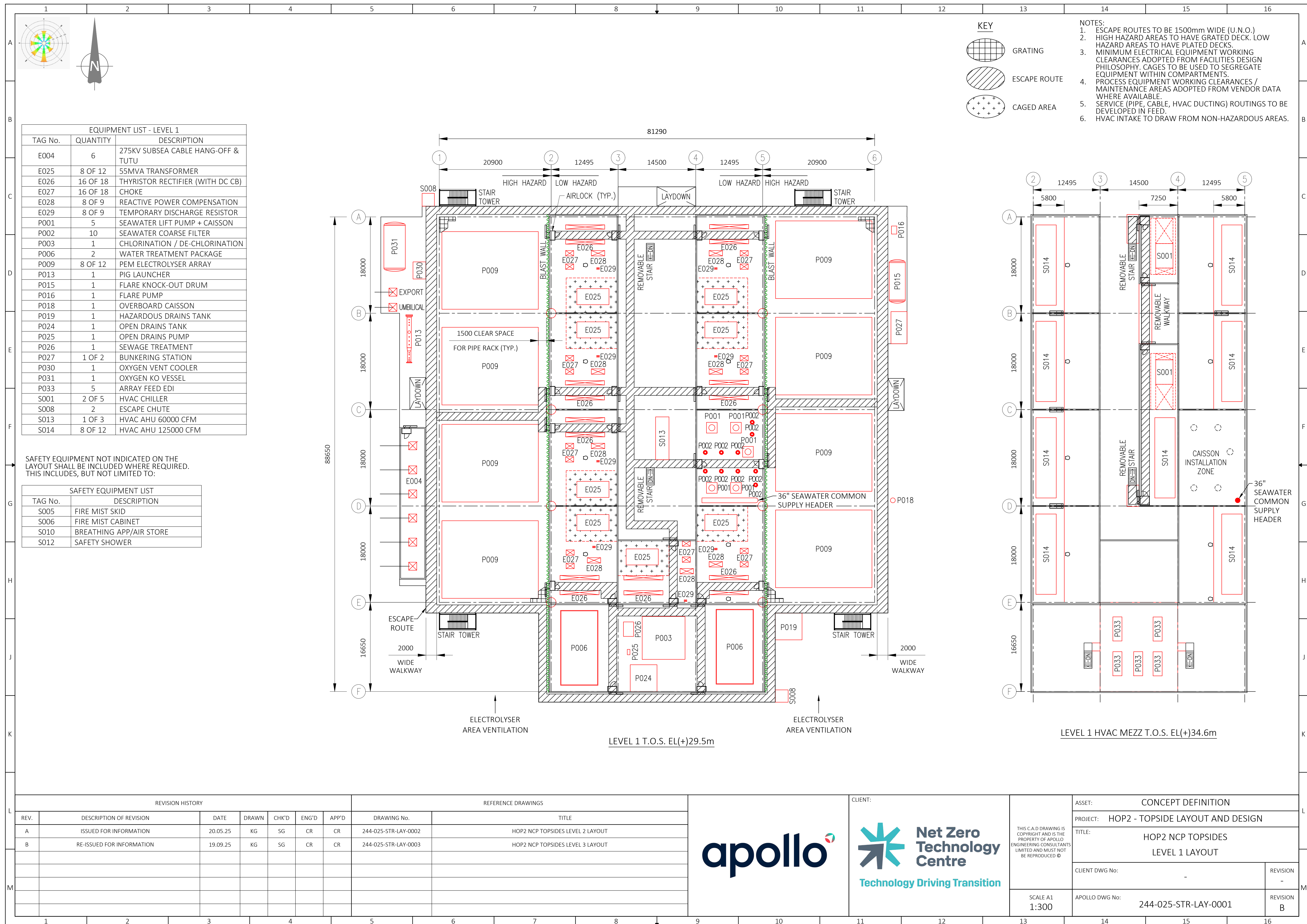
Appendix A Layout Drawings

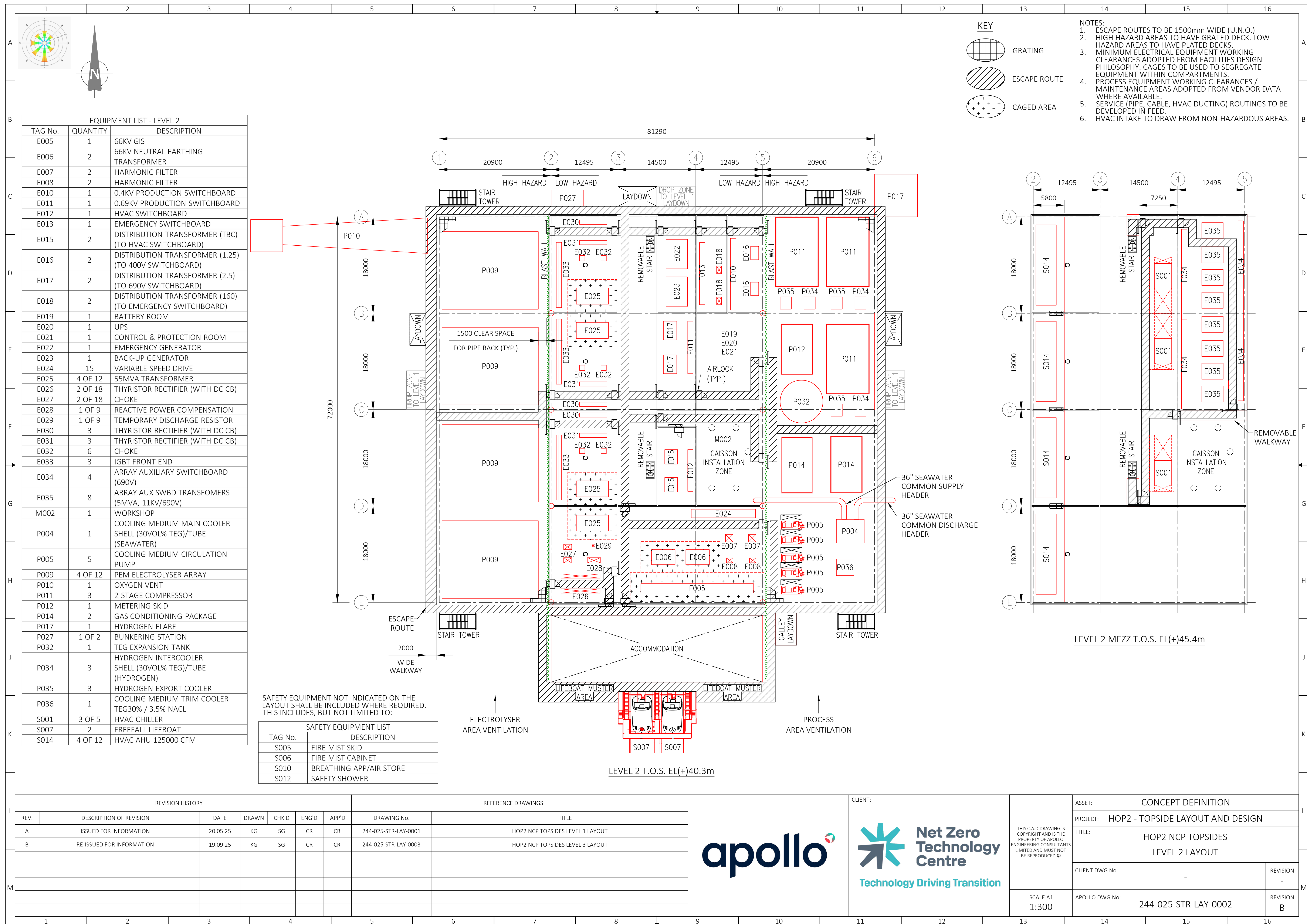
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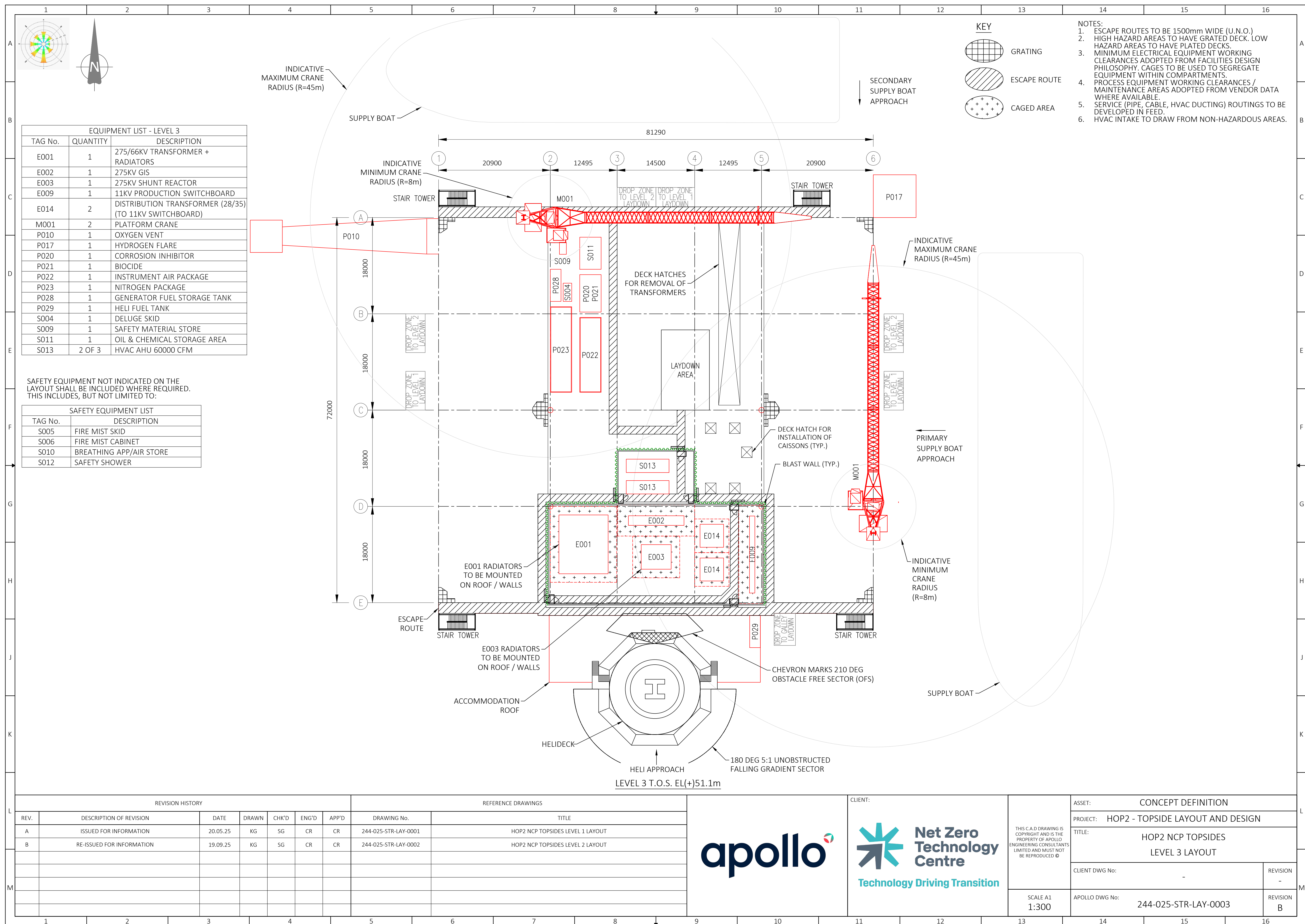
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244-025-STR-LAY-0002-B

244-025-STR-LAY-0003-B







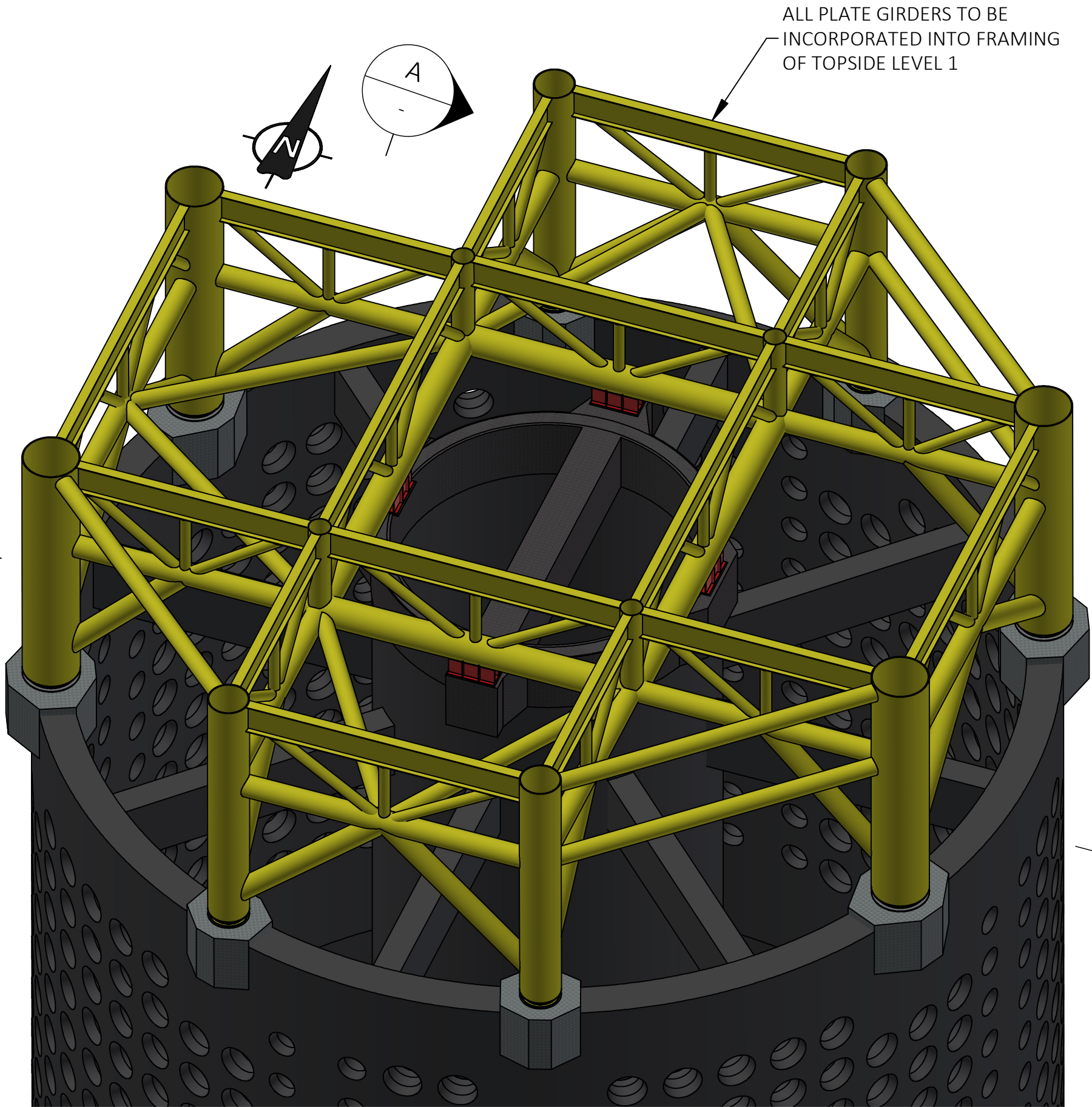
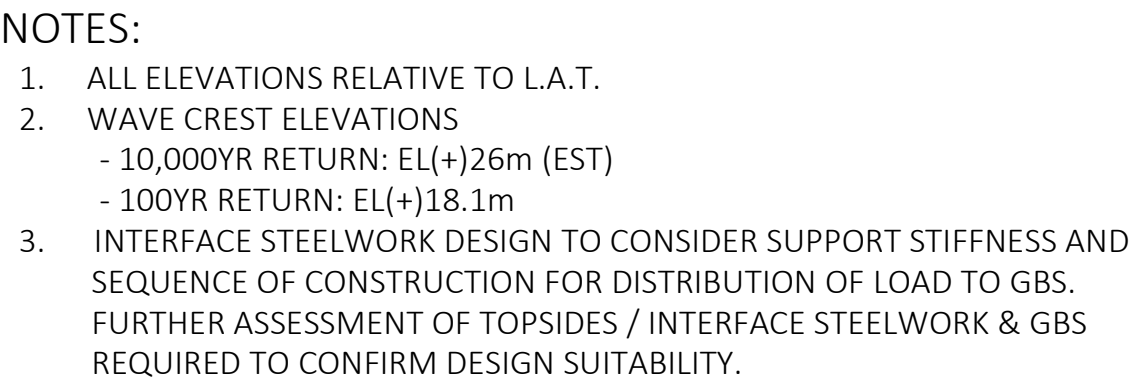


Appendix B Interface Steelwork Drawings

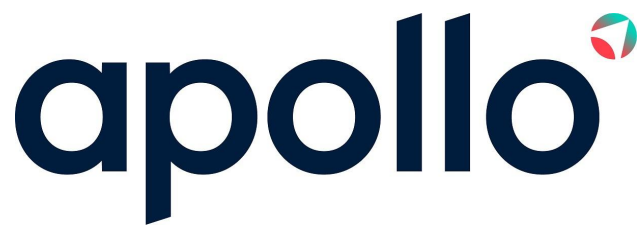
Attached separately:

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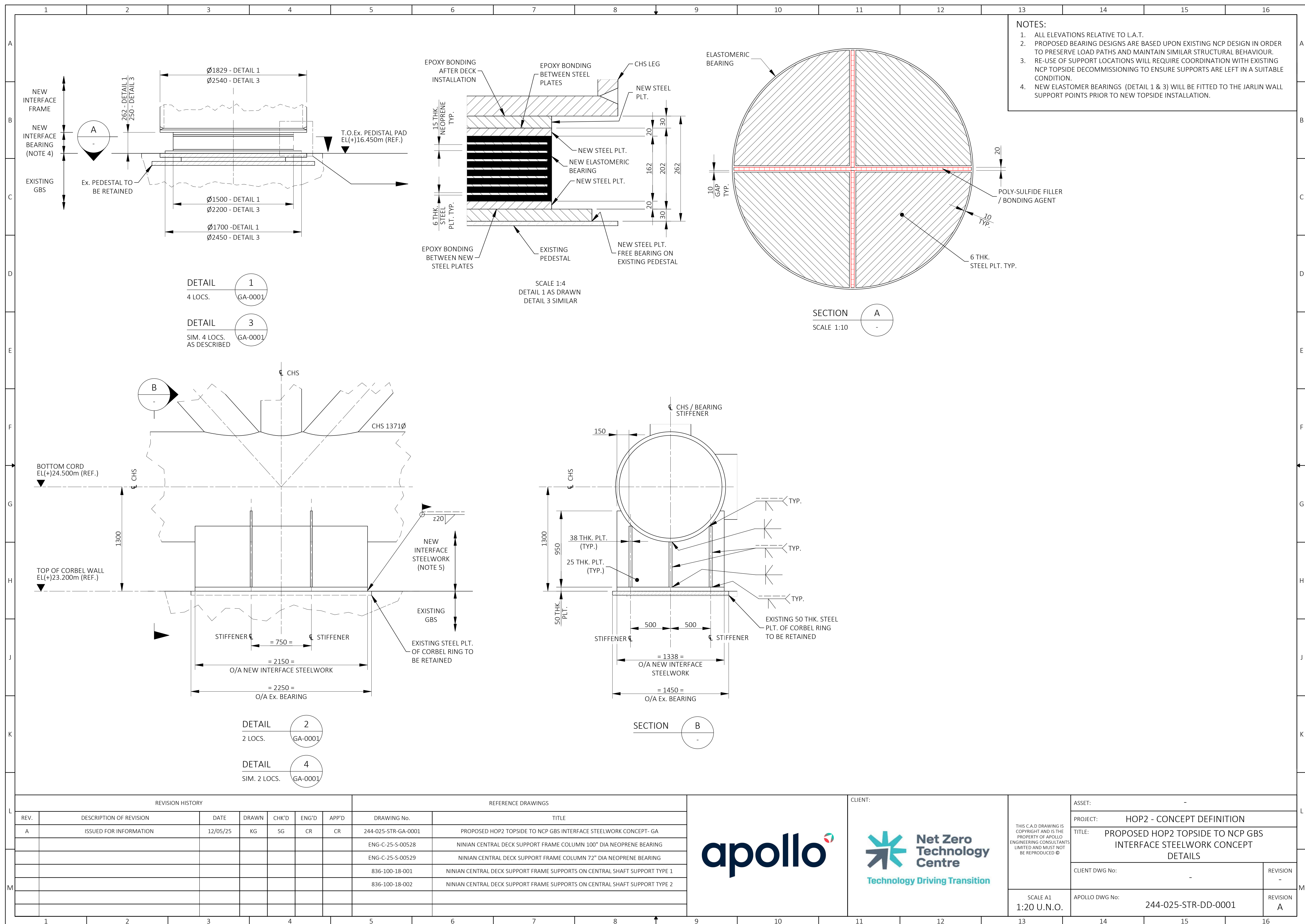


OVERALL VIEW OF INTERFACE STEELWORK ON EXISTING GBS
SCALE N.T.S.

[illegible]

CLIENT:

ASSET:	-	
PROJECT:	HOP2 - CONCEPT DEFINITION	
TITLE:	PROPOSED HOP2 TOPSIDE TO NCP GBS INTERFACE STEELWORK CONCEPT GENERAL ARRANGEMENT	
CLIENT DWG No:	-	REVISION -
APOLLO DWG No:	244-025-STR-GA-0001	REVISION A





Appendix C Crane requirements calculations

244-025-CAL-0002-A Pedestal crane specification



Engineering tomorrow, today.

Client:	Net Zero Technology	Rev. No.:	A
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HOP2 Concept Definition

Pedestal Crane Specifications

Calculation for Net Zero Technologies



04 March 2025 | 244-025-CAL-0002-A | Pedestrian Crane Specifications

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Revisions and approvals

Revision	A	Description	Issued for use	
Originated by		Check by	Approved by	Date
MBS		DM	DM	04 March 2025



Client:	Net Zero Technology	Rev. No.:	A
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1 Introduction & purpose of calculation

The pedestal crane specifications for the 500MW offshore hydrogen production facility will be defined based on critical operational and design parameters. These include the required lifting capacities, proposed crane layout, and constructability/installation considerations. The crane requirements will be carefully documented to ensure alignment with the overall engineering and installation strategy, facilitating seamless integration into the project's execution plan.

2 References

2.1 Reference documents / drawings

- [1] 244-021-GRL-RPT-0001-C HOP2 - Study Report
- [2] 244-021-GRL-GEN-0001-C Master equipment list1.xlsx
- [3] 244-025-GRL-GRN-0001-A Master equipment list
- [4] <https://www.scribd.com/document/477962188/T06f56-Offshore-Crane-Operator-Handbook>
- [5] <https://www.liebherr.com/en-int/maritime-cranes/downloads/offshore-cranes-5391767>
- [6] 244-025-GRL-RPT-A HOP2 Concept Definition

2.2 Standards and directives

- [A1] AISC 360-16: Specification for structural steel buildings (ASD)
- [F3] BS 3692:2014 ISO metrix precision hexagon bolts, screws and nuts - Specification
- [G1] BS EN 10025-2: Hot rolled products of structural steels (2019)
- [H1] LOLER (Lifting Operations and Lifting Equipment Regulations, UK)
- [I1] DNV-ST-0378 (Standard for Offshore and Platform Lifting Appliances)
- [J1] API SPEC 2C (Specification for Offshore Pedestal-mounted Cranes)

3 Design criteria & assumptions

- Assume high-strength steel (S690QL) [J1].
- Assume the boom cross-section is hollow and rectangular with: Outer width 0.8m, Outer height 1.2m and Thickness 0.025m [5].
- Assume the pedestal height of 8m, diameter of 2.5m and wall thickness of 0.06m [J1].

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4 Constants

S690QL Yield Strength $YS := 690 \text{ MPa}$

S690QL Elastic modulus $E := 210 \text{ GPa}$

S690QL Density $p := 7850 \frac{\text{kg}}{\text{m}^3}$

S690QL Safety factor $SF := 1.3$

Dynamic factor for fixed structure
[\[I1\]](#) [\[J1\]](#) $DF := 1.1$

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5 Lifting capacity

Boom studied is assumed to be a simple box design with steel tubular members.

Boom Outer Width $b_{out} := 0.8 \text{ m}$

Boom Outer Height $b_{height} := 1.2 \text{ m}$

Boom Thickness $b_{thick} := 0.025 \text{ m}$

Boom Length $b_{length} := 45 \text{ m}$

[1]

5.1 API SPEC 2C Lifting Capacity Calculation

Boom Inner Width $b_{in} := b_{out} - 2 \cdot b_{thick} = 0.75 \text{ m}$

Boom Outer Inner Height $b_{heightin} := b_{height} - 2 \cdot b_{thick} = 1.15 \text{ m}$

Distance from neutral axis $c := \frac{b_{height}}{2} = 0.6 \text{ m}$

Boom Second Moment of Inertia $I_{boom} := \frac{b_{out} \cdot b_{height}^3 - b_{in} \cdot b_{heightin}^3}{12} = 0.02 \text{ m}^4$

To prevent failure, the maximum stress must be less than yield strength.

Static Load $L_{static} := \frac{\left(\frac{YS \cdot I_{boom}}{c \cdot b_{length}} \right)}{9.81 \cdot \frac{\text{m}}{\text{s}^2}} = 52.48 \text{ tonne}$

Load Chart Reduction factor $LCRF := 0.95$ (Considering operational safety margin)

[J1]

Lifting capacity $L_{capacity} := \frac{L_{static}}{DF \cdot LCRF} = 50.22 \text{ tonne}$

5.2 DNV-ST-0378 Capacity Calculation

The pedestal (base of the crane) must resist the overturning moment.

Pedestal height $P_{height} := 8 \text{ m}$

Pedestal outer diameter $P_{odiameter} := 2.5 \text{ m}$

Pedestal wall thickness $P_{WT} := 0.06 \text{ m}$

Pedestal inner diameter $P_{idiameter} := P_{odiameter} - 2 \cdot P_{WT} = 2.38 \text{ m}$

Pedestal Second Moment of Inertia $I_{pedestal} := \frac{\pi}{64} \cdot (P_{odiameter}^4 - P_{idiameter}^4) = 0.34 \text{ m}^4$

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Distance from neutral axis $cp := \frac{P_{odiameter}}{2} = 1.25 \text{ m}$

Static Load $C_{static} := \frac{\left(\frac{YS \cdot I_{pedestal}}{cp \cdot b_{length}} \right)}{9.81 \cdot \frac{m}{s^2}} = 428.25 \text{ tonne}$

Lifting capacity $L_{capacity2} := \frac{C_{static}}{DF \cdot 1.3} = 299.48 \text{ tonne}$

The pedestal can resist much higher loads (299.48 tonnes), meaning the crane's lifting capacity is driven by 50.22 tonnes.

5.3 Governing lifting load check

The estimated dry weight of the transformers is 45 tonnes. Given the substantial weight of these transformers, the north crane must be appropriately rated to accommodate the full operating load of 45 tonnes for lifting operations. This ensures the crane is capable of safely lifting all the equipment used in the platform. As such, the maximum operating weight of the transformer is considered the governing load for crane capacity evaluation. This load is applied at 30m, which is the distance to the north laydown area. Where the transformers will be placed [6].

Boom Angle $b_{angle} := 48.19 \text{ deg}$

Boom Radius $b_{radius} := b_{length} \cdot \cos(b_{angle}) = 30 \text{ m}$

To prevent failure, the maximum stress must be less than yield strength.

