Net Zero Technology Centre

Technology Driving Transition

Hydrogen Offshore Production Project

HOP2

Technical Note
Phase 2 Concept Definition



Phase 2 of the HOP2 project represents the Concept Definition stage, building directly on the findings and recommendations established during the Phase 1 Concept Development stage.





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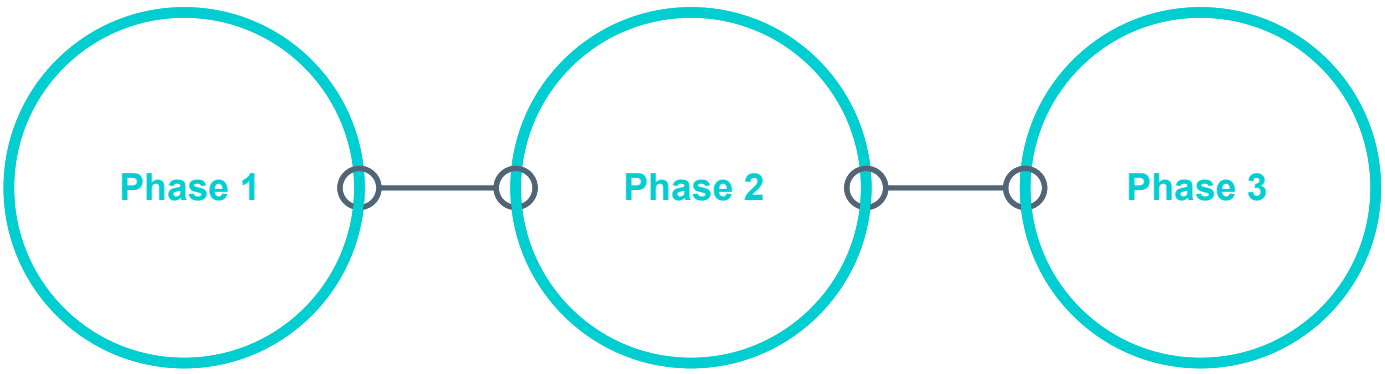
01
Executive Summary

The UK stands at a crucial point in its energy transition. While the North Sea boasts vast offshore wind resources, much remains untapped due to distance from the grid. Unlocking this potential is vital to benefit our communities, workforce, and climate goals.

The main question is how to harness these remote wind assets to deliver positive outcomes, especially for people in Scotland's North-East and Moray, where oil and gas history presents both opportunities and responsibilities.

The Hydrogen Offshore Production Project (HOP2) is an initiative designed to review the practicality and viability of large-scale offshore green hydrogen production at a capacity of 500MW. HOP2 is funded by the Scottish Government's Just Transition Fund with the aim of anchoring the hydrogen production sector in Scotland and creating a positive impact on jobs, skills, education and decarbonisation across Scotland and in the North-East and Moray specifically.

The HOP2 project is being delivered across three distinct phases, each addressing a critical aspect of offshore hydrogen production:



Phase 1 found that is it technically feasible to repurpose existing substructures for 500MW Offshore Hydrogen production.

Phase 2 (this report) has transformed the initial vision delivered under Phase 1, a design based on onshore layout principles into a detailed, actionable design of an optimised offshore integrated hydrogen system, addressing critical challenges in electrolyser selection, system integration, and operational efficiency. This marks a significant milestone in the journey towards large-scale offshore green hydrogen production, focusing on the concept definition and engineering integration required for a 500MW facility.

Phase 3 is currently ongoing and will look further ahead, exploring what could be possible as technology and markets evolve, and setting out a vision for offshore hydrogen production that maximises benefits for Scotland's people and supply chains.

Phase 2 Outcomes



Electrolyser Selection and Integration:
Following a period of vendor engagement, the Bosch ELY1250 PEM stack was selected for incorporation into the design due to its modular design and suitability for a tailored Balance of Stack (BoS) solution. Further work is needed to address the environmental requirements for PEM stacks in offshore settings, particularly marinisation and integration into topsides design.