Static Load $L_{staticgov} := \frac{\left(\frac{YS \cdot I_{boom}}{c \cdot b_{radius}} \right)}{9.81 \cdot \frac{m}{s^2}} = 78.72 \text{ tonne}$

Lifting capacity $L_{capacitygoc} := \frac{L_{staticgov}}{DF \cdot LCRF} = 75.33 \text{ tonne}$

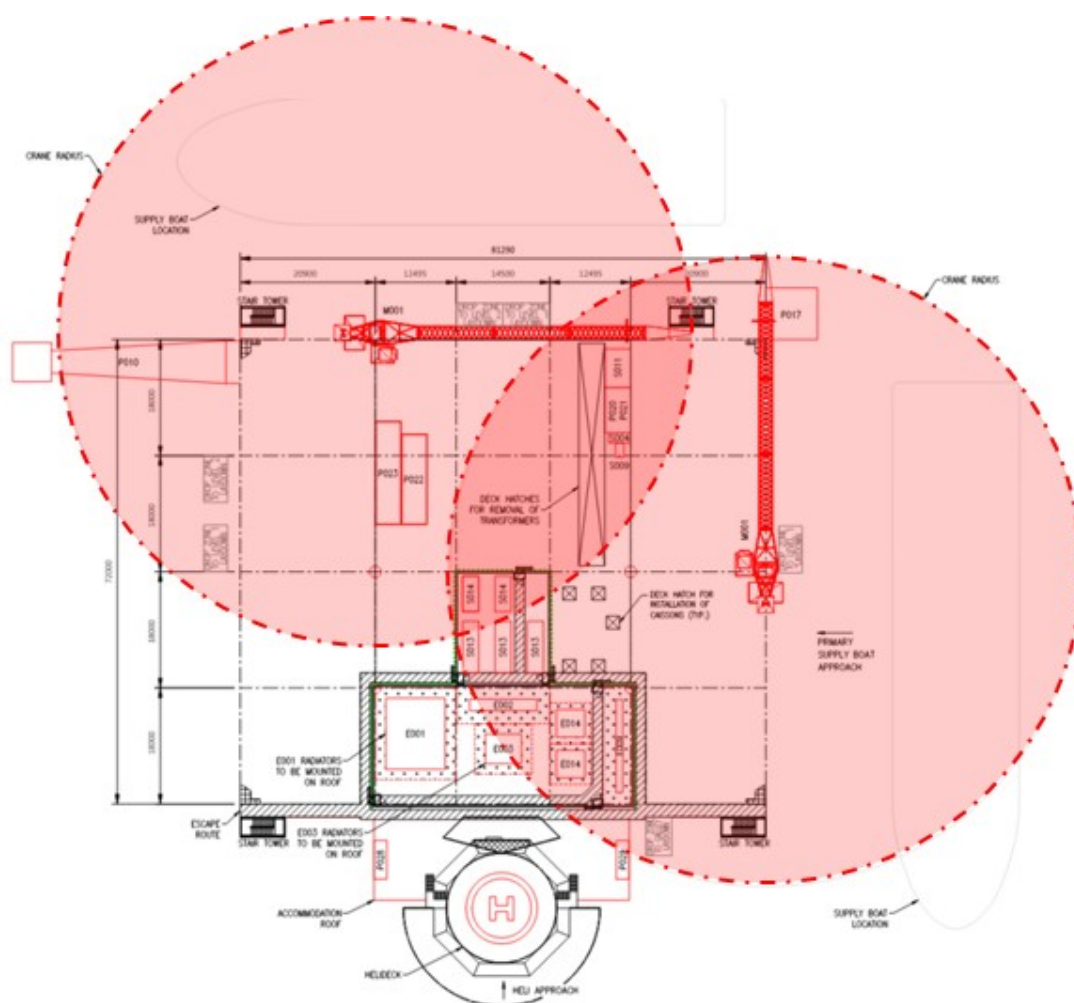
Utilisation $U_{Maxlift} := 45 \cdot \frac{\text{tonne}}{L_{capacitygoc}} = 0.6$

A crane angle of 48.2° will give a 30m boom radius to reach the north laydown area. At this length, the 45 Tonne transformer lift will contribute to 60% of the crane's total lifting capacity, remaining well within safe operational margins.

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6 Proposed Layout

The proposed layout of the pedestal cranes is the similar to the one proposed in the previous phase study [1]. The crane layout consists of two pedestal-mounted offshore cranes, each strategically positioned at a 90-degree angle relative to one another to maximise operational coverage and efficiency, covering an approximate 80% of the area, covering all four drop zones. The pedestals are positioned almost at the edges of the platform, ensuring a wide operational radius while minimising boom interference. When operating the cranes simultaneously, it's important to avoid interference between them. Cranes should also be placed away from critical evacuation paths and should have clear access for maintenance teams.



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7 Constructability/Installation Activities

The installation of offshore pedestal cranes is a comprehensive process that ensures safe and efficient lifting operations. It begins with pre-installation evaluations, which are critical for confirming that the crane's pedestal is capable of supporting the required loads and can withstand the environmental conditions it will face once operational. This step ensures that the crane is structurally sound and able to handle the significant forces it will encounter during its lifecycle. After these evaluations, the crane components are fabricated to meet rigorous industry specifications. Careful logistical planning follows to ensure the safe transport of the crane components to the offshore site, where they will be assembled and installed.

Once on-site, the crane is positioned with the use of heavy-lift equipment to ensure precision. Installation is carefully executed to meet all safety standards, followed by extensive testing to confirm the crane's ability to safely handle both static and dynamic loads. The crane's performance is also assessed under environmental conditions such as wind and wave loads, ensuring it can operate effectively in all expected conditions. This testing phase is crucial to verify that the crane is fully capable of performing the lifting operations for the platform's equipment.

After the installation and successful testing phases, the crane is handed over to the operational team. Training is provided to ensure personnel are fully equipped to use and maintain the crane safely and effectively. In addition to training, comprehensive documentation is provided, detailing the crane's specifications, operating guidelines, and maintenance requirements. A final inspection is carried out to verify that the crane complies with all safety and operational standards, ensuring it is ready for use.

The crane's design and installation process are closely aligned with the platform's operational needs, including the lifting of various equipment such as the 55MVA Electrolyser Transformers (E025) and the 66kV/11kV transformers. For heavier items like the 275kV/66kV transformers and the shunt reactor, a Heavy Lift Vessel (HLV) will be employed for removal and replacement. This structured, multi-step process ensures that the crane is not only capable of meeting the platform's lifting requirements but also operates safely, efficiently, and in full compliance with all relevant regulations. Ultimately, this approach guarantees the crane's reliability throughout its operational life on the offshore platform.

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8 Conclusion

A typical 45-meter offshore crane is considered, constructed using high-strength structural steel (S690QL) to ensure durability and load-bearing performance under harsh marine conditions. The crane features a hollow rectangular boom section with outer dimensions of 0.8 m in width and 1.2 m in height, and a uniform wall thickness of 25 mm. The supporting pedestal is 8 meters tall, with an outer diameter of 2.5 m and a wall thickness of 60 mm, providing a stable and robust foundation for the crane's operation [5].

Comprehensive structural checks are performed on the crane to assess the allowable loading limits of both the pedestal and boom. It was also verified the crane's capacity to handle the maximum expected lift loads, imposed by the heaviest equipment present on the platform (45 tonne transformer).

According to API SPEC 2C and DNV-ST-0378 standards, the crane demonstrates a lifting capacity of 50.22 tonnes, primarily governed by the boom's structural limit. It is verified that the crane can safely lift the maximum expected load to the North Laydown Area, operating at a 30 m boom radius. At this reach, the expected lift corresponds to approximately 60% of the crane's total lifting capacity, remaining well within safe operational margins.



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9 Summary

Check	Results
API SPEC 2C Lifting Capacity (Tonnes)	50.22
DNV-ST-0378 Lifting Capacity (Tonnes)	299.48
Utilisation for Max. lift (45 Tonnes)	0.60



Appendix D HVAC Requirements calculations

244-025-CAL-0001-A HVAC Requirements Calculation



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Subject:	HVAC requirements calculations	Check:	GS
		Approve:	DM
		Sheet:	1 of 24

HOP2 Concept Definition

HVAC Requirements Calculation

Calculation for Net Zero Technologies



14 May 2025 | 244-025-CAL-0001-A | HVAC Requirements Calculation

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Subject:	HVAC requirements calculations	Check:	GS
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Revisions and approvals

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MBS		GS	DM	14 May 2025



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Subject:	HVAC requirements calculations	Check:	GS
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Facility:	Ninian Central Platform	Date:	14/05/2025
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Subject:	HVAC requirements calculations	Check:	GS
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1 Introduction & purpose of calculation

The Concept Definition activity (Phase 2) on a 500MW offshore hydrogen production facility. The study will address ventilation for electrical equipment rooms, along with heat loss, airflow calculations, and the integration of ducting, chillers, and air handling units (AHUs), following ASHRAE standards. These HVAC specifications will ensure safe and efficient hydrogen production and export operations.

2 References

2.1 Reference documents / drawings

- [1] 244-021-GRL-RPT-0001-C HOP2 - Study Report.
- [2] email: HOP2 HVAC Cooling Duties for Primary Electrical Equipment, 11/04/2025.
- [3] HVAC - Practical Basic Calculations, Jurandir Primo, 2020.
- [4] 244-025-GRL-GEN-0001-A Master equipment list.xlsx
- [5] https://www.tranehk.com/files/Products/CTV-SLB056-EN.pdf?utm_.com
- [6] <https://www.carrierrentalsystems.pl/index.php/en/rental-offer/cooling/ac/ahu/84-ahu-50-500-kw?utm.com>
- [7] https://elibrary.tranetechnologies.com/public/commercial-hvac/Literature/Product%20Catalog/CLCH-PRC023K-EN_08152024.pdf

2.2 Standards and directives

- [A1] AISC 360-16: Specification for structural steel buildings (ASD)
- [F3] BS 3692:2014 ISO metrix precision hexagon bolts, screws and nuts - Specification
- [G1] BS EN 10025-2: Hot rolled products of structural steels (2019)
- [H1] ASHRAE Standards for HVAC

3 Design criteria & assumptions

- Seawater cooling design temperature is 15°C that after cooling with chillers, will make the air supply temperature of 6°C.
- Assume the electrical equipment performs best at a temperature of 20°C with +-15°C allowance.
- Assume the ambient temperature is of 8°C.
- Based on Apollo's expertise and engineering knowledge, assume 10% of the power loss of the main transformer goes to the actual transformer and 90% to the radiators.
- Sizes from chillers and AHU's are obtained from online catalogues of different manufacturers.
- Assume the platform walls are steel with minimal insulation (thin lining or spray foam), giving a U-value of 2 W/m²·K.

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4 Constants

E025 4 winding Transformer
power loss to the room
[2]

$$Q_{025} := 1.5 \text{ MW}$$

E026 Thyristor Rectifier for
Electrolysis power loss to the
room
[2]

$$Q_{026} := 0.5 \text{ MW}$$

E027 DC Switchgear for
Electrolysis power loss to the
room
[2]

$$Q_{027} := 0.25 \text{ MW}$$

E001 Main Transformer power
loss to the room (assume 10%
taken by the transformer and
90% by the radiators)
[2]

$$Q_{001} := 2.25 \cdot 0.1 \text{ MW} = 0.23 \text{ MW}$$

E028 QCOMP power loss to the
room
[2]

$$Q_{028} := 0.05 \text{ MW}$$

E005 66kV GIS power loss to
the room
[4]

$$Q_{005} := 35 \text{ kW}$$

E006 66kV NET power loss to
the room
[4]

$$Q_{006} := 18.75 \text{ kW}$$

E007 Harmonic Filter power
loss to the room
[4]

$$Q_{007} := 610 \text{ kW}$$

E008 Harmonic Filter power
loss to the room
[4]

$$Q_{008} := 64 \text{ kW}$$

E010 400V SWBD power loss
to the room
[4]

$$Q_{010} := 20 \text{ kW}$$

E011 690V SWBD power loss
to the room
[4]

$$Q_{011} := 25 \text{ kW}$$

E012 HVAC SWBD power loss
to the room
[4]

$$Q_{012} := 15 \text{ kW}$$

E015 HVAC XFMR power loss
to the room
[4]

$$Q_{015} := 100 \text{ kW}$$

E016 400V XFMR power loss
to the room
[4]

$$Q_{016} := 25 \text{ kW}$$

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E017 690V XFMR power loss
to the room
[4] $Q_{017} := 37.5 \text{ kW}$

E018 EMERG XFMR power
loss to the room
[4] $Q_{018} := 5 \text{ kW}$

E013 EMERG SWBD power
loss to the room
[4] $Q_{013} := 10 \text{ kW}$

E019 Battery room power
loss to the room
[4] $Q_{019} := 15 \text{ kW}$

E020 UPS power loss to the
room
[4] $Q_{020} := 15 \text{ kW}$

E021 Control and protection
power loss to the room
[4] $Q_{021} := 100 \text{ kW}$

E022 EMERG generator
power loss to the room
[4] $Q_{022} := 1100 \text{ kW}$

E023 Backup generator
power loss to the room
[4] $Q_{023} := 1100 \text{ kW}$

E024 Variable speed drives
power loss to the room
[4] $Q_{024} := 432 \text{ kW}$

E002 275kV GIS power loss to
the room
[4] $Q_{002} := 10 \text{ kW}$

E009 11kV SWBD power loss
to the room
[4] $Q_{009} := 30 \text{ kW}$

E014 66/11kV XFMR power
loss to the room
[4] $Q_{014} := 550 \text{ kW}$

E035 Array Aux Swbd
Transformers (5MVA, 11Kv/690V)
[4] $Q_{035} := 136 \text{ kW}$

E034 Array Auxiliary
Switchboard (690V)
[4] $Q_{034} := 50 \text{ kW}$

Room A volume
Appendix A $V_{RoomA} := 12495 \text{ mm} \cdot 18000 \text{ mm} \cdot 10000 \text{ mm} = 2249.1 \text{ m}^3$
 $V_{RoomA} = 79437.85 \text{ ft}^3$

Room A wall area
Appendix A $A_{RoomA} := 2 \cdot (12495 \cdot \text{mm} \cdot 10000 \cdot \text{mm}) \downarrow = 1059.72 \text{ m}^2$
 $+ 2 \cdot (18000 \text{ mm} \cdot 10000 \text{ mm}) \downarrow$
 $+ 2 \cdot (12495 \cdot \text{mm} \cdot 18000 \text{ mm})$



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Room B volume

Appendix A

$$V_{RoomB} := 14500 \text{ mm} \cdot 11950 \text{ mm} \cdot 10000 \text{ mm} = 1732.75 \text{ m}^3$$

$$V_{RoomB} = 61200.45 \text{ ft}^3$$

Room B wall area

Appendix A

$$A_{RoomB} := 2 \cdot (14500 \cdot \text{mm} \cdot 10000 \cdot \text{mm}) \downarrow = 875.55 \text{ m}^2$$

$$+ 2 \cdot (11950 \text{ mm} \cdot 10000 \text{ mm}) \downarrow$$

$$+ 2 \cdot (14500 \cdot \text{mm} \cdot 11950 \text{ mm})$$

Room C and C.1 volume

Appendix A

$$V_{RoomC} := 7250 \text{ mm} \cdot 18000 \text{ mm} \cdot 10000 \text{ mm} = 1305 \text{ m}^3$$

$$V_{RoomC} = 46092.39 \text{ ft}^3$$

Room C and C.1 wall area

Appendix A

$$A_{RoomC} := 2 \cdot (7250 \cdot \text{mm} \cdot 10000 \cdot \text{mm}) \downarrow = 766 \text{ m}^2$$

$$+ 2 \cdot (18000 \text{ mm} \cdot 10000 \text{ mm}) \downarrow$$

$$+ 2 \cdot (7250 \cdot \text{mm} \cdot 18000 \text{ mm})$$

Room D and D.1 volume

Appendix A

$$V_{RoomD} := 12495 \text{ mm} \cdot 18000 \text{ mm} \cdot 10000 \text{ mm} = 2249.1 \text{ m}^3$$

$$V_{RoomD} = 79437.85 \text{ ft}^3$$

Room D and D.1 wall area

Appendix A

$$A_{RoomD} := 2 \cdot (12495 \cdot \text{mm} \cdot 10000 \cdot \text{mm}) \downarrow = 1059.72 \text{ m}^2$$

$$+ 2 \cdot (18000 \text{ mm} \cdot 10000 \text{ mm}) \downarrow$$

$$+ 2 \cdot (12495 \cdot \text{mm} \cdot 18000 \text{ mm})$$

Room E volume

Appendix A

$$V_{RoomE} := 7250 \text{ mm} \cdot 14800 \text{ mm} \cdot 10000 \text{ mm} = 1073 \text{ m}^3$$

$$V_{RoomE} = 37898.19 \text{ ft}^3$$

Room E wall area

Appendix A

$$A_{RoomE} := 2 \cdot (7250 \cdot \text{mm} \cdot 10000 \cdot \text{mm}) \downarrow = 655.6 \text{ m}^2$$

$$+ 2 \cdot (14800 \text{ mm} \cdot 10000 \text{ mm}) \downarrow$$

$$+ 2 \cdot (7250 \cdot \text{mm} \cdot 14800 \text{ mm})$$

Room F volume

Appendix A

$$V_{RoomF} := (14500 + 12495) \text{ mm} \cdot 18000 \text{ mm} \cdot 10000 \text{ mm} = 4859.1 \text{ m}^3$$

$$V_{RoomF} = (1.72 \cdot 10^5) \text{ ft}^3$$

Room F wall area

Appendix A

$$A_{RoomF} := 2 \cdot ((14500 + 12495) \cdot \text{mm} \cdot 10000 \cdot \text{mm}) \downarrow = 1871.72 \text{ m}^2$$

$$+ 2 \cdot (18000 \text{ mm} \cdot 10000 \text{ mm}) \downarrow$$

$$+ 2 \cdot ((14500 + 12495) \cdot \text{mm} \cdot 18000 \text{ mm})$$

Room G volume

Appendix A

$$V_{RoomG} := (14500 + 12495 + 12495) \text{ mm} \cdot 18000 \text{ mm} \downarrow = 8529.84 \text{ m}^3$$

$$\cdot 12000 \text{ mm}$$

$$V_{RoomG} = (3.01 \cdot 10^5) \text{ ft}^3$$

Room G wall area

Appendix A

$$A_{RoomG} := 2 \cdot ((14500 + 12495) \cdot \text{mm} \cdot 10000 \cdot \text{mm}) \downarrow = 1871.72 \text{ m}^2$$

$$+ 2 \cdot (18000 \text{ mm} \cdot 10000 \text{ mm}) \downarrow$$

$$+ 2 \cdot ((14500 + 12495) \cdot \text{mm} \cdot 18000 \text{ mm})$$

Room H volume

Appendix A

$$V_{RoomH} := (12495) \text{ mm} \cdot 18000 \cdot 2 \text{ mm} \downarrow = 2788.88 \text{ m}^3$$

$$\cdot 6200 \text{ mm}$$

$$V_{RoomH} = 98502.93 \text{ ft}^3$$

Room H wall area

Appendix A

$$A_{RoomH} := 2 \cdot (12495 \cdot \text{mm} \cdot 6200 \cdot \text{mm}) \downarrow = 1500.98 \text{ m}^2$$

$$+ 2 \cdot (2 \cdot 18000 \text{ mm} \cdot 6200 \text{ mm}) \downarrow$$

$$+ 2 \cdot ((12495) \cdot \text{mm} \cdot 2 \cdot 18000 \text{ mm})$$

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Air density	$p_{Air} := 1.2 \frac{kg}{m^3}$
Specific heat of air	$c_p := 1005 \frac{J}{kg \cdot K}$
Room Temperature	$T_{Room} := 35 \text{ } ^\circ C$
Temperature entering room after going through chillers from 15 degree seawater	$T_{Entering} := 6 \text{ } ^\circ C$

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5 Cooling Load Calculation

5.1 Required cooling capacity Room A and B

Number of transformers (E025)
for electrolysis per room $N_{E025} := 1$

Number of Thyristor rectifier
(E026) per room $N_{E026} := 2$

Number of DC Switchgear
(E027) per room $N_{E027} := 2$

Number of QCOMP (E028) per
room $N_{E028} := 1$

Equipment power loss to the
room A and B $Q_{EquipmentA} := (N_{E025} \cdot Q_{025}) + (N_{E026} \cdot Q_{026}) + (N_{E027} \cdot Q_{027}) + (N_{E028} \cdot Q_{028})$

$$Q_{EquipmentA} = 3050 \text{ kW}$$

$$Q_{EquipmentA} = (1.04 \cdot 10^7) \frac{\text{BTU}}{\text{hr}}$$

$$Q_{EquipmentA} = 867.25 \text{ Ton}$$

5.2 Required cooling capacity Room C

Number of Generators
(E022/23) per room $N_{E023} := 1$

Equipment power loss to the
room C $Q_{EquipmentC} := (N_{E023} \cdot Q_{023})$

$$Q_{EquipmentC} = 1100 \text{ kW}$$

$$Q_{EquipmentC} = (3.75 \cdot 10^6) \frac{\text{BTU}}{\text{hr}}$$

$$Q_{EquipmentC} = 312.78 \text{ Ton}$$

5.3 Required cooling capacity Room C.1

Number of 690V XFMR (E017)
per room $N_{E017} := 2$

Number of 690V SWBD (E011)
per room $N_{E011} := 1$

Equipment power loss to the
room C.1 $Q_{EquipmentC.1} := (N_{E017} \cdot Q_{017}) + (N_{E011} \cdot Q_{011})$

$$Q_{EquipmentC.1} = 100 \text{ kW}$$

$$Q_{EquipmentC.1} = (3.41 \cdot 10^5) \frac{\text{BTU}}{\text{hr}}$$

$$Q_{EquipmentC.1} = 28.43 \text{ Ton}$$

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5.4 Required cooling capacity Room D

Number of EMRG XFMR (E018) $N_{E018} := 2$
per room

Number of 400V XFMR (E016) $N_{E016} := 2$
per room

Number of 400V SWBD (E010) $N_{E010} := 1$
per room

Number of EMRG SWBD (E013) $N_{E013} := 1$
per room

Equipment power loss to the room D $Q_{EquipmentD} := (N_{E018} \cdot Q_{018}) + (N_{E016} \cdot Q_{016}) + (N_{E010} \cdot Q_{010}) + (N_{E013} \cdot Q_{013})$

$$Q_{EquipmentD} = 90 \text{ kW}$$

$$Q_{EquipmentD} = (3.07 \cdot 10^5) \frac{\text{BTU}}{\text{hr}}$$

$$Q_{EquipmentD} = 25.59 \text{ Ton}$$

5.5 Required cooling capacity Room D.1

Number of Battery room (E019) $N_{E019} := 1$
per room

Number of UPS (E020) per room $N_{E020} := 1$

Number of Control and protection (E021) per room $N_{E021} := 1$

Equipment power loss to the room D.1 $Q_{EquipmentD.1} := (N_{E019} \cdot Q_{019}) + (N_{E020} \cdot Q_{020}) + (N_{E021} \cdot Q_{021})$

$$Q_{EquipmentD.1} = 130 \text{ kW}$$

$$Q_{EquipmentD.1} = (4.44 \cdot 10^5) \frac{\text{BTU}}{\text{hr}}$$

$$Q_{EquipmentD.1} = 36.96 \text{ Ton}$$

5.6 Required cooling capacity Room E

Number of Battery room (E006) $N_{E006} := 2$
per room

Equipment power loss to the room E $Q_{EquipmentE} := (N_{E006} \cdot Q_{006})$

$$Q_{EquipmentE} = 37.5 \text{ kW}$$

$$Q_{EquipmentE} = (1.28 \cdot 10^5) \frac{\text{BTU}}{\text{hr}}$$

$$Q_{EquipmentE} = 10.66 \text{ Ton}$$

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5.7 Required cooling capacity Room F

Number of Variable speed drives (E024) per room $N_{E024} := 1$

Number of HVAC XFMR (E015) per room $N_{E015} := 2$

Number of HVAC SWBD (E012) per room $N_{E012} := 1$

Number of Harmonic filters (E007) per room $N_{E007} := 2$

Number of Harmonic filters (E008) per room $N_{E008} := 2$

Number of 66kV GIS (E005) per room $N_{E005} := 1$

Equipment power loss to the room F $Q_{EquipmentF} := (N_{E024} \cdot Q_{024}) + (N_{E015} \cdot Q_{015}) + (N_{E012} \cdot Q_{012}) + (N_{E007} \cdot Q_{007}) + (N_{E008} \cdot Q_{008}) + (N_{E005} \cdot Q_{005})$

$$Q_{EquipmentF} = 2030 \text{ kW}$$

$$Q_{EquipmentF} = (6.93 \cdot 10^6) \frac{\text{BTU}}{\text{hr}}$$

$$Q_{EquipmentF} = 577.22 \text{ Ton}$$

5.7 Required cooling capacity Room G

Number of Main transformer (E001) per room $N_{E001} := 1$

Number of 275kV GIS (E002) per room $N_{E002} := 1$

Number of 66/11kV XFMR (E014) per room $N_{E014} := 2$

Number of 11kV SWBD (E009) per room $N_{E009} := 1$

Equipment power loss to the room G $Q_{EquipmentG} := (N_{E001} \cdot Q_{001}) + (N_{E002} \cdot Q_{002}) + (N_{E014} \cdot Q_{014}) + (N_{E009} \cdot Q_{009})$

$$Q_{EquipmentG} = 1365 \text{ kW}$$

$$Q_{EquipmentG} = (4.66 \cdot 10^6) \frac{\text{BTU}}{\text{hr}}$$

$$Q_{EquipmentG} = 388.13 \text{ Ton}$$

5.7 Required cooling capacity Room H

Number of transformer(E035) per room $N_{E035} := 8$

Number of switchboard (E034) per room $N_{E034} := 1$

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Equipment power loss to the room D

$$Q_{EquipmentH} := (N_{E035} \cdot Q_{035}) + (N_{E034} \cdot Q_{034})$$

$$Q_{EquipmentH} = 1138 \text{ kW}$$

$$Q_{EquipmentH} = (3.88 \cdot 10^6) \frac{BTU}{hr}$$

$$Q_{EquipmentH} = 323.58 \text{ Ton}$$

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6 Heat loss per room due to conduction

Thermal transmittance of
offshore walls
[H1]

$$U := 2 \frac{W}{m^2 \cdot K}$$

6.1 Room A

Heat loss room A

$$Q_{lossA} := U \cdot A_{RoomA} \cdot (298 \text{ K}) = 631.59 \text{ kW}$$

Total Heat gain

$$Q_{TotalA} := Q_{EquipmentA} - Q_{lossA} = 2418.41 \text{ kW}$$

$$Q_{TotalA} = (8.25 \cdot 10^6) \frac{BTU}{hr}$$

$$Q_{TotalA} = 687.66 \text{ Ton}$$

6.2 Room B

Heat loss room B

$$Q_{lossB} := U \cdot A_{RoomB} \cdot (298 \text{ K}) = 521.83 \text{ kW}$$

Total Heat gain

$$Q_{TotalB} := Q_{EquipmentA} - Q_{lossB} = 2528.17 \text{ kW}$$

$$Q_{TotalB} = (8.63 \cdot 10^6) \frac{BTU}{hr}$$

$$Q_{TotalB} = 718.87 \text{ Ton}$$

6.3 Room C

Heat loss room C

$$Q_{lossC} := U \cdot A_{RoomC} \cdot (298 \text{ K}) = 456.54 \text{ kW}$$

Total Heat gain

$$Q_{TotalC} := Q_{EquipmentC} - Q_{lossC} = 643.46 \text{ kW}$$

$$Q_{TotalC} = (2.2 \cdot 10^6) \frac{BTU}{hr}$$

$$Q_{TotalC} = 182.97 \text{ Ton}$$

6.4 Room C.1

Heat loss room C.1

$$Q_{lossC.1} := U \cdot A_{RoomC} \cdot (298 \text{ K}) = 456.54 \text{ kW}$$

Total Heat gain

$$Q_{TotalC.1} := Q_{EquipmentC.1} - Q_{lossC.1} = -356.54 \text{ kW}$$

$$Q_{TotalC.1} = -1.22 \cdot 10^6 \frac{BTU}{hr}$$

$$Q_{TotalC.1} = -101.38 \text{ Ton}$$

Since the total cooling required is negligible, it is assumed that the room won't need cooling.

6.5 Room D

Heat loss room D

$$Q_{lossD} := U \cdot A_{RoomD} \cdot (298 \text{ K}) = 631.59 \text{ kW}$$

Total Heat gain

$$Q_{TotalD} := Q_{EquipmentD} - Q_{lossD} = -541.59 \text{ kW}$$

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$$Q_{TotalD} = -1.85 \cdot 10^6 \frac{BTU}{hr}$$

$$Q_{TotalD} = -154 \text{ Ton}$$

Since the total cooling required is negative, it is assumed that the room won't need cooling.

6.6 Room D.1

Heat loss room D.1

$$Q_{lossD.1} := U \cdot A_{RoomD} \cdot (298 \text{ K}) = 631.59 \text{ kW}$$

Total Heat gain

$$Q_{TotalD.1} := Q_{EquipmentD.1} - Q_{lossD.1} = -501.59 \text{ kW}$$

$$Q_{TotalD.1} = -1.71 \cdot 10^6 \frac{BTU}{hr}$$

$$Q_{TotalD.1} = -142.63 \text{ Ton}$$

Since the total cooling required is negligible, it is assumed that the room won't need cooling.

6.7 Room E

Heat loss room E

$$Q_{lossE} := U \cdot A_{RoomE} \cdot (298 \text{ K}) = 390.74 \text{ kW}$$

Total Heat gain

$$Q_{TotalE} := Q_{EquipmentE} - Q_{lossE} = -353.24 \text{ kW}$$

$$Q_{TotalE} = -1.21 \cdot 10^6 \frac{BTU}{hr}$$

$$Q_{TotalE} = -100.44 \text{ Ton}$$

Since the total cooling required is negative, it is assumed that the room won't need cooling.

6.8 Room F

Heat loss room F

$$Q_{lossF} := U \cdot A_{RoomF} \cdot (298 \text{ K}) = 1115.55 \text{ kW}$$

Total Heat gain

$$Q_{TotalF} := Q_{EquipmentF} - Q_{lossF} = 914.45 \text{ kW}$$

$$Q_{TotalF} = (3.12 \cdot 10^6) \frac{BTU}{hr}$$

$$Q_{TotalF} = 260.02 \text{ Ton}$$

6.9 Room G

Heat loss room G

$$Q_{lossG} := U \cdot A_{RoomG} \cdot (298 \text{ K}) = 1115.55 \text{ kW}$$

Total Heat gain

$$Q_{TotalG} := Q_{EquipmentG} - Q_{lossG} = 249.45 \text{ kW}$$

$$Q_{TotalG} = (8.51 \cdot 10^5) \frac{BTU}{hr}$$

$$Q_{TotalG} = 70.93 \text{ Ton}$$

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6.10 Room H

Heat loss room H

$$Q_{lossH} := U \cdot A_{RoomH} \cdot (298 \text{ K}) = 894.58 \text{ kW}$$

Total Heat gain

$$Q_{TotalH} := Q_{EquipmentH} - Q_{lossH} = 243.42 \text{ kW}$$

$$Q_{TotalH} = (8.31 \cdot 10^5) \frac{BTU}{hr}$$

$$Q_{TotalH} = 69.21 \text{ Ton}$$



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7 Required Airflow Calculation

7.1 Room A

Required Airflow Room A

$$CFM_{RoomA} := \frac{\langle Q_{TotalA} \rangle}{(T_{Room} - T_{Entering}) \cdot c_p \cdot \rho_{Air}}$$

$$CFM_{RoomA} = 146539.26 \text{ CFM}$$

7.2 Room B

Required Airflow Room B

$$CFM_{RoomB} := \frac{\langle Q_{TotalB} \rangle}{(T_{Room} - T_{Entering}) \cdot c_p \cdot \rho_{Air}}$$

$$CFM_{RoomB} = 153190.31 \text{ CFM}$$

7.3 Room C

Required Airflow Room C

$$CFM_{RoomC} := \frac{\langle Q_{TotalC} \rangle}{(T_{Room} - T_{Entering}) \cdot c_p \cdot \rho_{Air}}$$

$$CFM_{RoomC} = 38989.61 \text{ CFM}$$

7.6 Room F

Required Airflow Room F

$$CFM_{RoomF} := \frac{\langle Q_{TotalF} \rangle}{(T_{Room} - T_{Entering}) \cdot c_p \cdot \rho_{Air}}$$

$$CFM_{RoomF} = 55409.84 \text{ CFM}$$

7.6 Room G

Required Airflow Room G

$$CFM_{RoomG} := \frac{\langle Q_{TotalG} \rangle}{(T_{Room} - T_{Entering}) \cdot c_p \cdot \rho_{Air}}$$

$$CFM_{RoomG} = 15115.3 \text{ CFM}$$

7.7 Room H

Required Airflow Room H

$$CFM_{RoomH} := \frac{\langle Q_{TotalH} \rangle}{(T_{Room} - T_{Entering}) \cdot c_p \cdot \rho_{Air}}$$

$$CFM_{RoomH} = 14749.45 \text{ CFM}$$

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8 Ducting requirements

It is assumed that the HVAC ducting in the platform will be square.

Application	Recommended Velocity (FPM)
Main Supply Duct	1,200 – 2,000
Branch Ducts	800 – 1,200
Return Ducts	800 – 1,500
Exhaust Ducts	1,500 – 2,000
High-Velocity Systems	2,500 – 3,500

[H1]

Exhaust duct velocity $FPM_{exhaust} := 2000 \cdot \frac{ft}{min}$

8.1 Room A

Duct sizing room A

$$DS_{RoomA} := \frac{CFM_{RoomA}}{FPM_{exhaust}} = 73.27 \text{ ft}^2$$

8.2 Room B

Duct sizing room B

$$DS_{RoomB} := \frac{CFM_{RoomB}}{FPM_{exhaust}} = 76.6 \text{ ft}^2$$

8.3 Room C

Duct sizing room C

$$DS_{RoomC} := \frac{CFM_{RoomC}}{FPM_{exhaust}} = 19.49 \text{ ft}^2$$

8.5 Room F

Duct sizing room F

$$DS_{RoomF} := \frac{CFM_{RoomF}}{FPM_{exhaust}} = 27.7 \text{ ft}^2$$

8.6 Room G

Duct sizing room G

$$DS_{RoomG} := \frac{CFM_{RoomG}}{FPM_{exhaust}} = 7.56 \text{ ft}^2$$

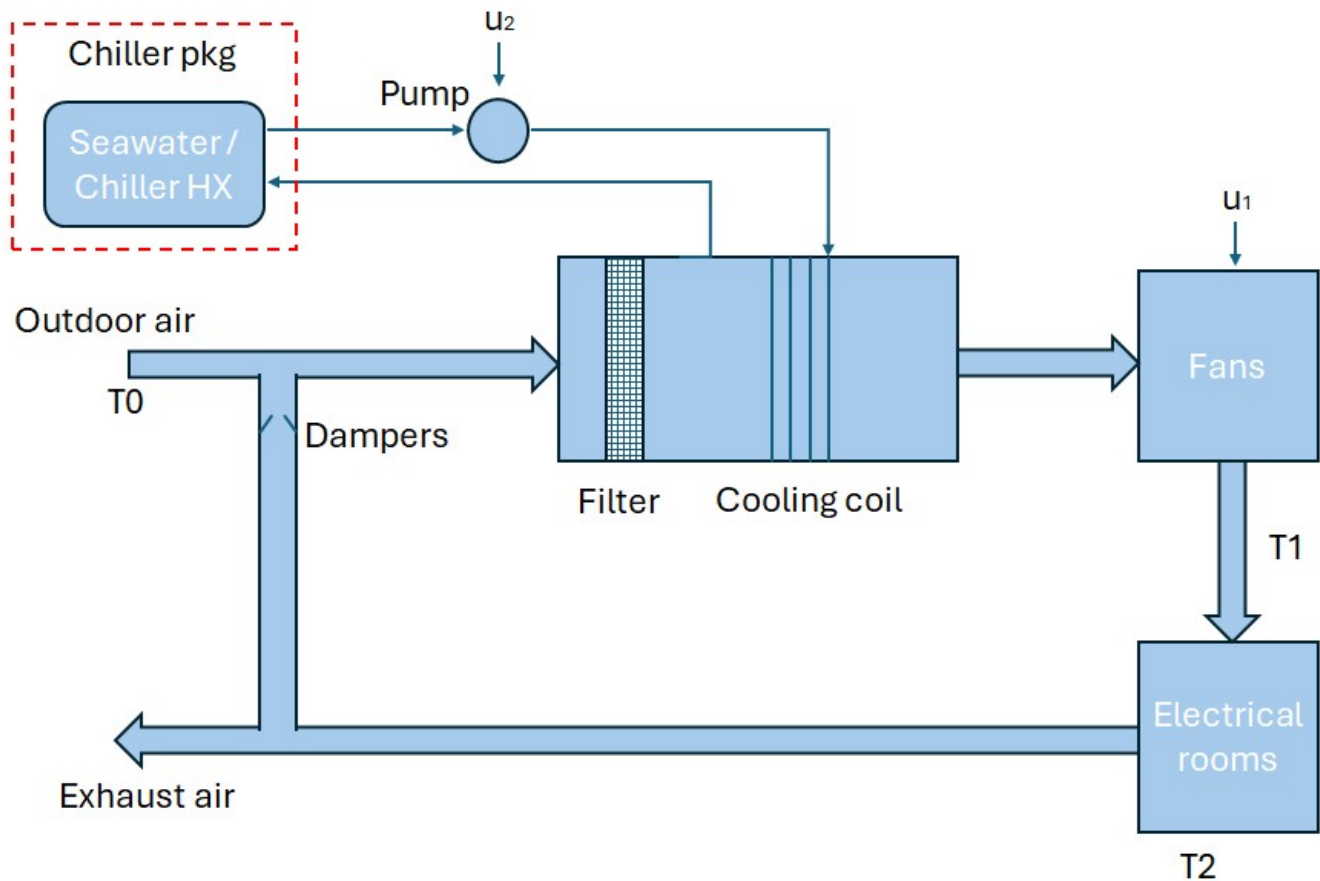
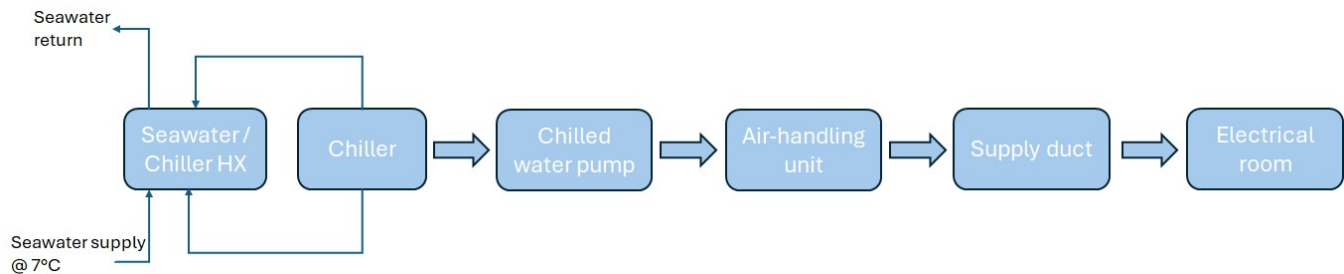
8.7 Room H

Duct sizing room H

$$DS_{RoomH} := \frac{CFM_{RoomH}}{FPM_{exhaust}} = 7.37 \text{ ft}^2$$

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9 HVAC Block Flow Diagram (BFD)



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10 Conclusion & Summary

Different manufacturers are considered for the chillers and AHU's. This was only done in order to estimate the size, ratings and the weight of these packages. 125,000 CFM Trane Performance Climate Changer AHUs [7] and 60,000 CFM Carrier 39HQ AHU [6].

It is assumed a standard duct size of 30 ft², considered to be the maximum duct size for the system, this is due to size restrictions and routing convenience [H1]. If the duct size of the room is found to be lower than 30 ft², the duct size will be taken as calculated. If it is bigger, the ducting of the room would be divided into several 30 ft² ducts.

10.1 Total chiller cooling requirements

Number of rooms A and B
(assume maximum 10 rooms working full load at the same time)

$$N_{A\&B} := 10$$

Number of rooms C

$$N_C := 1$$

Number of rooms C.1

$$N_{C.1} := 1$$

Number of rooms F

$$N_F := 1$$

Number of rooms G

$$N_G := 1$$

Number of rooms H

$$N_H := 1$$

Assuming not all the electrical components will work at 100% all the time, a safe factor of 90% is applied.

$$\text{Total cooling requirement} \quad Q_{Total} := 0.9 \cdot \left(N_{A\&B} \cdot Q_{TotalA} + N_C \cdot Q_{TotalC} + N_F \cdot Q_{TotalF} + N_G \cdot Q_{TotalG} + N_H \cdot Q_{TotalH} \right)$$

$$Q_{Total} = 6713.78 \text{ Ton}$$

The chiller that would fit with the mezzanine deck size restrictions is a 1500 ton 50Hz CenTraVac centrifugal Simplex chiller [5]. With these chiller specifications, the platform will require the following number of chillers to provide the desired cooling:

1500 ton Chillers requires

$$N_{Chillers} := \frac{Q_{Total}}{1500 \cdot \text{Ton}} = 4.48$$

5 x 1500 ton CenTraVac centrifugal Simplex chiller will be required to provide the adequate cooling to the platform's electrical equipment.

10.2 Room A Cooling, Ducting and respective AHU's

For HVAC control purposes, the following cooling should be provided to room A. Also, for ducting layout and routing, the following ducting size should be considered.

Total cooling load room A

$$Q_{TotalA} = \left(8.25 \cdot 10^6 \right) \frac{\text{BTU}}{\text{hr}}$$

$$Q_{EquipmentA} = 867.25 \text{ Ton}$$

A standard duct size of 2.5 ft² is considered as the maximum duct size for the system due to routing convenience. If the

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Duct sizing room A

$$DS_{RoomA} = 73.27 \text{ ft}^2$$

Number of 30 ft² ducts room A

$$N_{ductsA} := \frac{DS_{RoomA}}{30 \text{ ft}^2} = 2.44$$

3 x 30 ft² ducts will be needed for each of the Rooms A.

Total required Airflow for
Rooms A and B

$$CFM_{TotalRoomA} := CFM_{RoomA} \cdot N_{A\&B} = 1465392.64 \text{ CFM}$$

Number of 125000 CFM AHU
for Rooms A and B

$$AHU_{NRoomA} := \frac{CFM_{TotalRoomA}}{125000 \cdot CFM} = 11.72$$

12 x 125,000 CFM Trane Performance Climate Changer AHU are needed to provide the desired airflow to Rooms A and B. Since there are 12 rooms, one AHU will be placed in each room to provide the required air change.

10.3 Room B Cooling, Ducting and respective AHU's

For HVAC control purposes, the following cooling should be provided to room B. Also, for ducting layout and routing, the following ducting size should be considered.

Total cooling load room B

$$Q_{EquipmentA} = (1.04 \cdot 10^7) \frac{BTU}{hr}$$

Duct sizing room B

$$DS_{RoomB} = 76.6 \text{ ft}^2$$

Number of 30 ft² ducts room B

$$N_{ductsB} := \frac{DS_{RoomB}}{30 \text{ ft}^2} = 2.55$$

3 x 30 ft² duct will be needed for Room B.

10.4 Room C Cooling, Ducting and respective AHU's

For HVAC control purposes, the following cooling should be provided to room C. Also, for ducting layout and routing, the following ducting size should be considered.

Total cooling load room C

$$Q_{EquipmentC} = (3.75 \cdot 10^6) \frac{BTU}{hr}$$

Duct sizing room C

$$DS_{RoomC} = 19.49 \text{ ft}^2$$

A single 20 ft² duct will be needed for Room C.

Total required Airflow for
Room C

$$CFM_{TotalRoomC} := CFM_{RoomC} \cdot N_C = 38989.61 \text{ CFM}$$

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10.6 Room C.1, D, D.1 and E

Since the cooling required of these rooms will result in negative or negligible. No cooling will be required for these rooms.

In case of extreme cold or hot weather conditions, a redundant 60,000 CFM will be use to either heat or cool these rooms.

10.7 Room F Cooling, Ducting and respective AHU's

For HVAC control purposes, the following cooling should be provided to room F. Also, for ducting layout and routing, the following ducting size should be considered.

Total cooling load room F

$$Q_{EquipmentF} = (6.93 \cdot 10^6) \frac{BTU}{hr}$$

Duct sizing room F

$$DS_{RoomF} = 27.7 \text{ ft}^2$$

A single 28 ft2 duct will be needed the Room F.

Total required Airflow for Room F

$$CFM_{TotalRoomF} := CFM_{RoomF} \cdot N_F = 55409.84 \text{ CFM}$$

10.8 Room G Cooling, Ducting and respective AHU's

For HVAC control purposes, the following cooling should be provided to room G. Also, for ducting layout and routing, the following ducting size should be considered.

Total cooling load room G

$$Q_{EquipmentG} = (4.66 \cdot 10^6) \frac{BTU}{hr}$$

Duct sizing room G

$$DS_{RoomG} = 7.56 \text{ ft}^2$$

A single 8 ft2 duct will be needed for each of the Room G.

Total required Airflow for Room G

$$CFM_{TotalRoomG} := CFM_{RoomG} \cdot N_G = 15115.3 \text{ CFM}$$

10.9 Room H Cooling, Ducting and respective AHU's

For HVAC control purposes, the following cooling should be provided to room HAlso, for ducting layout and routing, the following ducting size should be considered.

Total cooling load room H

$$Q_{EquipmentH} = (3.88 \cdot 10^6) \frac{BTU}{hr}$$

Duct sizing room H

$$DS_{RoomH} = 7.37 \text{ ft}^2$$

A single 8 ft2 duct will be needed for each of the Room H.

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Total required Airflow for
Room H

$$CFM_{TotalRoomH} := CFM_{RoomH} \cdot N_H = 14749.45 \text{ CFM}$$

For HVAC purposes, the following cooling should be provided to rooms C, F, G and D.

Total required Airflow for
Room C, F, G and H

$$CFM_{TotalCFGH} := CFM_{TotalRoomC} + CFM_{TotalRoomC} \downarrow = 107843.96 \text{ CFM} \\ + CFM_{TotalRoomG} + CFM_{TotalRoomH}$$

Total number of 60,000 AHUs
for Rooms C, F and G

$$N_{AHUs} := \frac{CFM_{TotalCFGH}}{60000 \cdot CFM} = 1.8$$

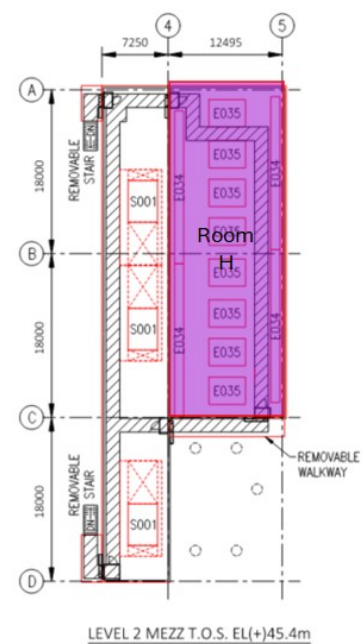
2 x 60,000 CFM Carrier 39HQ AHUs are needed to provide the desired air flow to Rooms C, F and G.

10.10 HVAC Equipment Summary

- 5 x 1500 ton CenTraVac centrifugal Simplex chiller [5]
- 12 x 125,000 CFM Trane Performance Climate Changer AHU (15 x 3.8 x 2.5 m and 14000 kg) [7]
- 3 x 60,000 CFM Carrier 39HQ AHUs (8 x 2.5 x 2m and 2700 kg) [6]
- Room A: 2 x 30 ft2 duct
- Room B: : 2 x 30 ft2 duct
- Room C: A single 22 ft2 duct
- Room F: A single 28 ft2 duct
- Room G: A single 8 ft2 duct
- Room G: A single 8 ft2 duct

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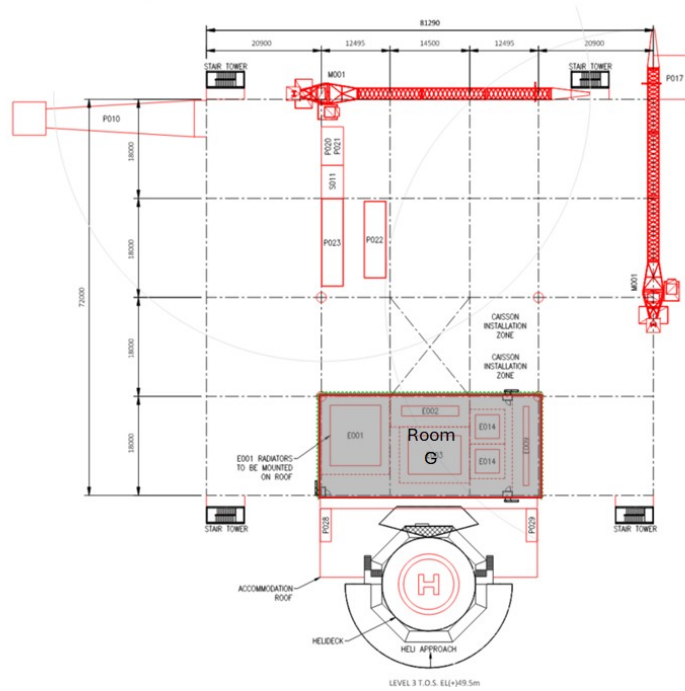
Appendix A - Room naming





Engineering tomorrow, today.

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Appendix E Process Equipment List

Heat Exchangers

[illegible]

						Notes	CLIENT NZTC PROJECT HOP2 Concept Definition
B	KM	LH	KM	19/05/25	Incorporated Client Comments	1. Heat exchanger sizing and dimensions by vendor, preliminary process data presented only.	DOC. TITLE Process Equipment List
A	KM	LH	KM	18/03/25	First Issue	2. Alternative flowrate case in Remarks section is minimum load, exchangers to operate effectively both at full and min. load	
REV	ORIG	CHECK	APP.	DATE	REVISIONS	3. E1402 and E-1403 have been presented per compressor train 3 x 50%.	
							DOC. NO 244-025-PRO-PEL-0001 REV. SHEET 2 OF 7 B

Compressors																					
	Tag	Compressor Name Description			Contents	Phase	Flow Total kg/hr	Op Temp. °C	Suction Press. barg	Disch, Press. barg	Density kg/m3	Viscosity cP	Cp kJ/kgK	No. Compr. Operating	Cp/Cv	Flow Per Compr. kg/hr	Abs. P Per Comp kW	Motor P Per Comp. kW	Remarks		
	A1402	Hydrogen compressor package Note 3			Hydrogen	V	10,000	30.0	28.0	103.0	2.30	0.01	14.2	2	1.42	5,000	3056	3420	N operating + 1 spare. Values based on preliminary		
							Note 1, 2														vendor specification, see Ref 14.
										Notes 1. 10,000kg/hr total, 5000kg/hr per 50% compressor train 2. Minimum H2 forward flow turndown 10% required i.e. 1000kg/hr. 3. Data for total input/output to/from package. Internally, the compressor will comprise 2 stages in series with intercooling and product cooling in vendor's scope.						CLIENT NZTC PROJECT HOP2 Concept Definition					
	B	KM	LH	KM	19/05/25	Incorporated client comments															
	A	KM	LH	KM	18/03/25	First Issue															
	REV	ORIG	CHECK	APP.	DATE	REVISIONS															
																DOC. TITLE Process Equipment List					
																DOC. NO		244-025-PRO-PEL-0001		REV.	
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LINE SIZING PROCESS DATA																					
No.	Str. No	Line No. / Description	Contents	State	Flow kg/hr	Op Temp. °C	Op Press. barg	Density kg/m³	Visc. cP	Line Size mm	Line size NPS in	Length NOTE 1 m	Line vel m/s	pv² kg/m.s²	Press. Drop bar	Max vel m/s	Line Sch	Remarks			
1	001	18"-SW1522-1101-N	Seawater (NOTE 4)	L	2,642,737	15.0	5.0	1024.6	1.20	450	18	125	4.75	-	0.452	5.0	STD	Length is for 5 total in parallel			
2	002	36"-SW1523-1102-N	Seawater (NOTE 4)	L	10,570,948	15.1	2.0	1024.5	1.20	900	36	50	4.55	-	0.071	5.0	STD				
3	003	30"-SW1523-1103-N	Seawater	L	7,510,948	15.1	2.0	1024.5	1.20	750	30	75	4.70	-	0.141	5.0	STD				
4	004	24"-SW1523-1104-N	Seawater	L	3,060,000	15.1	1.0	1024.4	1.20	600	24	100	3.03	-	0.106	5.0	STD				
5	005	16"-DW1521-1201-PP	Demin water	L	1,383,005	60.0	0.2	980.4	0.46	400	16	25	3.32	-	0.048	3.7	STD				
6	006	16"-DW1521-1202-PP	Demin water	L	1,383,005	60.1	9.0	980.7	0.46	400	16	25	3.32	-	0.048	3.7	STD				
7	007	16"-DW1521-1203-PP	Demin water	L	1,383,005	60.1	8.0	980.7	0.46	400	16	150	3.32	-	0.286	3.7	STD				
8	008	24"-SW1523-1105-N	Seawater	L	3,573,988	15.1	2.0	1024.5	1.20	600	24	75	3.54	-	0.107	3.7	STD				
9	009	12"-SW1523-1106-N	Seawater	L	830,662	15.1	2.0	1024	1.20	300	12	75	3.12	-	0.187	3.7	STD				
10	010	24"-SW1523-1107-N	Seawater	L	3,106,298	15.1	2.0	1024	1.20	600	24	100	3.07	-	0.109	3.7	STD				
11	011	36"-SW1523-1108-N	Seawater	L	7,510,948	25.1	1.0	1017	0.93	900	36	75	3.26	-	0.054	3.7	STD				
12	012	8"-PH3021-1401-PP	Hydrogen	V	10,000	65.0	29.0	2.1	0.01	200	8	150	37.09	2930	0.145	45	10	Common			
13	013	8"-PH3021-1402-PP	Hydrogen	V	10,000	30.0	28.0	2.3	0.01	200	8	25	34.39	2717	0.022	45	10	Common			
14	014	Vendor scope, not sized																			
15	015	Vendor scope, not sized																			
16	016	Vendor scope, not sized																			
17	017	6"-PH9021-1404-PP	Hydrogen	V	10,000	60.0	102.0	7.2	0.01	150	6	100	22.86	3771	0.187	45	80	Common			
18	018	6"-PH9021-1405-PP HOLD 1	Hydrogen	V	10,000	60.1	100.0	7.1	0.01	150	6	25	23.30	3845	0.048	45	80				
19	019	36"-XY1524-1701-PP	Oxygen	V	79,200	65.0	0.5	1.6	0.02	900	36	100	21.27	738	0.005	30	10	Oxygen service, reduced velocity			
20	020	36"-XY1524-1702-N	Oxygen	M	79,200	40.0	0.2	1.5	0.02	900	36	25	22.89	-	0.001	30	10	Oxygen service, reduced velocity			
21	021	36"-XY1524-1703-N	Oxygen	V	75,970	40.0	0.2	1.5	0.02	900	36	25	22.89	762	0.001	30	10	Oxygen service, reduced velocity			
22	022	Below min size limit.																			
23	023	36"-CM1501-1501-N	TEG/Water	L	7,237,924	47.5	4.5	1042	5.50	750	30	250	4.45	-	0.488	5.0	STD				
24	024	Same as 023																			
25	025	Same as 023																			
26	026	Same as 023																			
27	027	Same as 023																			
28	028	Same as 023																			
29	029	10"-CM1501-1502-N	TEG/Water	L	487,924	42.0	3.5	1046	6.40	250	10	100	2.55	-	0.253	3.7	40				
30	030	Same as 029																			
31	031	6"-CM1501-1503-N	TEG/Water	L	46,785	40.0	0.8	1048	6.79	150	6	25	0.66	-	0.010	2.1	40	Per train			
32	032	6"-CM1501-1504-N	TEG/Water	L	77,836	40.0	0.8	1048	6.79	150	6	25	1.11	-	0.026	2.1	40	Per train			
33	033	6"-CM1501-1505-N	TEG/Water	L	80,708	40.0	0.8	1048	6.79	150	6	25	1.15	-	0.028	2.1	40				
34	034	8"-CM1501-1506-N	TEG/Water	L	157,974	40.0	0.8	1048	6.79	200	8	150	1.30	-	0.147	2.5	40				
35	FLARE	6"-FL1521-1601-N	Hydrogen	V	10,000	60.0	3.0	0.3	0.01	150	6	100	477.17	63754	2.816	N/A	5	sized for M<0.5. Total length 300m			
							Notes 1. All line lengths measured from preliminary plot plan (Ref 15) plus design margin 2. Only lines 6" and above sized at this stage 3. Unique line numbers only taken at spec or size breaks 4. 18" seawater line per pump/filter pair. 36" common header downstream of filter. HOLDs 1. Pipe spec for hydrogen export line tbc.												CLIENT NZTC PROJECT HOP2 Concept Definition		
	B	KM	LH	KM	19/05/25	Incorporated client comments															
	A	KM	LH	KM	18/03/25	First Issue															
	REV	ORIG	CHECK	APP.	DATE	REVISIONS													DOC. TITLE Process Equipment List		
																			DOC. NO 244-025-PRO-PEL-0001		REV. B
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Pumps																			
No.	Pump Tag	Pump Name Description			Contents	Phase	Flow Total kg/hr	Op Temp. °C	Suction Press. barg	Disch, Press. barg	Density kg/m3	Viscosity cP	dH m	No. Pumps Operating	Margin Flow %	Flow Per Pump kg/hr (Note 2)	Hyd. P Per Pump kW	Abs. P Per Pump kW	Remarks
1	P-1101	Seawater Lift Pumps P-1101			Seawater	L	10,570,948	15.0	0.0	5.0	1024.6	1.2	49.74	4	10%	2,907,011	394.05	525.39	N operating + 1 spare. Indiv. Pumps lines 450mm, Note 3
2	P-1201	Demin Water Charge Pumps P-1201			Demin. Water	L	1,383,005	60.0	0.5	9.5	980	0.46	93.57	1	10%	1,521,306	387.92	517.22	N operating + 1 spare. Indiv. Pumps lines 300mm
3	P-1501	Cooling Medium Circ. Pumps P-1501			30wt% TEG	L	7,237,924	47.5	0.5	4.5	1105	2.10	36.9	4	10%	1,990,429	200.14	266.86	N operating + 1 spare. Indiv. Pumps lines 450mm
4	P-1701	Oxygen KO Drum Sump Pump			Demin. water	L	3,230	40.0	0.0	2.0	996	0.65	20.47	1	10%	3,553	0.20	0.55	No installed spare. Lines <<6" not sized.
						Notes 1. DELETED. 2. Flows per pump include 10% flow margin 3. Seawater lift pump P-1101 to be submerged in caisson to required NPSH 4. Pump mech. efficiency basis: <2kW 50%, <200kW 65%, <1000kW 75%, >1000kW 85%.						CLIENT NZTC PROJECT HOP2 Concept Definition DOC. TITLE Process Equipment List DOC. NO 244-025-PRO-PEL-0001 SHEET 5 OF 7						REV. B	

Vessels																							
Stream No.	Tag	Compressor Name Description			Contents	Phase	Inlet flow Total kg/hr	Op Temp. °C	Op. Press. barg	Liquid properties			Vapour properties			Tan-tan L or H m	Diameter m	Volume m3	L/D	Remarks			
										Density kg/m3	Flow kg/hr	Mw kg/kmol	Density kg/m3	Flow kg/hr	Mw kg/kmol								
005	T-1201	Array Feed Water Tank			Demin. Water	L	1,383,005	60.0	0.2	980	1,383,005	18.0		-		4.0	3.8	45.4	1.1	Client spec 45m3 Ref 1			
028	T-1501	TEG System Expansion Vessel			30vol% TEG	L	7,237,924	47.5	0.8	1041	7,237,924	57.7		-		4.0	3.0	28.3	1.3	Estimated TEG volume <350m³, sized for 2x thermal exp.			
035	V-1601	Flare KO Drum			H2 + N2	V	10,000	40.0	0.8	980	13	18.0	1047.9	10,000	2	5.0	2.5	24.5	2.0	Sizing based on nominal liquid (normally no liquid)			
020	V-1701	Oxygen Vent KO Drum			Oxygen + water	M	79,200	40.0	0.2	996	3230	18.0	1.5	75,970	31	8.0	4.3	113.5	1.9	Sizing based on liquid KO and min L/D ratio			
											Notes										CLIENT		
	B	KM	LH	KM	19/05/25	Incorporated client comments															NZTC		
	A	KM	LH	KM	18/03/25	First Issue															PROJECT		
	REV	ORIG	CHECK	APP.	DATE	REVISIONS															HOP2 Concept Definition		
																					DOC. TITLE		
																					Process Equipment List		
											DOC. NO					244-025-PRO-PEL-0001					REV.		
											SHEET					6 OF 7					B		

Packages																		
No.	Tag	Compressor Name Description			Contents	Phase	Sizing case	Op Temp. °C	Flow rate Sizing kg/hr	Op Press. barg	Density kg/m3	Velocity m/s	Diameter mm	Height m	Mach No.			Remarks
	A-1601	Flare package			Hydrogen	V	Blocked outlet	60.0	10000	3.5	0.32	230	450	36.4	0.2			Flare stack sizing basis Mach 0.2. Note 2
	A-1101	Chlorination package			14wt% hypochlorite	L	5mg/L full intake flow	15.0	368.5	5			Note 1	Note 1				Note 1, Note 4
	A-1102	Dechlorination package			Solid sodium bisulph	L	5mg/L of desal feed	15.0	14.9	5			Note 1	Note 1				Consumed solid, Note 1, 4
	A-1801	Nitrogen package			min 95%	V	Typical demand	15.0	132 Nm3/hr	7			Note 1	Note 1				Note 1
	A-1901	Instrument air package			Class 0 dry air	V	Typical demand	15.0	600 Nm3/hr	8			Note 1	Note 1				Note 1
	F-1001	Coarse seawater filters (Note 3)			Seawater	L	1 + 1 per pump	15.0	2,907,011	5	1025		1000					Inc 10% margin on flow, per filter, Note 3
										Notes 1. vendor to confirm physical sizes of dosing packages 2. Flare dimensions are for the flare stack to 1.52kW/m2 radiation contour. 3. Seawater filters 2 x 100% per pump (duty + standby), x 5 pumps. 10 off filters total installed. 4. Chlorination and dechlorination packages each equipped with 24 hour day tank for local storage of dosing chemicals.						CLIENT NZTC PROJECT HOP2 Concept Definition		
	B	KM	LH	KM	19/05/25	Incorporated client comments												
	A	KM	LH	KM	18/03/25	First Issue										DOC. TITLE Process Equipment List		
	REV	ORIG	CHECK	APP.	DATE	REVISIONS												
																SHEET 7 OF 7		



Appendix F Compressor Datasheet

244-025-PCS-DAT-0001 Compressor unit datasheet

HOP2 Concept Definition: Compressors Datasheet

DOC NO:
244-0025-PCS-DAT-0001

Revision:	Issue Description:	Issue Date:	Prepared:	Checked:	Approved:
A1	Issued For Comment	30/04/2025	MBS	DM	DM
B1	Issued For Use	27/08/2025	MBS	DM	DM

Client:	Net Zero Tenchnology
Project Name:	HOP2 Concept Definition
Document Title:	Compressors Datasheet
Document Number:	244-0025-PCS-DAT-0001

Compressor Data Sheet

Client Document Number:	244-0025-PCS-DAT-0001
Asset:	Ninian Central Platform
Equipment Tag Number(s):	P011

Revisions and Approvals					
Rev.	Date	Description	Originator	Checked	Approved
A	30/04/2025	Issued For Comment	MBS	DM	DM
B	26/08/2025	Issued For Use	MBS	DM	DM

Rev	Rev Description	By	Chkd By	Appd By	Date		Doc No	244-0025-PCS-DAT-0001	
A	Issued For Comment	MBS	DM	DM	30/04/2025		Client	Net Zero Tenchnology	
B	Issued For Use	MBS	DM	DM	8/26/2025		Asset	Ninian Central Platform	
							System	Compression Unit	
							Ref No.	-	
		COMPRESSOR DATA SHEET							Sheet 3 of 3
Specification	1	Tag number			P011/K1402-1402				
	2	P&ID no.			TBC				
	3	Service			H2 compressor				
	4	Phase			2 phases				
	5	Operation (C / I)			Intercooled				
	6	Compression Stage			6 cranks 2 stages				
	7	Compressor Type			2C3SC				
	8	Driver Type			Electric motor				
	9	No Required	No. Operating		3 x 100%		2 x 100%		
	10	Material	Casing	Internal	High-strength carbon steel		Persisto		
	11	Footprint (m)			13 x 8 x 5.3				
	12	Design Pressure (barg)			29 to 103				
	13	Design Temperature (°C)			30				
Purchase	14	Manufacturer			Burckhart Compression				
	15	Model number			6LP250V-4S				
	16	Purchase Order			Q-029023-A				
	17	Serial Number			TBC				
Suction	18	Pressure			29.00			barg	
	19	Temperature			30.00			°C	
	20	Total Mass flowrate			10000			kg/h	
	21	Volume flowrate @ P&T			4320			m3/h	
	22	Nominal flow			94.26			MMSCFD	
	23	Cp / Cv (Ideal)			1.40			-	
	24	Compressibility Z			TBC			-	
Discharge	25	Pressure			103.00			barg	
	26	Cp / Cv (Ideal)			1.40			-	
	27	Compressibility Z			TBC			-	
	28	Molecular weight			TBC			-	
	29	Compression ratio			TBC			-	
Performance	30	Polytropic head			TBC			kJ/kg	
	31	Polytropic efficiency			TBC			%	
	32	Estimated absorbed power			3420.00			kW	
	33	Compressor Speed			TBC			rpm	
	34	Estimated Work			1015.30			J/kg	
	35	Settle out pressure			TBC			barg	

Rev	Rev Description	By	Chkd By	Appd By	Date		Doc No	244-0025-PCS-DAT-0001
A	Issued For Comment	MBS	DM	DM	30/04/2025		Client	Net Zero Tenchnology
B	Issued For Use	MBS	DM	DM	8/26/2025		Asset	Ninian Central Platform
							System	Compression Unit
							Ref No.	-

NOTES AND HOLDS

- 1. Lead time 18 months EXW Winterhur.
- 2. Skid-mounted installation.
- 3. Vertical piston design, Non-lubricated compression
- 4. Design and manufacturing according to manufacturer's standards.

HOP2 Concept Definition: Compressors Datasheet

DOC NO:
244-0025-PCS-DAT-0001

Revision:	Issue Description:	Issue Date:	Prepared:	Checked:	Approved:
A1	Issued For Comment	30/04/2025	MBS	DM	DM
B1	Issued For Use	27/08/2025	MBS	DM	DM

Client:	Net Zero Tenchnology
Project Name:	HOP2 Concept Definition
Document Title:	Compressors Datasheet
Document Number:	244-0025-PCS-DAT-0001

Compressor Data Sheet

Client Document Number:	244-0025-PCS-DAT-0001
Asset:	Ninian Central Platform
Equipment Tag Number(s):	P011

Revisions and Approvals					
Rev.	Date	Description	Originator	Checked	Approved
A	30/04/2025	Issued For Comment	MBS	DM	DM
B	26/08/2025	Issued For Use	MBS	DM	DM

Rev	Rev Description	By	Chkd By	Appd By	Date		Doc No	244-0025-PCS-DAT-0001	
A	Issued For Comment	MBS	DM	DM	30/04/2025		Client	Net Zero Tenchnology	
B	Issued For Use	MBS	DM	DM	8/26/2025		Asset	Ninian Central Platform	
							System	Compression Unit	
							Ref No.	-	
		COMPRESSOR DATA SHEET							Sheet 3 of 3
Specification	1	Tag number			A-1402A/B/C				
	2	P&ID no.			TBC				
	3	Service			H2 compressor				
	4	Phase			2 phases				
	5	Operation (C / I)			Intercooled				
	6	Compression Stage			6 cranks 2 stages				
	7	Compressor Type			2C3SC				
	8	Driver Type			Electric motor				
	9	No Required	No. Operating		3 x 50%			2 x 50%	
	10	Material	Casing	Internal	High-strength carbon steel			Persisto	
	11	Footprint (m)			13 x 8 x 5.3				
	12	Design Pressure (barg)			29 to 103				
	13	Design Temperature (°C)			30				
Purchase	14	Manufacturer			Burckhart Compression				
	15	Model number			6LP250V-4S				
	16	Purchase Order			Q-029023-A				
	17	Serial Number			TBC				
Suction	18	Pressure			29.00				barg
	19	Temperature			30.00				°C
	20	Total Mass flowrate			10000				kg/h
	21	Volume flowrate @ P&T			4320				m3/h
	22	Nominal flow			94.26				MMSCFD
	23	Cp / Cv (Ideal)			1.40				-
	24	Compressibility Z			TBC				-
Discharge	25	Pressure			103.00				barg
	26	Cp / Cv (Ideal)			1.40				-
	27	Compressibility Z			TBC				-
	28	Molecular weight			TBC				-
	29	Compression ratio			TBC				-
Performance	30	Polytropic head			TBC				kJ/kg
	31	Polytropic efficiency			TBC				%
	32	Estimated absorbed power			3420.00				kW
	33	Compressor Speed			TBC				rpm
	34	Estimated Work			1015.30				J/kg
	35	Settle out pressure			TBC				barg

Rev	Rev Description	By	Chkd By	Appd By	Date		Doc No	244-0025-PCS-DAT-0001
A	Issued For Comment	MBS	DM	DM	30/04/2025		Client	Net Zero Tenchnology
B	Issued For Use	MBS	DM	DM	8/26/2025		Asset	Ninian Central Platform
							System	Compression Unit
							Ref No.	-

NOTES AND HOLDS

- 1. Lead time 18 months EXW Winterhur.
- 2. Skid-mounted installation.
- 3. Vertical piston design, Non-lubricated compression
- 4. Design and manufacturing according to manufacturer's standards.



Appendix G FMEA

244-025-TSY-RPT-0001 FMEA worksheet

HOP2 Concept Definition Failure Mode and Effect Analysis

Revision:	Issue Description:	Issue Date:	Prepared:	Checked:	Approved:
A1	Issued for use	10/04/2025	MBS	DM	DM

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Client:	Net Zero Technologies	Date:	10-Apr-25
Job:	HOP2	Created by:	MBS
Document number:	244-025-TSY-RPT-0001	Checked by:	DM
Revision:	A	Approved by:	DM
Activity/Operations:	Concept Definition		

Module	System	Failure modes	Failure Mechanism/cause	Failure effects (local)	Failure effects (global)	Controls and detection	Initial			RPN	Action Recommendations	Revised			RPN	Comments
							Severity	Occurrence	Detectability			Severity	Occurrence	Detectability		
Metering	Metering	Pressure Relief	Loss of Power	No Flow	Power System Shutdown	Pressure Relief Devices	5	5	3	75	Install UPS/Voltage Regulators	5	4	2	40	Metering system provides inaccurate flow measurements. Downstream leak may go undetected due to high inventory volume masking pressure or flow anomalies.
		Process Valves	Leakage	High Pressure	Process Interruption	Flow Meters & Sensors					Preventive Maintenance					
		Shut Down Valves	Overpressure	Equipment Failure	Product Quality Deviation	Condition Monitoring										
		Filter	Fails to operate on command													
		Flow Meter	Blockage													
		Chemical Sampling														
H2 Production	Water Treatment	Pump	Loss of Power	No Flow	Power System Shutdown	Inline Filtration	5	5	7	175	Regular Inspections	5	4	5	100	Level control is dependent on proper operation of pumps P-1201A/B. Dechlorination is performed upstream of the main water treatment system to protect downstream equipment and ensure compliance.
		Heat exchanger	Overheating	Low Flow	Process Interruption	Chemical Compatibility Checks					Preventive Maintenance					
		Process Valves	Leakage	Low Pressure		Condition Monitoring					Testing					
		Vessel	Blockage	Liquids Release												
			Internal Component fails/breaks	Reduced Life												
			Wrong signal provided	Equipment Failure												
	PEM electrolysers array	Membrane	Loss of Power	Gas Release	Process Interruption	Safety Controls	8	3	7	168	Preventive Maintenance	8	2	6	96	Manufacturer's design should incorporate appropriate safeguarding measures to mitigate operational and safety risks. Hydrogen release may result in fire or explosion if not properly detected and contained.
			Leakage	Component Failure	Explosion/Fire						Testing					
			Overpressure	Reduced Life							Specification of safety systems					
			Blockage	Equipment Failure												
			Internal Component fails/breaks													
	Gas Treatment	Pump	Loss of Power	Gas Release	Plant-Wide Outage	Pressure Relief Devices	5	3	5	75	Preventive Maintenance	5	2	5	50	Failure of molecular sieve dehydration beds may result in inadequate moisture removal from gas stream. Liquid carryover to the compressor can cause mechanical damage, reduced efficiency, or compressor trip.
		Heat exchanger	Overheating	Component Failure	Product Quality Deviation	Flow Meters & Sensors										
		Process Valves	Operator Error			Routine Maintenance										
		Shut Down Valves	Fails to operate on command			Condition Monitoring										
		Control System	Internal Component fails/breaks			Safety Controls										
		Vessel	Structure Damage			Control Systems										
			Wrong signal provided													
	Oxygen Vent	Heat exchanger	Overheating	No Flow	Power System Shutdown	Pressure Relief Devices	8	5	8	320	Regular Inspections	8	3	8	192	Oxygen fire hazard resulting from inadequate or inappropriate operational procedures during handling or maintenance.
		Pressure Relief	Operator Error	Low Flow	Process Interruption	Routine Maintenance					Preventive Maintenance					
		Control System	Leakage	High Pressure	Explosion/Fire	Load Management					special care of procedures for install and ongoing O2					
		Vessel	Fails to operate on command	Gas Release		Safety Controls										
			Blockage	Equipment Failure		Control Systems										
	Gas compressor		Wrong signal provided				10	3	3	90		10	2	3	60	Hydrogen leak may result in an explosive atmosphere, posing a risk of fire or explosion if an ignition source is present.
		Heat exchanger	Loss of Power	High Pressure	Plant-Wide Outage	Pressure Relief Devices					Regular Inspections					
		Process Valves	Overheating	Gas Release	Process Interruption	Flow Meters & Sensors					Preventive Maintenance					
		Shut Down Valves	Operator Error	Component Failure	Explosion/Fire	Seal Monitoring					Testing					
		Vessel	Overpressure	Reduced Life	Loss of Structural Integrity	Vibration Monitoring					Train Personnel					
		Compressor	Power surge	Equipment Failure		Circuit Protection Devices (Fuses, Breakers)										
			Fuse Blow	Wrong reading		Surge Protection										
			Blockage			Load Management										
						Safety Controls										
						Control Systems										
						Vibration and Noise Control										
						Operational Procedures										

Client:	Net Zero Technologies	Date:	10-Apr-25
Job:	HOP2	Created by:	MBS
Document number:	244-025-TSY-RPT-0001	Checked by:	DM
Revision:	A	Approved by:	DM
Activity/Operations:	Concept Definition		

Module	System	Failure modes	Failure Mechanism/cause	Failure effects (local)	Failure effects (global)	Controls and detection	Initial			RPN	Action Recommendations	Revised			RPN	Comments
							Severity	Occurrence	Detectability			Severity	Occurrence	Detectability		
Electrical	Electrical Rooms	Transformer	Loss of Power	Component Failure	Power System Shutdown	Circuit Protection Devices (Fuses, Breakers)	8	4	3	96	Install UPS/Voltage Regulators	8	3	2	48	System fire may lead to equipment damage and pose serious risks to personnel safety.
		Switchgear	Overheating	Reduced Life	Plant-Wide Outage	Insulation Testing					Regular Electrical Testing					
		Rectifiers	Operator Error	Structural Failure	Safety System Compromise	Electrical Load Monitoring					Staff Training on Electrical Safety					
			Power surge	Equipment Failure	Explosion/Fire	Grounding Checks					Testing					
			Fails to operate on command		Loss of Structural Integrity	Surge Protection					Operate remotely					
			Fuse Blow		Loss of functionality of downstream component	Scheduled Inspections										
			Internal Component fails/breaks			Routine Maintenance										
						Condition Monitoring										
						Load Management										
						Operational Procedures										
Flare	Flare	Process Valves	Leakage	High Pressure	Plant-Wide Outage	Pressure Relief Devices	10	3	4	120	Regular Inspections	10	2	4	80	Ignition failure may result in a large unburned gas release, creating an explosive atmosphere that may ignite later. Inadequate nitrogen purging and permitting controls increases the risks.
		Control System	Overpressure	Gas Release	Environmental Release	Safety Controls					Preventive Maintenance					
		Vessel	Fails to operate on command	Component Failure	Explosion/Fire	Control Systems					Testing					
		Piping	Blockage	Structural Failure	Regulatory Violation						Train Personnel					
		Ignition pannel	Internal Component fails/breaks		Loss of Structural Integrity											
			Structure Damage													
Utilities	Utilities (N2, instrument air, UPS and emergency gen)	Pump	Loss of Power	No Flow	Power System Shutdown	Circuit Protection Devices (Fuses, Breakers)	9	4	3	108	Regular Electrical Testing	9	3	2	54	Loss of instrument air may cause valves to revert to their fail-safe positions, potentially impacting system's operations. Loss of nitrogen supply may compromise flare system operation. Although N2 is not specified for the client's selected PEM, this risk should be considered during design review.
		Process Valves	Overheating	Low Flow	Plant-Wide Outage	Scheduled Inspections					Staff Training on Electrical Safety					
		Filter	Single point failure	Low Pressure	Safety System Compromise	Routine Maintenance					Regular Inspections					
				Reduced Life	Loss of functionality of downstream component	Condition Monitoring					Preventive Maintenance					
		Compressor		Equipment Failure		Safety Controls					Testing					
		Piping				Control Systems					Train Personnel					
											Use Redundancy					

Client:	Net Zero Technologies	Date:	10-Apr-25
Job:	HOP2	Created by:	MBS
Document number:	244-025-TSY-RPT-0001	Checked by:	DM
Revision:	A	Approved by:	DM
Activity/Operations:	Concept Definition		

RISK PRIORITY NUMBER (RPN=S*O*D)	
RPN>200	Requires immediate attention
RPN 100-200	Needs corrective action soon
RPN <100	Considered low risk but should still be monitored

Severity	Occurrence	Detection
A numerical rating (1-10) for how serious the failure consequence is.	A numerical number (1-10) for how often the failure is expected to happen.	A numerical rating (1-10) indicates how easily the failure can be detected before it impacts the system.
Severity 1 = process unaffected	Occurrence 1 = Very unlikely	Detectability 1 = Very easy to detect
Severity 5 = process interruption	Occurrence 5 = Expected	Detectability 5 = Able to detect
Severity 10 = Fatality	Occurrence 10 = Certain to happen	Detectability 10 = No possible detection



Appendix H RAM Analysis

244-025-TSY-RPT-0002 RAM Analysis

HOP2 Concept Definition

Reliability, Availability and Maintainability

Revision:	Issue Description:	Issue Date:	Prepared:	Checked:	Approved:
A1	Issued for use	06/05/2025	MBS	DM	DM
B1	Issued for use	22/07/2025	MBS	DM	DM

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Notes:

- 1

Occurrence gotten from FMEA and applied as MTBF with the following scale:

10=1 year8=10 year5= 20 year3=50 year1=1000 year
- 2
- 3

Supporting documentation:

- 1

244-025-TSY-RPT-0001 FMEA worksheet.xlsm
- 2

244-025-GRL-GEN-0001-A Master equipment list.xlsx
- 3

PFD-001, 002, 003
- 4

UFD-001
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12
- 13
- 14
- 15

Abbreviation and symbols:

- N/A

Not Applicable
- TBD

To Be Determine



RAM - Worksheet

Client:	Net Zero Technologies	Date:	22-Jul-25
Job:	HOP2	Created by:	MBS
Document number:	244-025-TSY-RPT-0002	Checked by:	DM
Revision:	B	Approved by:	DM
Activity/Operations:	Concept Definition		

System	Availability	Module	Availability	Component	Availability	Equipment	Number	Availability
HOP 2 Platform	93.39080%	Seawater and feedwater	99.6914%	Sea Water	99.8810%	Pressure Relief valves	4	99.9520%
						Pump	4	99.8630%
						Filter	4	99.3172%
						Trim cooler	1	99.9817%
						Main Cooler	1	99.9867%
						Piping	1	99.9947%
						Flow meter	4	99.9663%
				Feed Water	99.8102%	Pressure Relief valves	3	99.9640%
						Process Valves	5	99.9250%
						Vessel	1	99.9853%
						Piping	1	99.9947%
						Pump	1	99.9657%
						Flow Meter	3	99.9747%
		Hydrogen and Oxygen production	97.5915%	O2	99.8890%	Pressure Relief valves	1	99.9880%
						Process Valves	1	99.9850%
						Pump	1	99.9657%
						Main cooler	1	99.9867%
						Vessel	1	99.9853%
						Control System	1	99.9920%
						Flow Meter	1	99.9916%
						Piping	1	99.9947%
				PEM electrolysers array	98.0223%	Membrane	12	99.0062%
						PEM Electrolyzer	12	99.0062%
				H2	99.6997%	Process Valves	17	99.7453%
						Piping	1	99.9947%
						Pressure Relief valves	2	99.9760%
						Flow Meter	1	99.9916%
						Control System	1	99.9920%
				Gas compressor	99.9713%	Heat exchanger	6	99.9041%
						Piping	1	99.9947%
						Compressor	2	99.7339%
		Electrical	97.0351%	Electrical rooms	97.0351%	Transformer	11	99.2696%
						Transformer to PEM	12	99.60100%
						Filter	4	99.3172%
						Switchgear	19	99.0422%
						Batteries	1	99.9947%
						Rectifiers	24	99.7763%
		Utilities	99.1678%	HVAC	99.2431%	AHU	11	99.5611%
						Chillers	6	99.6806%
				Flare	99.9242%	Vessel	1	99.9853%
						Process Valves	1	99.9850%
						Pressure Relief valves	2	99.9760%
						Flow meter	2	99.9832%
		Cooling System	99.7551%	Cooling	99.7551%	Piping	1	99.9947%
						Pressure Relief valves	10	99.8801%
						Flow meter	10	99.9158%
						Pump	4	99.8630%
						Vessel	1	99.9853%



RAM - Base Data



Client:	Net Zero Technologies	Date:	22-Jul-25
Job:	HOP2	Created by:	MBS
Document number:	244-025-TSY-RPT-0002	Checked by:	DM
Revision:	B	Approved by:	DM
Activity/Operations:	Concept Definition		

Tag number	Equipment	Reliability		Maintainability	Availability	Recommendations	Source
		MTBF (hrs)	Failure rate (1/MTBF)	MTTR (hrs)	Availability = MTBF/(MTBF+MTTR)		
1	Pump	35,000	2.86E-05	12	99.966%		[maintboard.com]
2	Heat exchanger	100,000	1.00E-05	16	99.984%		[Emerson, API 661 Guidelines]
3	Pressure Relief valves	100,000	1.00E-05	12	99.988%		[Swagelok, API 520]
4	Motors	75,000	1.33E-05	10	99.987%		[powertransmission.com]
5	Process Valves	80,000	1.25E-05	12	99.985%		[Emerson, ISA]
6	Shut Down Valves	70,000	1.43E-05	10	99.986%		[ISA, Yokogawa]
7	Chiller	45,000	2.22E-05	24	99.947%		[ASHRAE]
8	F&G system	100,000	1.00E-05	20	99.980%		[NFPA, ISA standards]
9	Control System	100,000	1.00E-05	8	99.992%		[bin95.com]
10	Membrane	12,000	8.33E-05	20	99.834%		[GE Water, Dow]
11	Filter	7,000	1.43E-04	12	99.829%		-
12	Enclosure	150,000	6.67E-06	6	99.996%		[IP rating specs]
13	Flow Meter	95,000	1.05E-05	8	99.992%		[brooksinstrument.com]
14	Generator	45,000	2.22E-05	24	99.947%		[Caterpillar, Cummins]
15	Vessel	150,000	6.67E-06	22	99.985%		[API 510]
16	Compressor	30,000	3.33E-05	40	99.867%		[maintboard.com]
17	Transformer	150,000	6.67E-06	100	99.933%		[ABB, Siemens]
18	Switchgear	75,000	1.33E-05	38	99.949%		[Schneider, Eaton]
19	Rectifiers	150,000	6.67E-06	14	99.991%		[Siemens, ABB]
20	Piping	225,000	4.44E-06	12	99.995%		-
21	Ignition pannel	60,000	1.67E-05	12	99.980%		[OEMs, field data]
22	PEM Electrolyzer	60,000	1.67E-05	100	99.834%		[Nel Hydrogen, Plug Power]
23	Batteries	300,000	3.33E-06	16	99.995%		[Panasonic, Tesla specs]
24	AHU	30,000	3.33E-05	12	99.960%		[ASHRAE]
25	Main Cooler	120,000	8.33E-06	16	99.987%		[API 661, Emerson, field data]
26	Trim Cooler	120,000	8.33E-06	22	99.982%		[GE Oil & Gas, industry estimates]

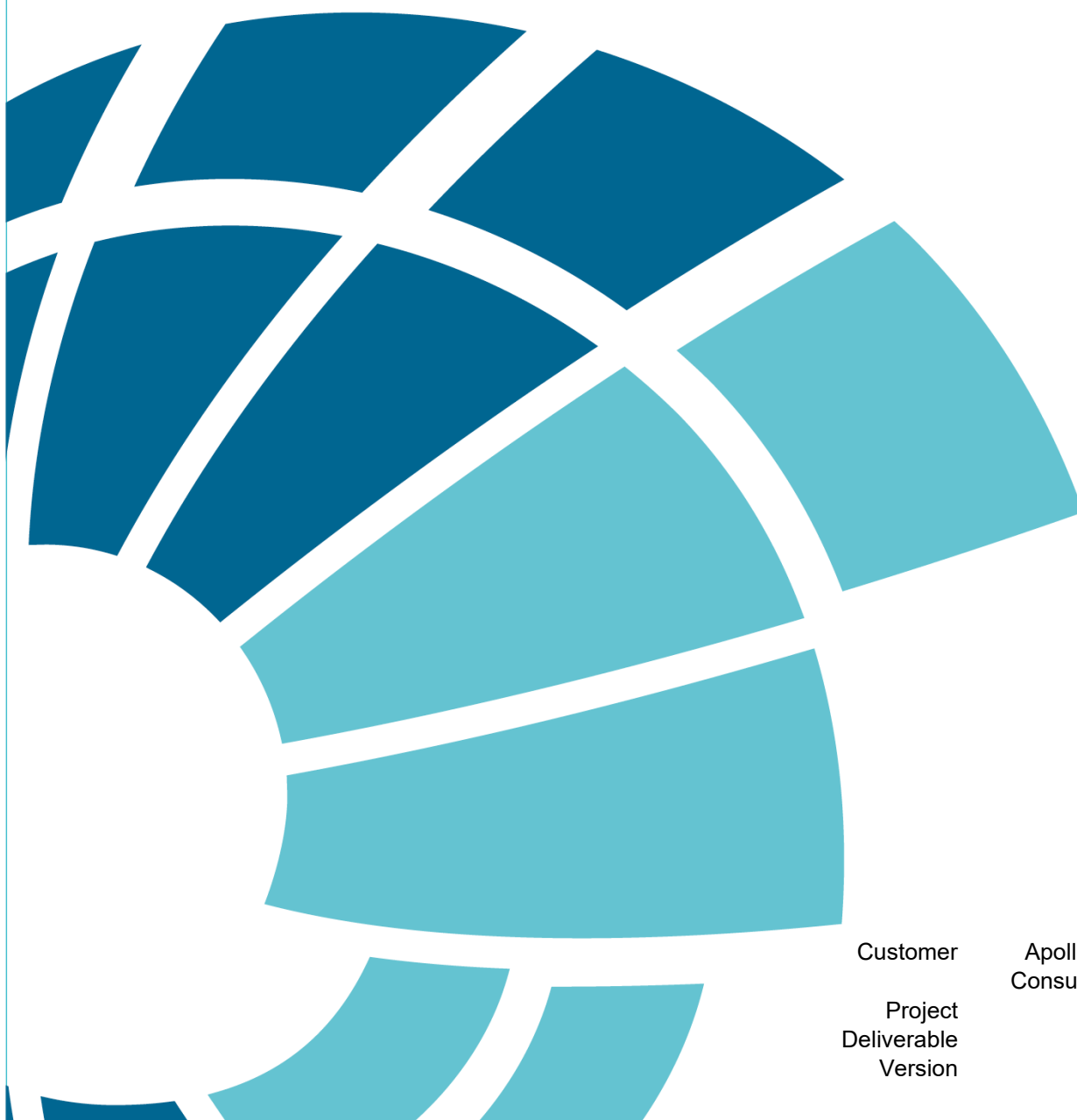
*Note 1: Maintainability numbers are dependent on specialist staff availability and on the ability to ship equipment and spares to the offshore location, which is a function of the onshore sparing philosophy and component lead times.



Appendix I Environmental & Consenting Risk Assessment

Environmental and Consenting Risk Assessment

Hydrogen Offshore Production Project



Customer	Apollo Engineering Consultants (Apollo)
Project	12536
Deliverable	001
Version	A3
	31 July 2025



Document Control

Document Identification

Title	Environmental and Consenting Risk Assessment
Project No	12536
Deliverable No	001
Version No	A3
Version Date	31 July 2025
Customer	Apollo Engineering Consultants (Apollo)
Classification	PUBLIC

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Amendment Record

The Amendment Record below records the history and issue status of this document.

Version	Version Date	Distribution	Record
A1	9 th May	Apollo	Draft report
A2	16 th May	Apollo	Revised report
A3	31 st July	Apollo	Final report

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Abbreviations, Acronyms and Glossary

Abbreviations		
µg/g		Micrograms per gram
µm		Micrometres
BAT		Best Available Techniques
BEIS		Department for Business, Energy & Industrial Strategy
CB4		Fourth Carbon Budget
CB5		Fifth Carbon Budget
CNR		Canadian Natural Resources
CNS		Central North Sea
CH ₄		Methane
CO		Carbon monoxide
CO ₂ e		Carbon dioxide equivalent
COP21		UN Climate Change Conference
DEFRA		Department of Environment, Food and Rural Affairs
DESNZ		Department for Energy Security & Net Zero
DTI		Department for International Trade
EMODnet		European Marine Observation and Data Network
ENVID		Environmental Risk Identification
EU		European
EUNIS		European Nature Information Systems
EIA		Environmental Impact Assessment
EPS		European Protected Species
ETS		Emissions Trading Scheme
ES		Environmental Statement
ESAS		European Seabirds at Sea
GHG		Greenhouse gas
GW		Giga watts
GWP		Global warming potential
H ₂		Hydrogen
HO		Hydroxyl radicals
HOP2		Hydrogen Offshore Production project
HQ		Hazard quotient

Abbreviations		
ICES		International Council for the Exploration of the Sea
IUCN		International Union for Conservation
JNCC		Joint Nature Conservation Committee
km		Kilometres
km ²		Kilometres squared
m		Metres
m/s		Metres per second
MCAA		Marine and Coastal Access Act 2009
MCZ		Marine Conservation Zone
Mm		Millimetres
MoD		Ministry of Defence
MPA		Marine protected areas
Mt		Mega tonnes
MW		Mega watts
N ₂		Nitrogen
NCMPA		Nature Conservation Marine Protected Area
NDC		Nationally Determined Contribution
NM		Nautical miles
NMP		National Marine Plan
NMPI		National Marine Plan Interactive
NNS		Northern North Sea
NO		Nitric oxide
NO ₂		Nitrogen dioxide
NO _x		Oxides of nitrogen
NSTA		North Sea Transition Authority
NZTC		Net Zero Technology Centre Limited
O ₂		Oxygen
OCNS		Offshore Chemical Notification Scheme
OESEA4		Offshore Energy Strategic Environmental Assessment 4
OPEP		Oil Pollution Emergency Plan
OPPC		Offshore Petroleum Activities (Oil Pollution Prevention and Control) Regulations 2005 (as amended)

Abbreviations		
OPRED		Offshore Petroleum Regulator for Environment and Decommissioning
PAHs		Polycyclic Aromatic Hydrocarbons
PMF		Priority Marine Features
PPC		Offshore Combustion Installations (Pollution Prevention and Control) Regulations 2013 (as amended)
ppt	ppt	Parts per thousand
REACH		Registration, Evaluation, Authorisation and restriction of CHemicals
SAC		Special Areas of Conservation
SCANS		Small Cetaceans in European Atlantic waters and the North Sea
SGMD		Scottish Government Marine Directive
SMRU		Sea Mammal Research Unit
SNH		Scottish Natural Heritage
SOx		Oxides of sulphur
SPA		Special Protection Area
SNS		Southern North Sea
SSI		Sites of Specific Scientific Interest
SSIV		Subsea isolation valve
THC		Total hydrocarbon
UK		United Kingdom
UKCS		United Kingdom Continental Shelf
UKDMAP		United Kingdom Digital Marine Atlas
UN		United Nations
UKHO		United Kingdom Hydrographic Office
VOC		Volatile organic compound

1 Introduction

1.1 Project Background

The Net Zero Technology Centre Limited (NZTC) has successfully applied for funding from the Scottish Government to support delivery of the Hydrogen Offshore Production Project (HOP2). HOP2 aims to repurpose existing oil and gas assets within the United Kingdom Continental Shelf (UKCS) for offshore green hydrogen production at a scale of 500 MW within the North Sea at a centralised facility.

NZTC has already undertaken Phase 1 of the proposed development which consists of a high-level basis of design, identification of assets for repurposing, production technologies, and transport and storage options. Phase 1 identified a number of existing oil and gas assets that were considered suitable for repurposing to offshore hydrogen production. The Ninian Central Platform, located in the northern North Sea (NNS) and operated by Canadian Natural Resources (CNR) International was selected as the template for the single large platform design and will form the basis of this assessment.

1.2 Location and Description of Site

It is envisaged that HOP2 will consist of a 500 MW centralised offshore production facility accommodated on a single large platform as shown in Figure 1.1. The platform is composed of a completely new-build topsides supported by the repurposed existing substructure of the Ninian Central Platform.

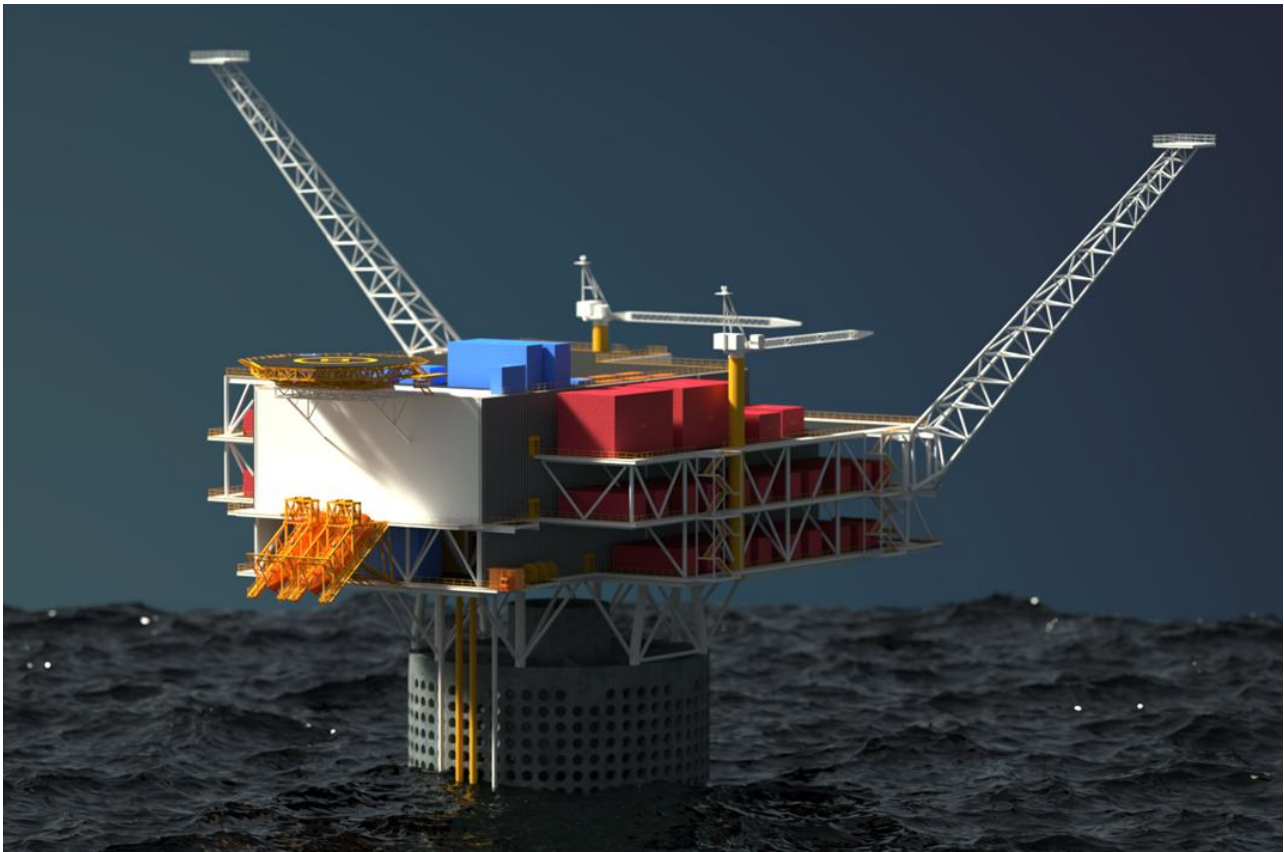


Figure 1.1 Concept Single Large Platform Option

1.3 Key Infrastructure

The platform is composed of a completely new-build topsides supported by the repurposed existing substructure. Key infrastructure required to support the topside unit operations and systems for hydrogen production and export is likely to include but is not limited to the following:

- Seawater lift caisson for the supply of raw seawater to water treatment plant and cooling system;
- Brine disposal (seawater dump) caisson for seawater reject and brine disposal to sea;
- Cooling system for cooling electrolyzers and other process cooling demands;
- Hydrogen export riser / subsea isolation valve (SSIV) umbilical; and
- Power cables for electrical supply cabling from windfarm, and for control and telecommunications.

2 Methodological Approach

This section outlines the methodological approach to undertaking this environmental and consenting risk assessment.

2.1 Report Objectives

This document outlines the key environmental and consenting risks associated with HOP2 based on the current, high-level concept design. Specifically, the objectives of this document are to:

- Undertake an initial review of the local receiving marine environment of HOP2 on the Ninian Central Platform including environmental and socioeconomic values;
- Identify anticipated environmental risks and undertake an initial assessment of potential impacts to the marine environment as a result of planning, construction, operation and decommissioning of HOP2;
- Assess potential mitigation and management options for environmental risk; and
- Present an overview of expected regulatory compliance, permitting and consenting requirements associated with HOP2 to inform decision-making for the next phase of development.

2.2 Data Review

To evaluate environmental risk associated with the HOP2, we have undertaken an initial data review to summarise baseline environmental values.

Environmental information has been collated and analysed using publicly available sources including, but not limited to:

- Spatial data including marine protected areas (MPAs) and other areas of sensitive ecological significance;
- Species records and habitat distribution focusing specifically on mammals, seabirds and fish;
- Fisheries landings and effort data;
- Information pertaining to other potential users of the area; and
- Any previous environmental surveys available undertaken within and adjacent to the investigation area if available.

3 Legislative and Planning Context

This section outlines the legislative and planning context applicable to hydrogen production. Note as hydrogen production is a rapidly emerging industry, regulatory requirements may change and should be reviewed as HOP2 progresses.

3.1 International Agreements and Hydrogen Production Regulation

In 2015, the Paris Agreement was signed at the United Nations (UN) Climate Change Conference (COP21) in Paris, providing a framework to reduce greenhouse gas (GHG) emissions and direct an international effort to limit global warming to below 2 °C when compared to pre-industrial levels, with the intention to pursue a limit of 1.5 °C warming when compared to pre-industrial levels. To meet the UK's long-term emissions reduction targets and the goals of the Paris Agreement, the Climate Change Act 2008 was amended by the UK Government in 2019 to commit to a legally binding target of Net Zero emissions by 2050.

Point 2 of the Ten Point Plan for a Green Revolution strategy, published in 2020, aims to develop 5 GW of low carbon hydrogen production capacity in the UK by 2030. The UK Government's 'Build Back Greener' strategy published in 2021 as part of the broader Net Zero Strategy corroborates the hydrogen production capacity goals.

The UK Hydrogen Strategy extends beyond the Ten Point Plan (HM Government, 2021) and sets out the approach to developing a thriving low carbon hydrogen sector in the UK to meet the increased ambition for 10 GW of low carbon hydrogen production capacity by 2030. At least half of this target aims to come from electrolysis indicating the production capacity of HOP2 of 500 MW would contribute 10% of the remainder. The strategy takes a holistic approach setting out what needs to enable the production, distribution, storage and use of hydrogen. The UK Hydrogen Strategy denotes that the use of low carbon hydrogen enabled by 5 GW production capacity could deliver total emissions savings of around 41 MtCO₂e between 2023 and 2032, equivalent to the carbon captured by 700 million trees over the same time period. This covers the period of the UK's Fourth and Fifth Carbon Budgets (CB4 and 5) and will contribute to achieving the UK's Nationally Determined Contribution (NDC) under the Paris Agreement of reducing emissions by 68 per cent compared to 1990 levels by 2030.

The most recent policy to be published is the British Energy Security Strategy of 2022 (HM Government, 2022) further emphasises support to hydrogen production capitalising on carbon capture storage in the North Sea.

The European (EU) Directive 2024/1788 on common rules for the internal markets for renewable gas, natural gas and hydrogen sets out the framework to facilitate decarbonisation of the EU's energy systems focusing on natural gas and hydrogen markets. It is an essential component of the "Fit for 55 Package" which aims to reduce carbon emissions by 55% by 2030 and ultimately reach climate neutrality by 2050. It also sets out the requirements for transporting, supplying and storing natural gas and hydrogen.

Though hydrogen is not explicitly referred to in the *Energy Act 2008*, the North Sea Transition Authority (NSTA) is pursuant to this Act and is the licensing authority for offshore gas storage and offshore gas unloading (including hydrogen). Consultation was undertaken with NSTA, Offshore Petroleum Regulator for Environment and Decommissioning (OPRED) and Department for Energy Security & Net Zero (DESNZ) in 2023 regarding Offshore Hydrogen Regulation. Outcomes of the consultation included incorporating hydrogen under the Act. Designation of hydrogen under this Act would deem hydrogen developments as "offshore installation" and therefore, subject to the *Petroleum Act 1998* and

subsequent decommissioning regimes. OPRED would be the responsible regulatory authority for the decommissioning of hydrogen projects. These provisions would likely apply to all offshore areas of the UK including relevant territorial seas and UKCS.

Though not necessarily an environmental permitting requirement, the *Gas Act 1986* stipulates the legal framework for regulating the gas industry in the UK. It establishes the licensing regime for the supply, shipping, and transport of gas including hydrogen, which is classified as a 'gas' under the Act. While a specific license is not required solely for gas production, one may be necessary if production cannot be clearly separated from supply and transport activities.

In addition, The Crown Estate manages the seabed and coastline around the UK and as such, is responsible for granting leases for seabed and subsurface rights to developers for hydrogen infrastructure, with the regulation of projects being carried out by the licensing authority, the NSTA. Carrying out regulated hydrogen production operations without a licence is prohibited.

3.2 Environmental Impact Assessment

The offshore elements of HOP2 are governed by The Offshore Oil and Gas Exploration, Production, Unloading and Storage (Environmental Impact Assessment) Regulations 2020 (the 2020 EIA Regulations). The 2020 EIA Regulations apply to activities related to proposed offshore oil and gas exploration and production, gas unloading and storage, and storage of carbon dioxide and requires the undertaking of an Environmental Impact Assessment (EIA) and the production of an Environmental Statement (ES). It is assumed gas unloading and storage activities also constitutes hydrogen production and storage. The EIA process (ES and Screening Direction) for hydrogen production should therefore mirror that detailed for offshore oil and gas activities.

3.3 Protected Sites and Species

This assessment of environmental risk must consider impacts of the proposed activity on the surrounding environment, including on any protected species and areas. Protected species and areas were designated around the UK as a result of EU Directives, in particular the Habitats Directive (92/43/EEC) and the Birds Directive (2009/147/EC). Since January 2021, areas up to 12 nautical miles (nm) from shore are maintained and designated under the Conservation of Habitats and Species Regulations 2017 (as amended), known as the Habitats Regulations.

Past 12 nm, protected areas are maintained and designated under the Offshore Petroleum Activities (Conservation of Habitats) Regulations 2001 (as amended), which set down the obligations for the assessment of the impact of offshore oil and gas activities (including gas and carbon dioxide unloading and storage activities) on habitats and species protected under the above directives. The Conservation of Offshore Marine Habitats and Species Regulations 2017, known as the Offshore Habitats Regulations, are the governing legislation for implementation of a number of the other requirements contained in the Directives. These regulations include provisions for the designation and protection of offshore areas that host important habitats and species, meaning the requirements of the EU Nature Directives continue to apply to how European sites are designated and protected. These sites are called Special Areas of Conservation (SACs) for the protection of certain habitats and marine species and Special Protection Areas (SPAs) for the protection of certain wild bird species. The Habitats Regulations also provide a legal framework for species requiring strict protection, e.g., European Protected Species (EPS).

3.4 Marine and Coastal Access Act 2009

The *Marine and Coastal Access Act 2009* (MCAA) introduced a marine planning system which controls marine activities in English and Welsh offshore and inshore waters and Scottish offshore waters (12 to 200 nm). The MCAA sets out a UK Marine Policy Statement which is the framework for preparing

marine plans. The MCAA allows the government to take a strategic and co-ordinated overview of the range of human activities and use of space and resources in the marine environment, while ensuring there is adequate space for marine wildlife. The MCAA makes provision for a streamlined marine licensing system, improved marine nature conservation measures, improved enforcement measures, and for marine plans which will set out in detail what is to happen in the different parts of the areas to which they relate. As well as this, it also provides the designation of Marine Conservation Zones (MCZs) in English and Welsh waters. Most activities authorised solely under DESNZ (formerly the Department for Business, Energy & Industrial Strategy (BEIS)) environmental regime, including chemical and hydrocarbon discharges, use of explosives and decommissioning are exempt from the MCAA.

3.5 Marine (Scotland) Act 2010

The *Marine (Scotland) Act 2010* compliments the MCAA, making provisions in relation to functions and activities in Scottish inshore waters with the objective of protecting and enhancing the marine environment including the designation of Nature Conservation Marine Protected Areas (NCMPAs). Part 4, s.21 sets out the requirements for marine licensing which state a licence is required "To construct, alter or improve any works within the Scottish marine area either- a) in or over the sea, or b) on or under the seabed". Marine Licences are issued by the Scottish Government Marine Directorate (SGMD) and will be required for works in Scottish waters.

3.6 The Natural Environment and Rural Communities

The *Natural Environment and Rural Communities Act 2006* requires public authorities in England to consider biodiversity conservation when carrying out their duties. It applies in relation to England, including England's adjacent territorial seas.

Section 40 (1) of the Act states that "Every public authority must, in exercising its functions, have regard, so far as is consistent with the proper exercise of those functions, to the purpose of conserving biodiversity", while section 40 (3) of the Act explains that "Conserving biodiversity includes, in relation to a living organism or type of habitat, restoring or enhancing a population or habitat."

3.7 Protection of Wrecks Act 1973

The *Protection of Wrecks Act 1973* stipulates the protection of underwater shipwrecks in territorial waters of the UK and the sites of such wrecks, from interference by unauthorised persons. Specifically, Protected Wreck Site form part of the National Heritage List for England with designated exclusion zones around them to prevent uncontrolled interference. Under this legislation, certain activities are restricted including tampering, diving and salvage operations which may cause damage to the wreck site. In some instances, approved licences enable access to the wreck site for specific activities including surveying and recovery of artifacts. A licence may be required for a development near a Protected Wreck Site.

3.8 Discharges to Water

Under the Offshore Chemical Regulations 2002 (as amended) a chemical permit is required for the use and discharge of chemicals used offshore (with some exemptions). All offshore activities, including production, drilling, discharges through pipelines and decommissioning are covered by the aforesaid 2002 Regulations. A risk assessment of chemical discharges is required as part of the permit application.

The REACH Enforcement Regulations 2008 enforce the provisions of the EU REACH Regulation which requires the registration of chemical substances based on tonnage levels and the properties/toxicity of certain substrates.

The Offshore Installations (Emergency Pollution Control) Regulations 2002 prevent and reduce pollution, and the risk of pollution following an accident involving an offshore installation.

3.9 Atmospheric Emissions

The Offshore Combustion Installations (Pollution Prevention and Control) Regulations 2013 (as amended) (PPC) transpose the relevant provisions of The Industrial Emissions Directive 2010/75/EU in respect to specific atmospheric pollutants from combustion installations with a thermal capacity rating ≥ 50 MW on offshore platforms undertaking activities involving oil and gas production. These regulations mirror those of the Offshore Petroleum Activities (Oil Pollution Prevention and Control) Regulations 2005 (as amended) (OPPC Regulations). Permitting under these regulations include emission allowances for carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulphur (SO_x), methane (CH₄) and volatile organic compounds (VOCs) including, as with the OPPC Regulations, demonstration of Best Available Techniques (BAT). Combustion installations on oil and gas platforms with a rated thermal input of equal to or greater than 20 MW require permitting under the UK Emissions Trading Scheme (UK ETS), which replaced the EU Emissions Trading Scheme (EU ETS) on 1st January 2021. The UK ETS is established through The Greenhouse Gas Emissions Trading Scheme Order 2020. This includes emission allowances for CO₂.

A Policy paper published by the DESNZ and BEIS in 2022 (Warwick et al. 2022) outlines the possible impacts of hydrogen leakage as a result of storage, production and transport of hydrogen. It notes that though hydrogen provides an opportunity to minimise GHG emissions overall, its increased use could lead to enhanced hydrogen emissions which have an estimated global warming potential (GWP) over a 100-year period that is approximately 11 (+/- 5) times greater than CO₂. These emissions may also interact with atmospheric oxidants, such as hydroxyl radicals (OH), potentially reducing their availability. This reduction could slow the breakdown of methane, a potent GHG contributor. The policy paper emphasises the necessity for stringent monitoring and management of hydrogen emissions to mitigate these indirect effects on climate change and air quality.

3.10 Accidental Events

The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998 (as amended by the Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 2015) make provision for certain facilities in the UK's internal waters, territorial sea and continental shelf to have an Oil Pollution Emergency Plan (OPEP). The 2015 amendments extend the requirement for an OPEP to non-production installations in the territorial sea and the continental shelf and apply further requirements to installations and their connected infrastructure which are carrying out offshore oil and gas operations, including decommissioning operations. The regulations require the arrangements for responding to incidents which cause, or may cause, marine pollution by oil to be in place and the consequences of potential incidents to be assessed. As the asset will no longer be an oil and gas facility, it may be certified as hydrocarbon free, to allow the relinquishment of the current OPEP.

3.11 Scotland's National Marine Plan

The *Marine (Scotland) Act 2010* and the MCAA established a legislative and management framework for the marine environment allowing the competing demands on the sea to be managed in a sustainable way across all of Scotland's seas (Scottish Government, 2015). The Scottish and UK Governments published a marine plan for Scotland's inshore waters and a marine plan covering Scottish offshore waters in a single document collectively referred to as the National Marine Plan (NMP). The NMP was prepared in accordance with, and gives consideration to, EU 'Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning' (the 'Directive') which came into force in July 2014 (Scottish Government, 2015), before the UK's departure from the EU. The Directive introduced a framework for maritime spatial

planning and promotes the sustainable development of marine areas and the sustainable use of marine resources.

In Scotland, NCMPAs are a national designation under the *Marine (Scotland) Act 2010* for inshore waters and the MCCA 2009 for offshore waters, where Scottish Ministers have executive devolution of authority for the designation of NCMPAs for the conservation of important marine biodiversity and geodiversity out to 200 nm (JNCC, 2019a).

In accordance with Article 5(3) of the Directive, a wide range of sectoral uses and activities have been considered within the NMP. The General Policies of the NMP introduce General Policy 9 (Natural Heritage), which concerns the development and use of the marine environment. The policy states that development and use of the marine environment must not result in significant impact on the national status of Priority Marine Features (PMFs). Supporting the NMP, the Strategy for Marine Nature Conservation in Scotland's seas sets out aims and objectives to achieve sustainable development and use, including the protection and, where appropriate, enhancement of the health of the Scottish marine area. Scottish Natural Heritage (SNH), the Joint Nature Conservation Committee (JNCC) and Marine Scotland have been working together to develop a priority list of marine habitats and species in Scotland's seas known as PMFs. The list contains 81 habitats and species considered to be of conservation importance in Scotland's seas that will help to focus future conservation action and marine planning, direct research and education and promote a consistent approach to marine nature conservation advice. Habitats and species on the PMF list in the vicinity of HOP2 area are acknowledged within this document.

The Ninian Central Platform and HOP2 is located within UKCS Block 3/3, approximately 120 km east of the northern Shetland coastline. The proposed operations are within the area covered by the Scottish NMP; therefore, the NMP Interactive (NMPI) map has been used where appropriate to inform this assessment (NMPI, 2024).

3.12 Summary of Likely Permitting Requirements

Table 3.1 provides a summary of likely permitting requirements related to HOP2. Note this is an indicative summary based on current legislation requirements and anticipated trends. HOP2 will need to be reviewed as the project progresses to ensure alignment with the latest legislation and planning requirements.

Table 3.1 Expected Permitting Requirements for HOP2

Overarching Legislation	Administering Authority	Relevance to HOP2
<i>Marine and Coastal Access Act 2009</i> <i>Marine (Scotland) Act 2010</i>	DESNZ Marine Directorate	Marine Licence may be required for works within Scottish waters.
<i>Energy Act 2008</i>	DESNZ	Variations to existing Ninian Central Consent to Locate may be required for change in use of facility from oil and gas production to hydrogen production. New Consent to Locate may be required for the installation of additional offshore infrastructure.

Overarching Legislation	Administering Authority	Relevance to HOP2
Offshore Chemical Regulations 2002 (as amended)	OPRED	A Chemical Permit may be required for the release of any chemicals at sea.
Offshore Oil and Gas Exploration, Production, Unloading and Storage (Environmental Impact Assessment) Regulations 2020	DESNZ NSTA	HOP2 requires the undertaking of an EIA and ES.
<i>Petroleum Act 1998</i>	NSTA	A Pipeline Works Authorisation (PWA) will be needed to permit changes to the function of the export pipeline.
<i>Gas Act 1986</i>	NSTA	A licence is required to ship, transport or supply hydrogen.

4 Physical and Chemical Environmental Baseline

This section provides a description of the physical and chemical environment within the vicinity of the Ninian Central Platform and associated HOP2. An understanding of the existing environmental baseline will inform the assessment of risks associated with the proposed HOP2 described in Section 7.

Characteristics of the bathymetry, currents, meteorology, sea temperature, salinity and seabed sediments in the area of HOP2 are described in the following sections.

4.1 Location of Ninian Infrastructure

The Ninian Central Platform is a circular concrete gravity structure located in approximately 140 m of water in the NNS in UKCS Block 3/3, approximately 120 km east of the northern Shetland coastline and 23 km from the UK/Norway median line (Figure 4.1). The Ninian Northern Platform is located approximately 6.5 km northwest of Ninian Central Platform.

4.2 Bathymetry

The North Sea basin is shallow, varying from 30 to 200 m with the deep Norwegian Trench in the northeast margin reaching approximately 700 m depth. Depth in the UK sector of the NNS varies between 50 and 200 m (NSTF, 1993).

The depth within the vicinity of HOP2 development ranges from approximately 140 to 146 m (Fugro ERT, 2011).

4.3 Metocean Conditions and Coastal Processes

Several water masses exist in the North Sea with differing temperature, salinity and residual current patterns and/or stratification. These factors play a major role in the supply and dispersion of nutrients, plankton and fish larvae. The major water masses in the North Sea can be classified as Atlantic water, Scottish coastal water, NNS water, Norwegian coastal water, central North Sea (CNS) water, southern North Sea (SNS) water, Jutland coastal water and Channel water. The Ninian Central Platform is located in the area influenced most by the NNS water mass (Figure 4.1).

Over most of the North Sea, maximum tidal stream speeds vary from 0.25 to 0.5 m/s and reach in excess of 1.0 m/s around the Orkney and Shetland Islands (UKDMAP, 1998). Tidal currents in the location of HOP2 are typical of the NNS, with relatively weak surface current velocities and mean spring tides ranging from 0.11 to 0.25 m/s and neap tides below 0.11 m/s (ABPmer, 2016). Annual wave heights range between 2.51 and 2.75 m within Block 3/3 with the highest waves recorded in winter between 3.51 and 3.75 m.

4.4 Wind

In the vicinity of HOP2, winds vary seasonally and are characterised by large variations in wind direction and speed, frequent cloud and relatively high precipitation. The annual wind data indicates that winds in the area are multidirectional (Atkins, 2010). Within Block 3/3, annual wind speeds range between 10.0 and 11.0 m/s with the lowest speeds recorded in summer between 8.0 – 8.5 m/s and highest wind speeds recorded in winter between 12.5 and 13.0 m/s (ABPmer, 2016).

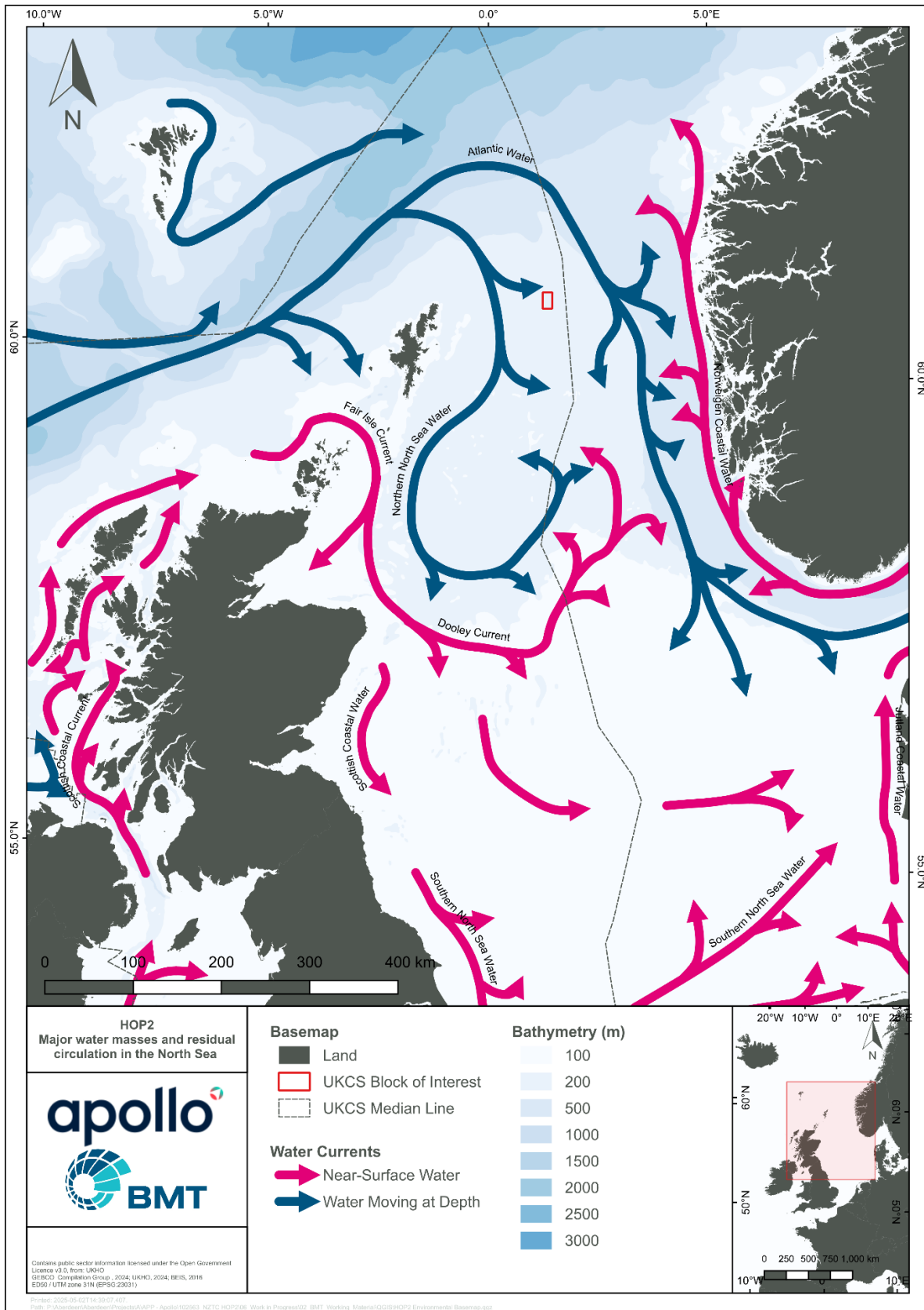


Figure 4.1 Water Currents in the Vicinity of the Ninian Central Platform

4.5 Sea Temperature and Salinity

In the North Sea, water temperature is relatively uniform throughout the water column during the winter months. Over the summer months, the increase in solar radiation can result in a thermocline, which separates an upper warmer less dense surface layer from the denser cooler water below (Gill, 1982). The strength of the thermocline is determined by the intensity of the input of solar heat and wind and tide generated turbulence. The depth at which the thermocline occurs in the NNS increases from May to September to a maximum depth of, approximately, 50 m in August and September (NSTF, 1993).

Table 4.1 provides information on the annual and seasonal sea surface salinity and temperature variation in the HOP2 area (1971 to 2000). Mean sea surface temperature is around 12 °C in the summer and 8 °C in the winter. Mean seabed water temperature is less variable, at around 7 °C in the summer and 8 °C in the winter (Berx & Hughes, 2009).

There is little seasonal variation in the salinity of the water column in the HOP2 area, which is around 35 parts per thousand (ppt).

Table 4.1 Typical values for temperature and salinity in the area of the Ninian Central Platform (1971 to 2000)

Parameter	March – May	June – August	September – November	December - February	Annual
Mean Sea Surface Temperature (°C)	7.65	11.98	10.54	8.24	9.60
Mean Seabed Temperature (°C)	7.15	7.38	8.35	8.14	7.75
Mean Sea Surface Salinity (ppt)	35.23	34.90	35.19	35.25	35.14
Mean Bottom Salinity (ppt)	35.27	35.27	35.30	35.26	35.28

Source: Berx & Hughes, 2009

4.6 Air quality

An understanding of the existing air quality in the area of a development is useful when assessing the potential future impact upon air quality from the proposed operations. However, data on air quality offshore is limited. Emissions of carbon dioxide, nitrous oxides and sulphur oxides will result from power generation from vessels during operations.

4.7 Sediment Characteristics

4.7.1 Sediment Types

Block 3/3 lies in an area of the NNS where much of the sediment is fine to coarse sand (Künitzer et al., 1992), with an approximate silt fraction of 5% and an organic fraction of 3% (Basford et al., 1990, Basford et al., 1989).

European Nature Information System (EUNIS) biotopes present within the UKCS Block 3/3 are characterised by MD52: Atlantic offshore circalittoral sand with a small area of MD32 Atlantic offshore circalittoral coarse sediment present within the southern portion of the block (EMODnet Seabed Habitats, 2024). Faunal communities associated with these biotopes are detailed in Section 5.2.

Sediment samples collected during the April/May 2011 Ninian Northern Platform pre-decommissioning environmental survey (approximately 6.5 km northwest of the HOP2 development area) consisted of very poorly to extremely poorly sorted very fine sand, and to a lesser degree fine sands, with mean diameters of 32 to 142 μm (Fugro ERT, 2011). Areas located close to the Ninian Northern Platform were classified as medium to coarse silt, with mean diameters of 31 to 39 μm , suggesting an input of drill cuttings. The silt/clay proportion in the samples near the platform ranged between 70.9 to 77.9%. The proportion of fine silt/clay material ranged from 18.5 to 70.8%, with silt material dominating (approximately 80% of total fines) in the samples further away from the platform.

The organic matter content of the sediment predominately ranged from 0.9 to 3.8% at all sampling sites apart from the two where it was 5.5 and 4.9%, respectively. Total carbonate (as calcium carbonate) and organic carbon levels ranged from 20.9 to 26.8% and 0.4 to 1.5% for most of the sampling sites. Samples close to the platform reported total carbonate levels of 42.4 and 48.8% and organic carbon levels of 2.7 and 1.2%, respectively. The elevated proportion of fines, higher organic content and differing granulometry at sampling sites to the platform were attributed to drilling activity at the platform (Fugro ERT, 2011).

4.7.2 Seabed Features

Based on the findings of the 2011 survey, seabed features are dominated by the Ninian Northern Platform drill cuttings pile and associated pipelines that run from the platform. There was no evidence of bedrock or biogenic reefs, pockmarks or unusual or irregular seabed forms (Fugro ERT, 2011). A large amount of seabed debris including wire spools, cables, scaffolding along with numerous boulders were also identified at the Ninian Northern Platform. It is presumed similar seabed features would be prevalent at HOP2; however further environmental surveys may be required to support the HOP2 as it progresses through to the development stage.

4.7.3 Sediment Chemical Properties

Chemical analysis of the seabed (concentrations of metals and hydrocarbons) provides an indication of the condition of seabed sediments in the area of the proposed operations. Sediment chemistry is an important factor in ecological investigations, with areas of fine sediments acting as sinks which have the potential to release their contaminant load following disturbance. The principal sources of hydrocarbons in the marine environment are anthropogenic; however, contamination of the marine environment with crude oils is not a recent phenomenon, nor solely attributable to anthropogenic activities (Douglas et al., 1981).

Though no specific chemical assessment has been undertaken at the HOP2 area, a summary of contaminants found in surface grab sediments collected during the 2011 Ninian Northern Platform Survey (Fugro ERT, 2011) is provided below:

- Total hydrocarbon (THC) levels in the Ninian Northern area ranged between 8.0 $\mu\text{g/g}$ at Station 17 to 1,390 $\mu\text{g/g}$ at Station 14 (mean 137 $\mu\text{g/g}$). Within 250 m of the Ninian Northern Platform the values exceed the background concentrations for THC in proximity to oil and gas installations;
- Polycyclic Aromatic Hydrocarbons (PAHs) ranged between 0.035 to 0.342 $\mu\text{g/g}$ (mean 0.164 $\mu\text{g/g}$) with higher concentrations of PAHs reported closer to the drill cuttings pile;
- Heavy metals testing indicated lead, mercury and cadmium exceeded background concentration values (0.29, 0.81, and 54.2 $\mu\text{g/g}$, respectively) within the first 250 m of the Ninian Northern Platform.

The chemical contaminants reported above from 2011 Ninian Northern Platform Survey (Fugro ERT, 2011) are anticipated to be broadly consistent with those within the immediate vicinity of HOP2.

5 Biological Environmental Baseline

This section provides a description of the biological environment within the vicinity of HOP2. These attributes will inform the assessment of risks associated with the proposed HOP2 described in Section 7. Note existing environmental surveys were carried out at the Ninian Northern Platform located approximately 6.5 km northwest of the Ninian Central Platform and where HOP2 infrastructure is proposed. It is expected that additional site-specific environmental surveys will be conducted as part of the broader EIA.

5.1 Regional Summary

HOP2 is located within the NNS, within the boundaries of Regional Sea 1 (between Flamborough front to the south) as defined under the UK Offshore Energy Strategic Environmental Assessment 4 (OESEA4) (BEIS, 2022). Regional Sea 1 has the following general biological characteristics:

- Moderate to high diversity and density of cetacean species from south to north. High densities of seals (particularly around the Northern Isles);
- Adjacent coastline represents an important migratory pathway for many Arctic breeding bird seabird species and seabird densities at sea are relatively high over much of the area; and
- Deeper waters of mud and muddy sand support an abundance of fish and *Nephrops* (Norway lobster).

5.2 Benthic Habitat Characterisation and Benthic Fauna

Deep water infaunal assemblages within the North Sea are characterised by the polychaetes *Prionospio cirrifera*, *Aricidea catherinae* and *Exogone verugera* and the bivalve mollusc *Thyasira* spp with high densities and species richness (Künitz et al., 1992).

Faunal communities within the EUNIS biotope MD52 include Maldanid polychaetes, *Eudorellopsis deformis*, *Owenia fusiformis* and *Amphiura filiformis* in deep circalittoral sand or muddy sand. Within the southernmost portion of Block 3/3, faunal communities of biotope MD32 consist of *Glycera lapidum*, *Thyasira* spp. and *Amythasides macroglossus* in offshore circalittoral gravelly sand and *Hesionura elongata* and *Protodorvillea kefersteini* in offshore circalittoral coarse sand (EMODnet Seabed Habitats, 2024).

The 2011 survey and seabed sampling indicate that the sediments of the Ninian Northern Platform survey area comprised of Holocene sediments of fine sands. Generally, macrofauna in the Ninian Northern Platform area were dominated by polychaetes (70.1% of taxa, and 72.4% of individual animals identified, respectively), followed by molluscs (20.9% of taxa and 24.7% of individuals) and echinoderms (4.7% of taxa and 0.7% of individuals). Sampling areas closer to the platform were dominated by increased numbers of cirratulid polychaetes, mainly *Chaetozone setosa* and *Cirratulus cirratu* where seabed disturbance was prevalent. Hydrocarbon intolerant species *Galathowenia oculata*, *Eclysippe vanelli*, *Amythasides macroglossus* were also observed up to 100 m away from the platform. Conversely, bivalves *Adontorhina similis*, *Axinulus croulinensis* and *Parvicardium minimum*, and the polychaetes *Paramphinoe jeffreysii*, *Galathowenia oculata*, *Pholoe assimilis* and *Paradoneis lyra* dominated areas more than 100 m away from the platform (Fugro ERT, 2011).

Visible epifauna and mobile megafauna were generally sparse across the survey area, however taxa encountered included *Paguridae* spp. (hermit crabs); *Ophiura* spp. (brittlestar); species of *Asteroidea* (starfish); *Echinocardium* spp. (sea urchins); and tubes of *sabellid* polychaetes. On some boulders and

debris anemones (*Thenaria* spp.) were also evident. Fish, mostly gadoid species and flatfish, were abundant around the platform but sparse across the rest of the survey area (Fugro ERT, 2011).

5.3 Plankton

The majority of the plankton occurs in the photic zone, the upper 20 m of the sea which receives enough light for photosynthesis to occur (Johns & Reid, 2001). The composition of the plankton community reflects environmental conditions such as salinity, temperature, water movements in the area and the presence of local benthic communities that have planktonic larval stages.

The phytoplankton community in the NNS is dominated by the dinoflagellate genus *Ceratium* (Johns & Reid, 2001). The zooplankton communities of the northern North Sea are dominated by copepods, predominantly *Calanus* spp. (Johns & Reid, 2001), mainly *Calanus finmarchicus* and *Calanus helgolandicus*, as well as smaller species such as *Para-Pseudocalanus* spp. and *Acartia* spp. (DTI, 2001). The larger zooplankton (or megaplankton) includes the Euphausiida (krill), Thaliacea (salps and doloids), Siphonophora and Medusae (jellyfish). Blooms of salps and doloids produce large swarms in late summer to October. Siphonophores (colonial hydrozoa) can also reach large densities in the North Sea. Peak plankton productivity occurs during the spring and summer months with inflowing warm, nutrient rich water from the north Atlantic promoting earlier stratification (BEIS, 2022).

5.4 Marine Growth

Over time offshore platforms are likely to become colonised by marine fauna. Steel and concrete platforms provide new attachment sites for marine life and, in effect, become artificial reefs. Algal spores and invertebrate larvae rapidly colonise submerged areas of the structures, establishing a 'biofouling' assemblage (Wolfson et al., 1979). Unless protected by anti-fouling measures, any marine structure is liable to become fouled. Organisms that typically colonise platforms in the North Sea include seaweeds and kelp (algae), hydroids, soft corals, anemones, sponges, tubeworms, hard corals and mussels.

Subsea inspections and marine growth surveys carried out on the Ninian Northern Platform concluded extensive cover of marine growth (CNR International, 2016). The main species identified was *Lophelia pertusa* on the platform conductor, particularly at depths greater than 80 m. Average thickness was reported between 64 to 230 mm with percentage cover ranging from between 5 to 55% (CNR International, 2016).

5.5 Fish and Shellfish Spawning and Nursery Grounds

Adult and juvenile stocks of finfish and shellfish are an important food source for seabirds, marine mammals and other fish species. Species can be categorised into pelagic and demersal finfish and shellfish:

- Pelagic species occur in shoals swimming in mid-water, typically making extensive seasonal movements or migrations between sea areas. Examples include herring, mackerel, blue whiting and sprat;
- Demersal species live on or near the seabed and include cod, haddock, plaice, sandeel, sole, and whiting;
- Shellfish species are demersal (bottom-dwelling) molluscs, such as mussels and scallops, and crustaceans, such as shrimps, crabs and *Nephrops*.

Generally, there is little interaction between fish species and offshore developments. Some fish and shellfish species are, however, vulnerable to some offshore activities, such as discharges to sea. The

most vulnerable period for fish species is during the egg and juvenile stages of their life cycles. Fish that lay their eggs on sediment or live in contact with sediments are susceptible to smothering by discharges and displaced sediment (Coull et al., 1998).

The Ninian Central Platform and HOP2 are located within International Council for the Exploration of the Sea (ICES) Rectangle 50F1. This ICES rectangle coincides with low intensity spawning grounds for cod (*Gadus morhua*), Norway pout (*Trisopterus esmarkii*) and saithe (*Pollachius virens*) between January and April, haddock (*Melanogrammus aeglefinus*) from February to May, sandeels (*Ammodytidae* spp.) from November to February and whiting (*Merlangius merlangus*) from February to June (Ellis et al., 2010; Coull et al., 1998).

ICES Rectangle 50F1 also support nursery grounds for monkfish (*Lophius piscatorius*), blue whiting (*Micromesistius poutassou*), European hake (*Merluccius merluccius*), haddock, herring (*Clupea harengus*), ling (*Molva molva*), mackerel (*Scomber scombrus*), Norway pout, sandeel, spurdog (*Squalus acanthias*) and whiting (Ellis et al., 2010; Coull et al., 1998).

5.6 Marine Mammals

Marine mammals include whales, dolphins and porpoises (cetaceans), and seals (pinnipeds). Marine mammals may be vulnerable to the effects of offshore anthropogenic activities and can be impacted by noise, contaminants, oil spills and effects on prey availability (SMRU, 2001). The abundance and availability of prey, including plankton and fish, can be of prime importance in determining the numbers and distribution of marine mammals and can also influence their reproductive success or failure.

5.6.1 Cetaceans

Cetaceans within the North Sea can be divided into two main categories: baleen whales (Mysticetes) which feed by sieving water through a series of baleen plates; and toothed whales (Odontocetes) which have teeth for prey capture. These cetaceans are widely distributed in UK waters and are recorded throughout the year (Reid et al., 2003; UKDMAP, 1998). Cetacean distribution may be influenced by variable natural factors such as water masses, fronts, eddies, upwellings, currents, water temperature, salinity and length of day. Moreover, availability of prey, mainly fish, plankton and cephalopods is a major factor likely to influence cetacean distribution.

The cetaceans typically present within the vicinity of HOP2 are the minke whale (*Balaenoptera acutorostrata*), long-finned pilot whale (*Globicephala melas*), killer whale (*Orcinus orca*), white-beaked dolphin (*Lagenorhynchus albirostris*) and the harbour porpoise (*Phocoena phocoena*) (Reid et al., 2003; UKDMAP, 1998) with sightings occurring throughout the year. The Harbour porpoise was recorded in very high numbers during February.

Table 5.1 provides a breakdown of the expected population distribution across a year for each of these species. Of the cetacean species recorded in offshore UK waters, the harbour porpoise and white-beaked dolphin are the most widespread and frequently encountered species, occurring regularly throughout most of the year, with very high numbers recorded in July for both species (BEIS, 2022). The harbour porpoise and other marine mammal species listed in Table 5.1 are mobile species on the PMF list, designated to receive appropriate protection and conservation measures.

Minke whales occur throughout the central and NNS as a seasonal visitor, particularly during summer months (BEIS, 2022; SMRU, 2001). They appear to move into the North Sea at the beginning of May and are present throughout the summer until October.

Killer whales have a worldwide distribution and are widely distributed in the deep North Atlantic and in coastal waters of northern Europe, particularly around Iceland, the Faroe Islands and western Norway. In UK waters they are most common off northern and western Scotland and occur in all months of the

year with increasing frequency towards the north of the area during the summer (BEIS, 2022). Between Shetland and Norway, the species is regularly recorded from November to March (Reid et al., 2003). No overall population estimates exist for killer whales in the Northeast Atlantic or UK waters (BEIS, 2016).

White-beaked dolphins are distributed over the continental shelf, and in the North Sea they tend to be more numerous within about 200 nm of the Scottish and north-eastern English coasts (Northridge et al., 1997). In 2022, the highest densities of white-beaked dolphins were estimated around the Shetland Islands, NNS, and in northwest Scotland (Giles et al., 2023). White-beaked dolphins are present year-round in the North Sea, with most sightings recorded between June and October (Reid et al., 2003; UKDMAP, 1998). Initial estimates for the total abundance of white-beaked dolphins in UK waters based on are approximately 67,138 individuals (Gilles et al., 2023).

The harbour porpoise is the most common cetacean in UK waters (BEIS, 2022). It is present throughout most of the North Sea throughout the year, with higher numbers occurring between May and October. Highest densities in summer are generally found north of 56 °N, mostly in a north-south band between 1 °E and 3 °E (SMRU, 2001). The northern and central areas of the North Sea appear to be important areas for harbour porpoises, especially in summer (BEIS, 2016; SMRU, 2001). The harbour porpoise is generally described as a coastal species, but there have been numerous sightings in deep, offshore waters. Abundance estimates of harbour porpoise calculated 339,000 individuals within the North Sea (Gilles et al., 2023)

Around the UK, long-finned pilot whales occur mainly along the continental shelf slope, particularly around the 1,000 m isobath (BEIS, 2022). The long-finned pilot whale is considered an occasional visitor of the NNS with moderate densities observed in the May (Reid et al., 2009; UKDMAP, 1998). There are currently no estimates of pilot whale abundance in UK waters (BEIS, 2016).

Table 5.1 Seasonal Cetacean Sightings around HOP2

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minke whale							L					
Long-finned pilot whale								M				
Killer whale					M							
White-beaked dolphin		M	M			L	VH					
Harbour porpoise	L	VH		L	L	L	VH	M	L			L
Key		No Data										
	L	Low densities (0.01 to 0.09 animals/km ²)										
	M	Moderate densities (0.10 to 0.19 animals/km ²)										
	H	High densities (0.20 to 0.49 animals/km ²)										
	VH	Very high densities (≥ 0.50 animals/km ²)										

Source: Reid et al., 2003; UKDMAP, 1998

SCANS Data

The Small Cetaceans in European Atlantic waters and the North Sea (SCANS) is a major international survey which studies the population distribution of cetaceans in Europe Atlantic waters. Survey data is obtained using aerial and shipboard surveys and provide information on changes in abundance and

distribution over a period of almost three decades, with the latest carried out in the summer of 2022 (SCANS-IV) (Gilles et al., 2023). The Ninian Central Platform is located within the SCANS III survey block U and SCANS IV survey block NS-F. Where SCANS survey data is available, abundance and density statistics are summarised in the following paragraphs. Note there is insufficient SCANS survey data to report on long-finned pilot whale and killer whale species.

Within SCANS-III survey block U, the Minke whale has an abundance of 895 animals, with an estimated density of 0.0150 per km² for the entire survey block (Hammond et al., 2017). For the immediate vicinity around the HOP2, density surface modelling indicates a density of 0.02 - 0.05 individuals per km² (Lacey et al., 2022). Within SCANS-IV survey block, the abundance is 1,630 animals, with an estimated density of 0.0271 per km² for the entire survey block (Gilles et al., 2023).

White-beaked dolphin reported 18,350 individuals within the SCANS-IV survey block NS-F, with an estimated density of 0.3056 per km². For the immediate vicinity around HOP2, density surface modelling indicates a density of 0 – 0.05 individuals per km² (Lacey et al., 2022). SCANS survey data for the harbour porpoise reported an abundance of 19,269 and 26,383 individuals and an estimated density of 0.32 and 0.44 individuals per km² within SCANS-III survey block U and SCANS-IV survey block NS-F respectively (Hammond et al., 2017; Gilles et al., 2023). Density surface modelling reports a density of 0.25 – 0.5 individuals per km² for the HOP2 area (Lacey et al. 2022).

5.6.2 Pinnipeds

Two species of seal are resident in UK waters, the grey seal (*Halichoerus grypus*) and the harbour or common seal (*Phoca vitulina*), both occurring regularly over large parts of the North Sea. Large numbers of grey and harbour seals breed within the NNS with higher densities observed in coastal waters (BEIS, 2022).

Grey Seals

The northeast Atlantic contains approximately half of the world's population of grey seals with, approximately, 38% occurring in the UK. The population size within UK waters has been estimated at 111,600 (BEIS, 2016). Approximately 84% of the UK population of grey seals breed in Scotland, mainly in the Hebrides and Orkney. Major colonies are also present on Shetland and the east coast of Scotland (BEIS, 2022).

The majority of the grey seal population will be on land for several weeks from October to December during the pupping and breeding seasons, and again in February and March during the annual moult. Densities of grey seals offshore are likely to be lower during these periods (BEIS, 2016). Satellite tracking data indicates average foraging trips for grey seal are typically up to 20 km from shore, with maximum trip lengths of over 150 km recorded for adults and pups respectively (BEIS, 2022). Therefore, while uncommon, grey seals may be present in the vicinity of HOP2.

Harbour Seals

Harbour (common) seals are one of the most widespread pinnipeds with almost circumpolar distribution in the Northern Hemisphere. Within UK waters they belong to a European sub-species, which mainly occur in UK, Icelandic, Norwegian, Swedish, Danish, German and Dutch waters. Approximately 30% of this population occurring in UK waters (BEIS, 2016). The harbour seal strongholds within the UK are Shetland, Orkney, the east coast of the Outer Hebrides, most of the Inner Hebrides and the west coast of Scotland, the Moray Firth and the Firth of Tay. Harbour seal counts in the UK are estimated at a minimum of 28,000 animals, the vast majority of which are found in Scotland (BEIS, 2022). Harbour seals haul out on tidally exposed areas of rock, sandbanks or mud. Pupping occurs on land between June and July, and the moult between August and September (BEIS, 2016).

Tracking of seals suggests they make feeding trips lasting two to three days, travelling less than 40 km from their haul-out sites and ultimately returning to the same haul-out site from which they departed. As the HOP2 area is a significant distance (more than 120 km) from the nearest coastline, it is unlikely that harbour seals would be found in the vicinity of the HOP2 area.

5.7 Seabirds

As denoted in the Section 5.1, much of the North Sea and its surrounding coastline is an internationally important breeding and feeding habitat for seabirds. Shetland and the north-east coast of Scotland support an array of seabird colonies. Bird species that frequent the HOP2 area throughout the year include the common guillemot (*Uria aalge*), northern fulmar (*Fulmarus glacialis*), razorbill (*Alca torda*), Atlantic puffin (*Fratercula arctica*), northern gannet (*Morus bassanus*), black-legged kittiwake (*Rissa tridactyla*), and great black-backed (*Larus marinus*), herring (*Larus argentatus*) and lesser black-backed (*Larus fuscus*) gulls (BEIS, 2022). Other species such as the glaucous gull (*Larus hyperboreus*), manx shearwater (*Puffinus puffinus*), arctic skua (*Stercorarius parasiticus*) and great skua (*Stercorarius skua*) also appear in significant numbers but typically have more localised distributions or specific seasonal patterns.

A number of seabird species, including the arctic tern, great skua, great black-backed gull, puffin and kittiwake, are on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species, meaning they are critically endangered. It should also be noted that the foraging area for adult seabirds taking prey to nests in coastal cliff colonies can be up to 300 km. Kittiwakes in particular are known to nest on offshore structures from mid-April.

The JNCC has released the latest analysed trends in abundance, productivity, demographic parameters and diet of breeding seabirds, from the Seabird Monitoring Programme (Harris et al., 2024). This data provides at-a-glance UK population trends as a percent of change in breeding numbers from complete censuses of 25 species of seabird that breed regularly in Britain and Ireland. From the years 2000-2023, the following population trends for species known to use the HOP2 area have been recorded within Scotland: northern fulmars (-40%), arctic skua (-71%), black-legged kittiwake (-40%), great black-backed gull (-70%), herring gull (-43%), razorbill (+16%), common guillemot (-25%), lesser black-backed gull (-63%) (Harris et al., 2024).

Kober et al. (2010) analysed European Seabirds at Sea (ESAS) density data for seabirds within the British Fishery Limit to identify 'hotspots,' with a view to assigning these marine areas SPA status. Several hotspots for seabirds have been identified around UK, however, none of these overlap with the HOP2 area. The nearest is Fetlar SPA off the coast of Shetland more than 120 km from the proposed HOP2 area. Table 5.2 presents predicated maximum monthly density of seabirds in the HOP2 area (Kober et al., 2010). Seabird density surface maps were developed to generate continuous density surface maps for 32 species and seabirds' assemblages. The most abundant species found in the area are northern fulmar, great black-backed gull, lesser black-backed gull, common guillemot, Atlantic puffin and black-legged kittiwake (Kober et al., 2010).

Table 5.2 Predicted Monthly Surface Density of Seabirds in the HOP2 Area

Species	Season	Month											
		J	F	M	A	M	J	J	A	S	O	N	D
Northern Fulmar <i>Fulmarus glacialis</i>	Breeding												
	Winter												
Northern Gannet <i>Morus bassanus</i>	Breeding												
	Winter												

Species		Season	Month											
			J	F	M	A	M	J	J	A	S	O	N	D
Arctic Skua	<i>Stercorarius parasiticus</i>	Breeding												
Great Skua	<i>Stercorarius skua</i>	Breeding												
		Winter												
Black-legged Kittiwake	<i>Rissa tridactyla</i>	Breeding												
		Winter												
Great Black-backed Gull	<i>Larus marinus</i>	Breeding												
		Winter												
Common Gull	<i>Larus canus</i>	Breeding												
		Winter												
Lesser black-backed gull	<i>Larus fuscus</i>	breeding												
		winter												
Herring Gull	<i>Larus argentatus</i>	Breeding												
		Winter												
Glaucous gull	<i>Larus hyperboreus</i>	winter												
Arctic tern	<i>Sterna paradisaea</i>	breeding												
Common Guillemot	<i>Uria aalge</i>	Breeding												
		Additional												
		Winter												
Razorbill	<i>Alca torda</i>	Additional												
Little Auk	<i>Alle alle</i>	Winter												
Atlantic Puffin	<i>Fratercula arctica</i>	Breeding												
		Winter												
All species combined		Breeding												
		Summer												
		Winter												

Key

Seabirds' density (numbers per km ²)	Not recorded	<1.0	1.0 – 5.0	5.1 – 10.0	10.1 – 20.0	>20.0
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Source: (Kober et al., 2010)

5.8 Offshore Conservation Areas

Designated conservation sites are widespread and abundant around the UK coastline and in the marine environment. Numerous levels of designation exist from statutory international to local voluntary schemes. These afford differing levels of protection for habitats, species, as well as geological, cultural and landscape features. More widespread designations include the SACs, SPAs, Ramsar Sites and the Sites of Special Scientific Interest (SSSIs). In addition, the MCAA has introduced measures for the designation of marine protected areas, known as MCZs in England.

There are no designated conservation areas that overlap with HOP2 infrastructure. The nearest SAC is the Pobie Bank Reef located 74 km west from HOP2 (refer to Figure 5.1). This SAC provides habitat to an extensive community of encrusting and robust sponges and bryozoans.

The closest NCMPA is the Fetlar to Haroldswick NCMPA, located 123 km to the west of HOP2 (refer to Figure 5.1) which supports the following features: black guillemot, circalittoral sand and coarse

sediment communities, horse mussel beds, kelp and seaweed communities on sublittoral sediment, maerl beds and shallow tide-swept coarse sands with burrowing bivalves.

There are no other Ramsar Sites or SSSIs within the vicinity of HOP2.

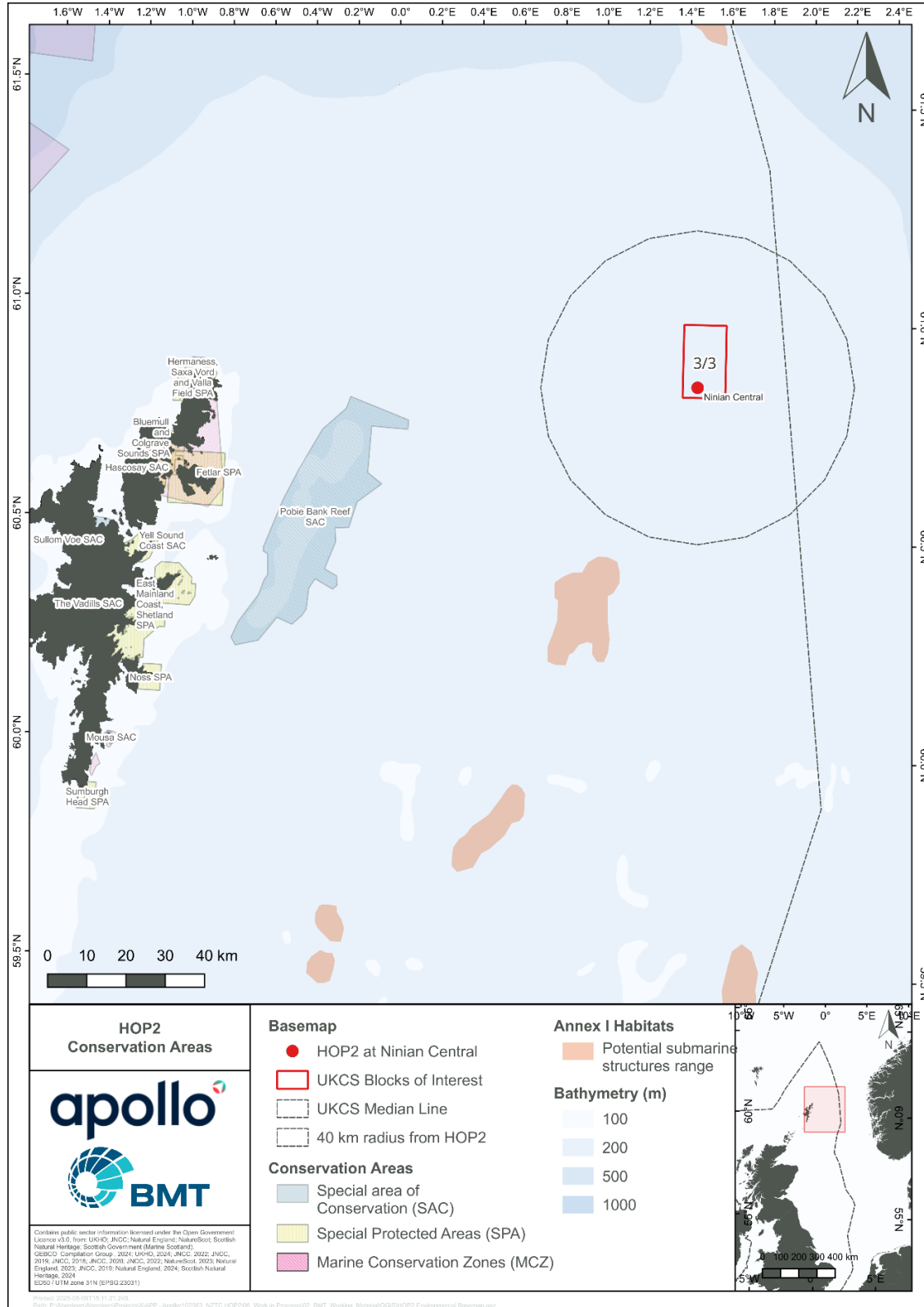


Figure 5.1 Conservation Areas in the vicinity of HOP2

5.8.2 Special Areas of Conservation

The UK government, with guidance from the JNCC and the Department of Environment, Food and Rural Affairs (DEFRA), had statutory jurisdiction under the EC Habitats Directive to propose offshore areas or species (based on the habitat types and species identified in Annexes I and II) to be designated as SACs. The UK's departure from the EU does not alter the standard of protection for these sites. Within UK offshore waters there are currently 24 designated SACs. Table 5.3 lists Annex I habitats and Annex II species of the European Union Habitats Directive (92/43/EEC) that have been considered for the identification of marine SACs.

The only Annex II species sighted within the HOP2 area is the harbour porpoise sighted in very high numbers in February and July and in low to moderate numbers during the rest of the year (Reid et al., 2003). Harbour and grey seals have also been observed in large numbers in the NNS, however predominately within coastal waters a significant distance away from the HOP2 area.

Table 5.3 Annex I Habitats and Annex II Species known to occur in UK Offshore Waters

Annex I habitats considered for SAC selection in UK offshore waters	Annex II species considered for marine SAC selection in UK waters
- Sandbanks which are slightly covered by seawater all the time. - Reefs (bedrock, biogenic and stony). - Bedrock reefs – made from continuous outcroppings of bedrock which may be of various topographical shapes. - Stony reefs – these consist of aggregations of boulders and cobbles which may have some finer sediment in interstitial spaces. - Biogenic reefs – formed by cold water corals (e.g., <i>Lophelia pertusa</i> and <i>Sabellaria spinulosa</i>). - Submarine structures made by leaking gases	- Harbour porpoise - Harbour seal - Grey seal - Bottlenose dolphin

5.8.3 Special Protection Areas

The Fetlar SPA and Hermaness, Saxa Vord and Valla Field SPA are both located 123 km west of HOP2 while the East Mainland Coast, Shetland SPA is situated approximately 139 km to the west. SPAs are protected areas which have been classified in accordance with Article 4 of the Conservation of Offshore Marine Habitats and Species Regulations 2017 (as amended) in the UK offshore area. They are classified based on the location of rare and vulnerable birds and for frequently occurring migratory species which are listed on Annex I of the Directive.

Due to the significant distance from HOP2 infrastructure, impacts to protected features within these conservation areas is considered negligible.

6 Socioeconomic Environment

This section provides information on the broader social and economic considerations within the HOP2 area. For offshore developments consideration is given to the potential impact on other sea users, such as the fishing and shipping industries, the renewable energy sector, and military operations. The existence of submarine cables, historic wrecks and oil and gas installations is also considered.

Socioeconomic considerations can also include changes in demographics and to communities, direct and indirect effects on employment, expenditures and incomes, and economic benefits to the wider area resulting from the proposed development. However, no attempt has been made to quantify these potential changes, and social benefits are only discussed in the context of potential economic impacts.

6.1 Commercial Fisheries

HOP2 is located within ICES rectangle 50F1. The ICES rectangles provide fisheries information for areas measuring 30 x 30 nm including fishing effort (which is defined by number of days multiplied by fleet capacity), fishing quantity (live weight of demersal, pelagic and shellfish landed by UK vessels) and value. It should be noted, however, that fishing activity may not be uniformly distributed over the whole area of the ICES rectangle; nevertheless this information provides a reasonable approach to quantify commercial fisheries within the region.

6.1.1 Fishing Effort and Value

The relative quantity and values of fish landed from ICES rectangle 50F1 are provided in Table 6.1. In 2023, total catch was made up of 67.94% pelagic species followed by demersal species accounting for 31.90% of total catch, while shellfish species were the remaining catch (0.16%). Between 2019 and 2023, the annual total live weight of fish landed from ICES rectangle 50F1 ranged from 1,201 tonnes in 2020 to 6,499 tonnes in 2023 (Scottish Government, 2024). Total annual value in ICES rectangle 50F1 was between £2,141,777 in 2020 and £8,470,359 in 2023.

Mackerel was the most valuable species caught in 2023 making up approximately 50% of the 2023 total catch value of £4,258,348 and a total weight landed of 3,139.01 tonnes. This was followed by Haddock, which had 754.75 tonnes landed in 2023, and a value of £859,148.58 (Scottish Government, 2024).

Table 6.1 Total Fishing Effort and Values for 2019 to 2023 within ICES Rectangle 50F1

Year	Total value (£)	Species type	Value (£)	Percentage of value (%)	Total quantity (tonnes)	Species type	Quantity (tonnes)	Percentage of quantity (%)	Effort (Days)
2023	8,470,359	Demersal	3,664,653	43.26	6,499	Demersal	2,073.00	31.90	361
		Pelagic	4,761,116	56.21		Pelagic	4,415.46	67.94	
		Shellfish	44,590	0.53		Shellfish	10.30	0.16	
2022	2,794,193	Demersal	2,686,209	96.14	1,690	Demersal	1,489.34	88.12	273
		Pelagic	98,906	3.54		Pelagic	197.81	11.70	
		Shellfish	9,077	0.32		Shellfish	2.94	0.17	
2021	6,422,918	Demersal	4,565,900	71.09	5,610	Demersal	2,437.95	43.45	445
		Pelagic	1,832,850	28.54		Pelagic	3,164.71	56.41	
		Shellfish	24,167	0.38		Shellfish	7.69	0.14	
2020	2,141,777	Demersal	2,111,828	98.60	1,201	Demersal	1,193.46	99.39	252
		Pelagic	-	0.00		Pelagic	-	-	
		Shellfish	29,949	1.40		Shellfish	7.35	0.61	

2019	2,768,025	Demersal	2,734,433	98.79	1,521	Demersal	1,516.74	99.72	282
		Pelagic	784	0.03		Pelagic	0.34	0.02	
		Shellfish	32,808	1.19		Shellfish	3.89	0.26	

Source: Scottish Government, 2024

6.2 Other Offshore Infrastructure

6.2.1 Oil and Gas

Oil and gas development in this region of the North Sea is relatively intensive. There are several oil and gas developments close to HOP2. Surface infrastructure within 40 km of HOP2 is presented in Table 6.2. The location of these platforms in relation to HOP2 are displayed in Figure 6.1.

There are a total of 1,419 wells and 369 pipelines located within 40 km of HOP2.

Table 6.2 Oil and Gas Developments within 40 km Radius of HOP2 (Ninian Central Platform)

Platform/Subsea Structure	Block containing platform/ structure	Distance (km)	Direction from site/ block	Status
Strathspey	3/4	15	Northeast	Post Cease of Production
North Alwyn A	8/9	16	East	Active
North Alwyn B	8/9	16	East	Active
Brent A	211/29	24	Northeast	Decommissioned
Brent B	211/29	26	Northeast	Decommissioned
Brent C	211/29	30	Northeast	Decommissioned
Brent D	211/29	33	Northeast	Decommissioned
Cormorant A	211/26	35	Northwest	Active
Dunbar	3/14	29	Southeast	Active
Ninian Northern	3/3	6	North	Active
Ninian Southern	3/8	6	South	Active
Heather A	2/5	31	Northwest	Active

Source: NSTA (2025)

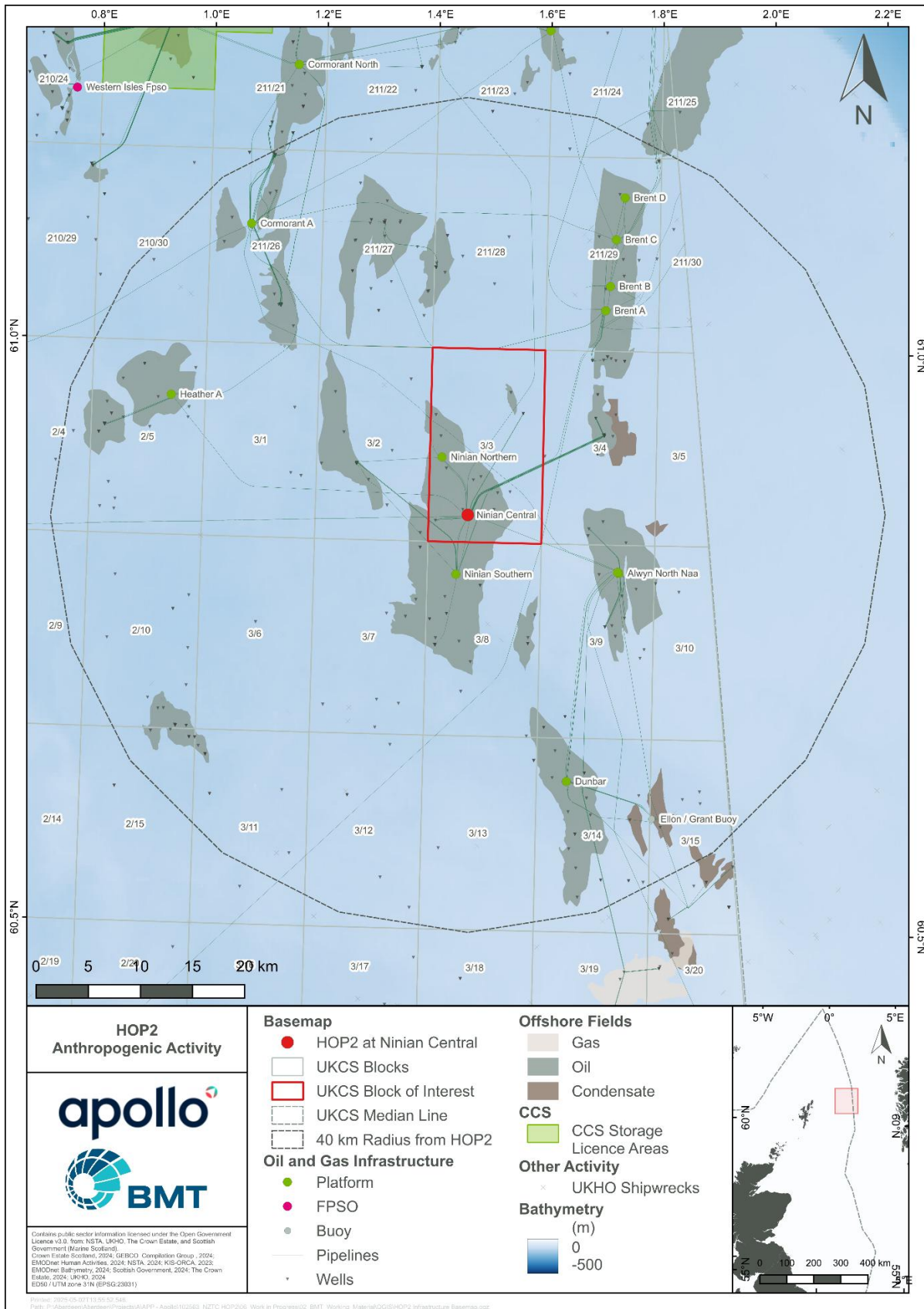


Figure 6.1 Infrastructure within proximity of HOP2

6.2.2 Windfarms and Carbon Capture Storage

There are no offshore wind developments or planned carbon capture storage projects in close vicinity of HOP2 (within a 40 km buffer). The nearest is the planned Stoura Offshore Wind Farm approximately 85 km southwest of HOP2 (EMODnet, 2024).

6.2.3 Telecommunication and Cabling

There are no telecommunication cables within vicinity of HOP2 in Block 3/3. The nearest is the KIS-ORCA over 73 km west beyond the UKCS Median Line (Kis-Orca, 2023).

6.3 Shipping

Vessel traffic in Block 3/3 is considered Moderate, however most vessel movements are associated with service vessels utilised for existing oil and gas infrastructure (NSTA, 2016; EMODnet, 2024).

6.4 Aggregate and Mineral Extraction

Aggregates are mixtures of sand, gravel, crushed rock or other bulk minerals used in construction, principally as a component of concrete. Most UK dredging sites are located in the SNS with the main region of aggregate extraction in the North Sea being the Humber Region (DTI, 2001).

There are currently no marine aggregate application options or licensing sites in Scottish waters.

6.5 Military Activity

Military operations in Scottish waters include the triennial exercises run jointly by the Royal Navy and the Royal Air Force. These exercises include operations to the north and east of Scotland. Several areas of the inner and outer Moray Firth, including an extensive area to the east of Orkney, are used by the Air Force for activities which include radar training, high and low-angle gunnery and air to sea or ground firing (DTI, 2001).

There are no recorded historic military disposal sites, nor licence conditions applied to Block 3/3 by DESNZ on behalf of the Ministry of Defence (MoD) within, or close, to HOP2. Notification to the MoD of offshore construction and surveys is not required.

6.6 Marine Archaeology and Wrecks

There are 3 shipwrecks located within the main block of interest (3/3) and a total of 77 wrecks within a 40 km radius of HOP2. Of these, 4 wrecks are named:

- North West Hutton Jacket (part of) located 29 km northwest within Block 211/27;
- Fertile II located 22 km Southwest within Block 3/7;
- Brent Alpha Jacket (part of) located 24 km northeast within Block 211/29; and
- Blagdon (possibly) located 18 km northeast within Block 3/4 (UKHO, 2024).

None are classed as designated Protected Wrecks.

6.7 Summary of Environmental Sensitivities

Table 6.3 Provides a summary of environmental sensitivities for the HOP2 area.

Table 6.3 Key Environmental Sensitivities in the Vicinity of HOP2

Aspect	Detail
Offshore conservation interests	
Protected areas	There are no protected areas in the vicinity of HOP2. The closest, Pobie Bank Reef SAC, is located 74 km west of HOP2 (refer to Figure 5.1). The Fetlar to Haroldswick NCPMA is situated 123 km west of HOP2.
Annex I habitats	There are no known Annex I habitats in the vicinity of HOP2.
Annex II species	The only Annex II species sighted within the area is the harbour porpoise, sighted in very high numbers in February and July and in low to moderate numbers during the rest of the year (Reid et al., 2003; UKDMAP 1998).
Physical and chemical characteristics	
Bathymetry and metocean conditions	Depth within the vicinity of HOP2 development ranges from approximately 140 to 146 m (Fugro ERT, 2011). Tidal currents in the location of HOP2 are typical of the NNS, with relatively weak surface current velocities and mean spring tides ranging from 0.11 to 0.25 m/s and neap tides below 0.11 m/s (ABPmer, 2016). Annual wave heights range between 2.51 and 2.75 m.
Sediment chemical properties	Though no specific chemical assessment has been undertaken at the HOP2 area, Sediment properties from the Ninian Northern Platform Survey (Fugro ERT, 2011) indicated THC levels between 8.0 µg/g and 1,390 µg/g, PAHs between 0.035 to 0.342 µg/g heavy metals including lead, mercury, and cadmium exceeding background concentration values.
Environmental characteristics and sensitivities	
Plankton	The plankton in the HOP2 area is typical of the northern North Sea. Peak productivity occurs in spring and summer (BEIS, 2022).
Habitat characterisation and benthic fauna	HOP2 lies in an area of the NNS where sediment is composed of fines and coarse sand (Künitzer et al., 1992). Surveys around the Ninian Northern Platform and proposed HOP2 ranged from poorly sorted very fine sand to a lesser degree fine sands (Fugro ERT, 2011). EUNIS Biotopes within UKCS Block 3/3 are characterised by Atlantic offshore circalittoral sand (MD52) and Atlantic offshore circalittoral coarse sediment (MD32) (EMODnet Seabed Habitats, 2024). Benthic communities in the HOP2 area are similar to those found throughout a large surrounding area of the northern North Sea (BEIS, 2022).
Fish spawning areas	HOP2 is located in low intensity spawning grounds for cod, Norway pout and saith (Jan to Apr), sandeels (Nov to Feb) and whiting (Feb to Jun) (Coull et al., 1998; Ellis et al., 2010).
Fish nursery areas	HOP2 is located in nursery grounds for herring, ling, mackerel, spurdog, haddock, Norway pout, blue whiting, sandeels, whiting, monkfish and European hake (throughout the year) (Coull et al., 1998; Ellis et al., 2010).
Marine mammals	Marine mammals sighted in and around the HOP2y area include minke whales, long finned pilot whale, killer whale, white beaked dolphins, and harbour porpoises. Peak sightings predominantly occur in the summer months (Reid et al., 2003; UKDMAP1998; Gilles et al., 2023). Grey seals have been recorded undertaking foraging trips of up to 150 km. While such occurrences are uncommon, individuals may still be present in the vicinity of HOP2.
Seabirds	The most abundant bird species found in the area throughout the year are the northern fulmar, great black-backed gull, lesser black-backed gull, common guillemot, atlantic puffin, razorbill, northern gannet, herring and black-legged kittiwake (Kober et al., 2010). There are no seabird hotpots within proximity to HOP2.
Societal characteristics and sensitivities	
Fisheries	Total annual value in ICES rectangle 50F1 was £8,470,359 in 2023. Of the total commercial catch in 2023, 4,415 tonnes of pelagic species, 2,073 tonnes of demersal species, and only 10 tonnes of shellfish species were caught (Scottish Government, 2024).
Shipping	Shipping density in the vicinity of the HOP2 (UKCS Block 3/3) is classified as "moderate" (NSTA, 2016; EMODnet, 2024).
Oil and gas industry	HOP2 lies within an area of high oil and gas intensity. There are 12 surface infrastructure located within 40 km radius of HOP2.
Other users of the sea	In the vicinity of the HOP2 there are no recorded military activities or offshore renewable developments. The nearest cable is over 73 km west beyond the UKCS Median Line (DTI, 2001; Kis-Orca, 2023). There are also 77 identified shipwrecks within a 40 km radius of HOP2.

7 Summary of Potential Impacts

The following sections outlines the potential impacts associated with the construction and operation of HOP2. Note as HOP2 is still in the early design phases, this is a preliminary overview based on likely impacts associated with hydrogen production facilities.

7.1 Seabed Disturbance

Seabed disturbance may occur during the installation and removal of infrastructure and protective material. Seabed disturbance can result in habitat loss, disturbance to seabed communities or smothering resulting from plumes of displaced sediment, with potential impacts on protected sites and the habitats and the species supported by them.

HOP2 will predominately consist of remodifying the existing substructure of the Ninian Central Platform accompanied with new-build topsides. This will include reconfiguration of subsea telecommunication and electricity cables, hydrogen export pipeline and seawater lift. Seabed disturbance may take the form of temporary disturbance (e.g. smothering of marine organisms from sediment displacement) or longer-term impacts including permanent habitat change. Repurposing existing subsea infrastructure is expected to omit the need for activities such as pile driving or drilling which may cause greater damage to the seabed and benthic habitat.

7.1.1 Permanent Habitat Change

Long term impacts may occur through the introduction of permanent features to the benthic environment. As such, the addition of new infrastructure, or protection materials, may lead to direct loss of benthic species and communities or loss of natural habitat. Specifically, localised impacts to epifauna and infauna due to direct physical disturbance to the seabed through crushing, physical abrasion and burial. Smothering of animals may also lead to direct mortality of sessile seabed organisms that cannot move away from the contact area. Seabed infrastructure will alter the physical characteristics of the seabed, transforming natural sandy benthic habitats into a stable, hard substrate. Over time, this newly created hard substrate, with limited sand cover, will be colonised by different species through a sequence of changes in the composition and structure of a community over time, known as ecological succession, leading to the establishment of a new benthic community.

The installation and operational activities of HOP2 may impact fish and shellfish species through burial, smothering and habitat alteration due to the introduction of new materials. These activities can displace or result in the mortality of mobile fish species and potentially affect spawning grounds. However, given that fish are highly mobile organisms, they are likely to avoid areas with re-suspended sediments and turbulence caused by the activities, although spawning and nursery grounds may be affected.

Nephrops, herring and sandeels, which have identified spawning areas within the wider NNS region, are demersal spawners and are therefore more susceptible to impacts from benthic disturbance (BEIS, 2022).

7.1.2 Temporary Disturbance

Wider indirect disturbance to the benthic environment may occur through the suspension and re-settlement of sediments. This would cause localised mortality of benthic organisms due to increased turbidity and smothering. Sessile benthic and epibenthic fauna are at particular risk of smothering effects and changes in oxygen availability, with some species being able to tolerate small sediment layers, while others cannot withstand any covering (Gubbay, 2003). Though smothering from suspension of sediment is expected to be localised and temporary. Evidence has shown that colonisation may occur within one to two years following cessation of seabed disturbance activities (e.g.

piling) and that benthic infauna and epifauna can recover relatively quickly in deep water communities (Neff, 2010; Jones et al., 2012).

Temporary deposits on the seabed (e.g. anchors) may also cause temporary impacts to benthic communities. Though, natural processes of sediment transportation and biological settlement are expected to restore the seabed once the temporary infrastructure is removed. As well as this, indirect impacts may occur from the potential release of contaminants from disturbed sediments, which can impact the early life stages of some fish species.

7.1.3 Management and Mitigation

The design of the project should consider seabed impacts and aim to minimise disturbance where possible. In particular, minimising the introduction of new substrate, such as protective rock, will reduce the area of permanent habitat loss. The strategy of re-purposing existing oil and gas infrastructure would be expected to minimise the seabed disturbance resulting from HOP2.

All necessary permitting and consenting will be submitted to the Regulator in line with current expectations.

HOP2 is not located within existing protected sites or sensitive seabed habitats.

7.2 Discharges to Sea

Discharges to sea refers to any planned contaminants released to the marine environment as a result of the proposed activities associated with HOP2. Discharges to sea may also occur as an accidental event. Marine discharges have the potential to impact the following receptor groups: water quality; benthos; plankton; fish and shellfish; and protected habitat and species, with the toxicity of certain products potentially harmful at high concentrations.

The exact chemicals and quantities to be used and discharged will be determined during the detailed design. However, the main contaminants are likely to be attributed to structure and pipeline commissioning and discharge of cooling water which is likely to be mixed with brine and other cleaning chemicals (Witteveen+Bos, 2024). Prior to any discharge, and if required following discussion with the Regulator, an appropriate discharge permit will be obtained through the UK Energy Portal Environmental Tracking System (PETS) in accordance with the Offshore Chemical Regulations 2002 or other appropriate regulations.

Benthic fauna are susceptible to smothering from marine discharges. Discharges that settle on the seabed have the potential to smother benthic organisms and communities and release pollutants into sediments. In the short-term, smothering would cause localised mortality of benthic organisms and a change in sediment composition. Though there may be temporary disturbance through localised smothering and changes in sediment composition, impacts would be expected to reduce over time with most of the discharged material is expected to settle on the seabed in close proximity to the discharge point.

Fish and shellfish that live in close contact with sediments, or which are demersal spawners, may be susceptible to smothering by discharged solids and physical disturbance of the seabed. However, due to the small volume of contaminants produced the area will largely be contained and impacts to highly mobile pelagic fish and shellfish is limited.

Operations at HOP2 will use desalination of seawater to produce water that is suitable for electrolysis. As a result of this process, brine will be discharged into the marine environment via a density plume that sinks to the seafloor (Fernández-Torquemada et al., 2019). This may cause impacts to water quality due to increased salinity. Heavily concentrated brine has the potential to cause mortality in

sessile benthic marine organisms that are unable to move away from the plume and are particularly sensitive to changes in marine salinity. Research has indicated changes in the community composition of soft-bottom benthic communities such as Polychaeta and Amphipoda that affect their diversity, abundance, and richness (Sola et al., 2024). Pelagic fish species may be vulnerable due to surface dispersal of hypersaline water mass at the discharge site (Fernández-Torquemada et al., 2019).

7.2.1 Management and Mitigation

The impacts of discharge to the marine environment may be mitigated by careful selection of chemical products, to minimise the use and discharge of those with Substitution warnings, or with Offshore Chemical Notification Scheme (OCNS) or hazard quotient (HQ) groupings higher than hazard level E or Gold. Carrying out full risk assessments, in which toxicity, biodegradability and bioaccumulation potential of products, along with obtaining all necessary permits required for the use and discharge of products offshore will be necessary.

Considering alternative options to product discharge, such as the shipping of chemical waste to shore will further reduce impacts on the marine environment. Moreover, the design may be refined in the planning stages to ensure minimal brine water discharge is released to the environment and to avoid discharging high concentrations of brine in proximity to sensitive benthic marine habitat.

7.3 Atmospheric Emissions

Although HOP2 is a project that aims to reduce overall atmospheric emissions as part of the push for renewable energies, there are several activities associated with the development that will release gases into the atmosphere which have the potential to affect air quality at a local level and contribute to global GHG emissions. Installations may have controlled or uncontrolled gas emissions of hydrogen (H₂), oxygen (O₂) and nitrogen (N₂) during construction and operation such as through pipeline rupturing (Witteveen+Bos, 2024) (refer to Section 7.7). CO₂ and carbon monoxide (CO) emissions would largely be associated with construction and service vessels. Combustion emissions have the potential to reduce the local air quality through the introduction of contaminants such as nitric oxide (NO) and nitrogen dioxide (NO₂) (NO_x), volatile organic compounds (VOCs) and particulates which contribute to the formation of local low-level ozone and photochemical smog. Environmental receptors present in the immediate vicinity of the operations tend to be sparsely distributed and/or mobile in their distribution, for example, marine mammals and seabirds. Local impacts are further mitigated by the open and dispersive nature of the offshore environment. Impacts at this level are likely to be difficult to measure and distinguish from naturally variable background levels. On this basis, localised impacts from combustion emissions during HOP2 installation and operations are anticipated to be negligible.

On a larger scale, emissions derived from the different phases of HOP2 will contribute to cumulative worldwide environmental impacts such as global climate change, noting hydrogen may have an estimated GWP of 11 (+/-5) times greater than carbon dioxide (Warwick et al., 2022). However, the direct impact will be difficult to assess as these emissions will only form a very small part of the overall global air emissions.

7.3.1 Management and Mitigation

As a renewable energy project, HOP2 should be designed and constructed with the intent to minimise and reduce emissions to the extent that is practicably feasible (e.g. by considering the use of renewable energy sources or biodiesel to power generators). The strategy of repurposing existing oil and gas infrastructure and utilising a nearby offshore wind platform will ultimately reduce the overall emissions required for newly manufactured equipment. Careful consideration in engineering design can minimise risk of pipeline ruptures and the accidental release of hydrogen emissions. Ongoing monitoring of atmospheric emissions should be undertaken at HOP2 to determine any exceedances or impacts to air

quality. Considered management of vessel plans to increase the efficiency of offshore operations will minimise operational emissions.

7.4 Underwater Noise

Noise may be produced by several sources in all lifecycle phases. The main sources for noise would be continuous noise from vessel activity and subsea engineering works during construction and operation. Should any seabed surveys, using equipment such as sub-bottom profilers (sparkers or pingers) be required prior to installation there would be impulsive noise disturbance. Note at this current stage of the development, piling activities are not anticipated as part of HOP2.

Marine mammals are highly adept at receiving and interpreting information within the marine environment using sound. Cetaceans use the sound for navigation, communication and prey detection. Anthropogenic underwater noise has the potential to impact marine mammals (JNCC, 2010; Southall et al., 2007). Animals have been reported to display a range of reactions from ignoring the vessel noise to avoiding the noise, leading to temporary displacement from an area and more severe effects including permanent hearing loss. Several species of cetacean have been recorded as present within the HOP2 area including the minke whale, common dolphin, white-beaked dolphin, Atlantic white-sided dolphin, long-finned pilot whale, bottlenose dolphin and harbour porpoise (Reid et al., 2003). Harbour porpoises are particularly sensitive to impulsive underwater noise. For example, high-intensity sound waves produced during an activity such as piling or seismic survey can cause temporary or permanent hearing loss, leading to disorientation and difficulty in navigating their environment.

Fish species have varying behavioural responses to sound due to differences in anatomy, physiology and ecology. At high sound levels, there may be temporary or partial loss of hearing or potential injury to fish species, fish eggs and larvae (Popper et al., 2014). However, given the relatively small disturbance area compared to the large spawning grounds in the North Sea, it is not expected that the operations associated with HOP2 will have a significant adverse effect. Marine invertebrates (e.g. cephalopods) may also be susceptible to impulsive noises, triggering behavioural and physiological responses, although it is not expected that noise disturbance from the activities at HOP2 will be as significant as that resulting from piling. It is important to note research on underwater noise impacts to marine invertebrates is limited.

7.4.1 Management and Mitigation

Appropriate mitigation measures may be implemented where practicably feasible to mitigate the impacts of underwater noise to cetaceans including soft starts, the use of dampers on noise-generating equipment, the implementation of Marine Mammal Observers (MMOs) during operations and reduction of vessel movements where possible. Where practicably feasible, works may be undertaken seasonally to avoid peak periods where marine mammals and other sensitive species may be particularly abundant in the HOP2 area, acknowledging that summer months will be peak periods for marine mammal abundance and also the safest and most practical time of year for engineering work at sea. If noise disturbance is expected to be significant (e.g. through use of impulsive survey techniques), risk assessment including noise modelling may be appropriate.

7.5 Physical Presence and Protected Sites and Species

There are no protected sites within 40 km of the HOP2 area, and as such significant impacts are deemed unlikely. However, protected species, particularly cetaceans and seabirds, are present in the area. Potential impacts on these species have been considered elsewhere in this section.

The physical presence of offshore infrastructure may provide opportunity for nesting sites for protected seabird species. Evidence has shown that black-legged kittiwakes have been recorded breeding on at least 26 offshore platforms in UK waters and are present across many more (GoBe, 2024). Other

species known to colonise offshore platforms within UK waters include guillemot and razorbills which have also been recorded within the HOP2 area (Kober et al., 2010). Research indicates that platforms enable a suitable alternative for population recruitment with productivity higher than averages at natural colonies. It is possible protected seabirds may utilise HOP2 area and associated Ninian Central Platform as a nesting site. This may pose a challenge when the time comes for decommissioning of the installation, as the disturbance of nesting birds is a criminal offence.

7.5.1 Management and Mitigation

Bird deterrent measures should be considered to minimise the chance of birds nesting on the platform. At the point of decommissioning, scheduling platform removal for a period outside the nesting season will reduce the risk of encountering nesting birds. Bird activity should be monitored through the lifespan of the installation so risks are understood and can be properly prepared for.

7.6 Socioeconomic Features and Other Sea Users

HOP2 has the potential to physically interact with other stakeholders of the sea, including shipping, fisheries, commercial vessels, wind farms, oil and gas and military activities. For example, a temporary increase in vessel traffic may increase vessel collision risk and the establishment of any new temporary or permanent exclusion zones, if required, would result in loss of access to fishing grounds. A detailed project EIA would assess the potential impact on other stakeholders of the sea.

There will be physical presence of infrastructure and other vessels during installation and the operational phases of HOP2, thus temporarily increasing vessel activity in the area. This increased activity may have potential impact on commercial fishing, shipping and other users of the sea. Throughout the operational life of HOP2, service vessels will also be required to maintain infrastructure. However, it is anticipated overall vessel traffic will be low compared to standard oil and gas activities.

The physical presence of infrastructure (e.g. cables) also have the potential to increase snagging risk and result in loss of access to fishing grounds. In terms of fisheries, ICES Rectangle 50F1 represent less than 1% of the UK's total fishing landings values for 2023. Therefore, the sensitivity of commercial fisheries to the proposed operations can be considered low.

There are several oil and gas installations and 77 identified shipwrecks within a 40 km radius of HOP2. Appropriate measures will be put in place to ensure there are no interferences with existing oil and gas operations or shipwrecks within the area. There is no other infrastructure expected to interact within a 40 km radius of HOP2.

7.6.1 Management and Mitigation

Extensive and ongoing engagement and consultation with key marine stakeholders and other sea users prior to the commencement of HOP2 would mitigate impact on other users. Ensuring all necessary maritime notifications and consents (e.g. Consent to Locate) are issued to aid navigation of vessels through the project area.

7.7 Accidental Events

Accidental events refer to the potential worst-case unplanned events that may result in consequential impacts to the receiving marine environment due to activities undertaken during HOP2. At a high-level the following accidental events have been identified for an offshore hydrogen production facility:

- Unplanned release of chemicals or other contaminants into the marine environment (e.g. fuels from vessel collision and exceedance of water quality objectives;
- Pipeline leaks or ruptures leading to release of atmospheric emissions (e.g. H₂, CH₄, CO₂);

- Metal hydrogen embrittlement;
- Vessel strike; and
- Objects dropped into the sea.

Vessel collision may lead to a loss of diesel inventory. While this could lead to local impacts on surface fauna (primarily seabirds), diesel is a light fuel and would be expected to evaporate and disperse quickly. Due to the distance involved, there would be little chance of diesel reaching the shoreline or impacting protected sites.

While there is expected to be minimal risk of loss of reservoir hydrocarbons resulting from HOP2, accidental damage to existing pipelines or offshore structures during installation or operational activities could potentially lead to a release. Only limited quantities of oil will be present, used in the cooling and lubrication of equipment and subject to containment to prevent leakage. In the event of a spill of oil, planktonic organisms living near the sea surface would be at high risk of floating hydrocarbons, experiencing high mortality and reduction in overall plankton biomass (Buskey et al., 2016; Ozhan et al., 2014). Seabirds would be susceptible to fuel pollution on the sea surface as they utilise these areas as feeding grounds. Fouling of feathers and the toxic effects of ingesting hydrocarbons can lead to seabird fatalities. The effects will depend on species presence, their abundance and the time of year. The Seabird Oil Sensitivity Index (Webb et al., 2016) indicates sensitivity ranges between low and moderate for the HOP2 area. Cetaceans are considered more likely to be able to deal with the effects of fuel spill due to a thicker body covering that is less susceptible to loss of waterproofing; however they will be at risk if they ingest prey contaminated with hydrocarbons (Helm et al., 2014). Offshore fish populations remain relatively unaffected by hydrocarbon pollution as hydrocarbon concentrations below the surface slick are generally low, but it may cause disruption to migration or spawning patterns due to avoidance behaviour. Benthic communities would be susceptible to impacts from hydrocarbons that reach the seabed. Hydrocarbon spills may also cause indirect impacts on the commercial fishing industry if fish and shellfish exposed to fuels may become tainted and unsuitable for commercial use. Should the oil reach shore, there would be impacts on protected areas and sensitive coastal habitats and species.

Current research on the environmental implications of unplanned hydrogen releases remains limited, highlighting the need for further investigation to fully understand the associated risks. However, several key safety and environmental concerns can already be identified based on hydrogen's physical and chemical properties. Hydrogen is an odourless, flammable and colourless gas, which may pose significant safety concerns. Its lack of sensory indicators makes leak detection difficult, and in confined environments, accumulated hydrogen can ignite, leading to potentially severe explosions (Osman et al., 2022). From an environmental standpoint, while hydrogen itself is not a direct greenhouse gas, the interactions with other atmospheric constituents from unplanned releases should be considered. For example, hydrogen can react with atmospheric oxidants such as hydroxyl radicals (OH), reducing their availability. This depletion may slow the atmospheric breakdown of methane leading to indirect impacts on overall greenhouse gas emissions.

Finally, unplanned hydrogen release can lead to material degradation through a process known as metal hydrogen embrittlement. The small molecular size of hydrogen enables it to pass through materials such as pipelines, weakening the metal's internal structure. This makes the material more prone to cracking or rupture, which can compromise asset integrity. The risk is even greater in aquatic environments, where the process tends to accelerate (Osman et al., 2022). As noted previously, a detailed assessment on environmental impact of hydrogen releases will require further investigation.

7.7.1 Management and Mitigation

Extensive construction and design planning will be required to minimise the risk of accidental events and unplanned release. For unplanned hydrogen release specifically, such measures may include pressure relief systems, double-lined piping for transport of gas and leak detection systems where possible to identify and respond to leaks quickly. Regular inspection and ongoing maintenance of infrastructure including pipelines should be undertaken to identify and address any defects such as stress-induced cracking, ruptures, changes in surface texture or any other signs of material degradation.

More generally, the compliance of operators and all contractors with all safety requirements, the reporting of accidents in line with best practice and the appropriate training of personnel will minimise the risk of accidental events. The ongoing engagement with stakeholders and ensuring that all necessary maritime notifications and consents are issued will ensure potential risks are identified early and can be mitigated against.

8 Summary and Conclusions

HOP2 aims to repurpose existing oil and gas assets within the UK Continental Shelf for offshore green hydrogen production, focusing on the Ninian Central Platform in the NNS. This environmental and consenting risk assessment outlines the project's potential impacts and likely associated regulatory requirements based on information provided to date. Environmental regulatory and consenting requirements may need to be revisited as HOP2 develops.

The environment around HOP2 is typical of the wider region, with a characteristic range of benthic, fish, marine mammals and bird species present. There are no designated conservation areas within the vicinity of HOP2. Socioeconomic considerations highlight evidence of commercial fishing activity, moderate vessel traffic primarily from service vessels, and proximity to several oil and gas platforms.

Potential impacts from the construction and operation of HOP2 identified include seabed disturbance, discharge to sea, atmospheric emissions, underwater noise, and accidental events such as chemical spills and vessel strikes. These impacts could affect water quality, benthic organisms, fish, marine mammals, seabirds and other sea users. The consideration of potential impacts in project design, along with early engagement with other users, stakeholders and regulators will help to mitigate these risks. Moreover, HOP2 has been designed to repurpose existing oil and gas subsea infrastructure and to utilise a nearby offshore wind platform as the power source, thereby reducing the need for subsea infrastructure and installation activities. The ultimate end use of HOP2 will reduce overall carbon emissions and impacts to environmental sensitivities in comparison to historic oil and gas use within the North Sea.

As project design is further developed, scoping, Environmental Risk Identification (ENVID) and EIA will allow a more detailed appraisal of environmental impact and risks.

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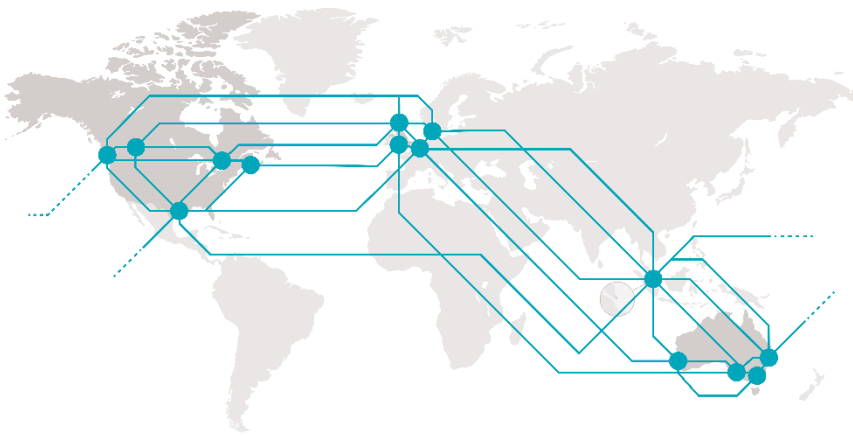
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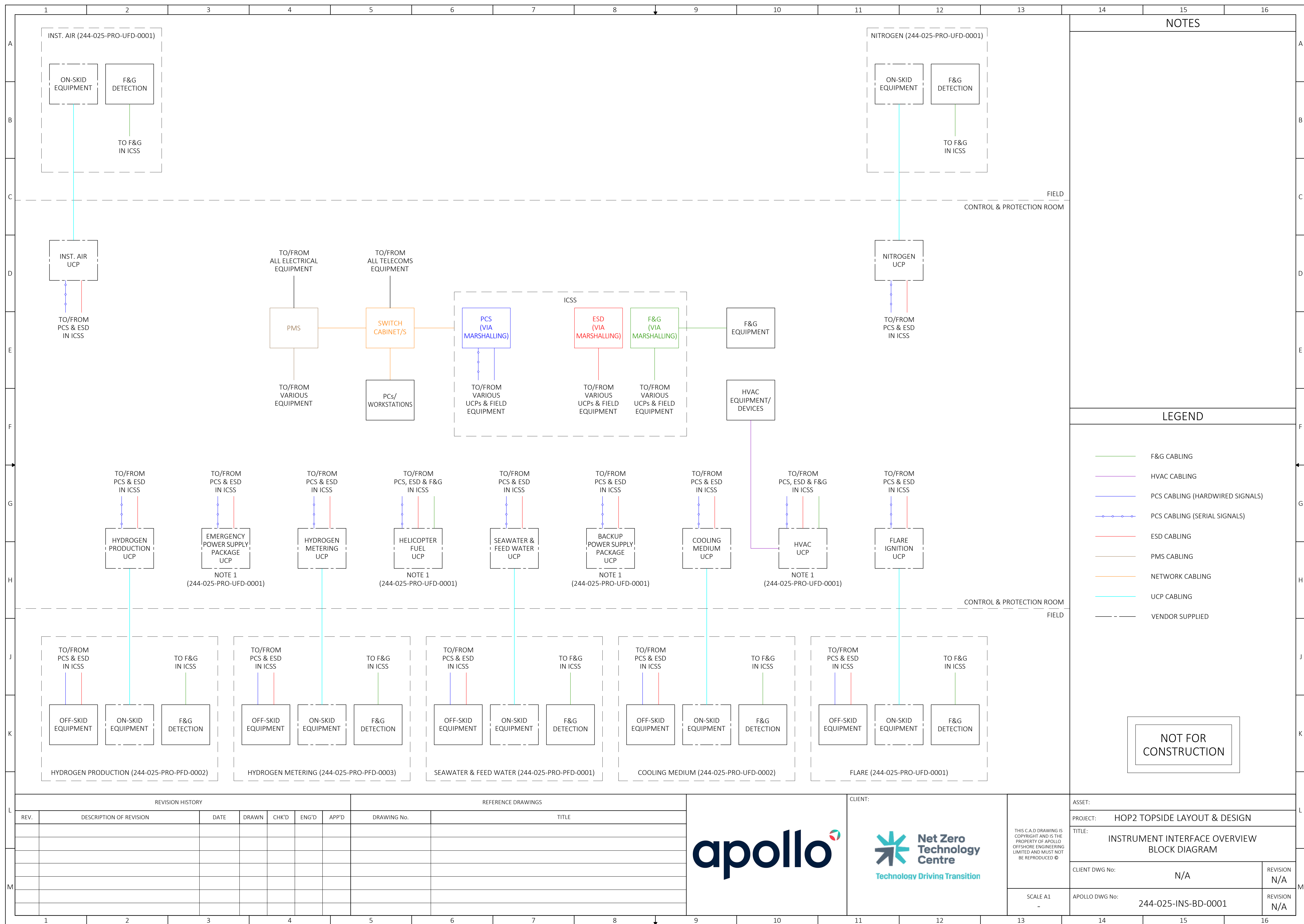
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Appendix J Instrument Block Diagram

244-025-INS-BD-0001 Instrument Interface Block Diagram



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