Innovative Balance of Stack and Plant Solutions:
Veolia's bespoke BoS and proprietary Balance of Plant (BoP) technologies were integrated to deliver a compact, efficient, and scalable system. The Phase 2 design optimises the use of space and weight, consolidating critical systems and maximising synergies—such as utilising excess heat from electrolysis for water treatment. This approach not only improves operational efficiency but also enhances maintainability and scalability for future expansion.



Advanced Water Treatment Technology:
The project adopted thermal Multi-Effect Distillation (MED) over Seawater Reverse Osmosis (SWRO) for desalination, leveraging waste heat from the electrolysers to reduce energy consumption, chemical use, and system footprint. Electrodeionisation (EDI) units ensure the final water quality meets the ultra-pure standards required for PEM electrolysis, supporting reliable and efficient hydrogen production.



Concept Definition: Topsides Integration:
The revised topsides design consolidates electrolyser arrays over three deck levels, enhancing safety zoning and operational efficiency. Key platform systems including seawater cooling, water treatment, hydrogen compression, flaring, HVAC, and secondary electrical systems are integrated to support reliable, safe operations while maximising space use. Despite the optimised layout and balance of stack / plant the estimate dry weight of 31,600 tonnes presents significant installation challenges (though it remains within substructure limits).

Focus should remain around safety, particularly regarding hydrogen leak and explosion risks with further assessment of explosion risk around electrolyser arrays advised. Installation contractors should be engaged early to confirm feasibility of heavy lift or modular installation approaches.



Cost Estimation:
The projected total capital expenditure (CAPEX) is approximately £1.56 billion. This cost encompasses the electrolysis stacks, balance of stack (BoS)/balance of plant (BoP), primary electrical systems, topsides integration (systems described above), and client costs with contingency. This estimate excludes costs associated with the offshore wind farm, substation, and subsea cables.

Conclusion and Next Steps



Phase 2 of the project produced a topsides design that makes efficient use of space, weight, and plant balance for offshore hydrogen production by converting an existing offshore platform. The engineering detail developed are thorough enough to give a clear picture of the potential for hydrogen production in this scenario.

Phase 3 will focus on what could be possible for offshore hydrogen production further in the future while the hydrogen market develops. It will incorporate "the art of the possible" and focus on a future vision for offshore hydrogen production, maximising use of digital technologies and emerging electrolysis technologies that would be well suited to the offshore environment.

02
Phase 2 Scope Overview

Background

Phase 1 of the project delivered a Basis of Study and Concept Development to assess the technical, economic, regulatory, and logistical viability of repurposing existing oil and gas assets in the UK Continental Shelf (UKCS) for hydrogen production, with a view to deployment in the early 2030s.

The scope included assessment of repurposing platforms and pipeline systems, the selection of key production and processing systems and undertook an assessment of regulatory gaps.

It was concluded that while substructures (jackets and foundations) may be reused, topsides repurposing or retrofitting was not considered feasible given the significant hydrogen production scale being targeted (500MW). New-build topsides would be required to accommodate the hydrogen production equipment and supporting utilities required.

Phase 1 also concluded that further concept engineering was required to optimise the design of the offshore hydrogen production facilities for space, weight and ultimately cost. Improved integration was required between the electrolyser design, Balance of Stack (BoS), and Balance of Plant (BoP) systems. It also identified the need for greater definition of the primary electrical systems to ensure sufficient provision was made on the topsides layouts for electrical equipment.

Phase 2 of the HOP2 project represents the Concept Definition stage, building directly on the findings and recommendations established during the Phase 1 Concept Development stage.

Phase 2 Overview

Phase 2 of the project scope was structured into four distinct work packages:



Electrolyser Selection:
Providing detailed technical input and design data for the electrolyser core technology and defining requirements for supporting systems.



Design of Balance of Stack / Balance of Plant:
For optimising the supporting BoS systems around the electrolyser and the associated BoP unit operations required to complete the hydrogen production process.



Design of Primary Electrical Systems:
Focused on the design and integration of primary electrical infrastructure.



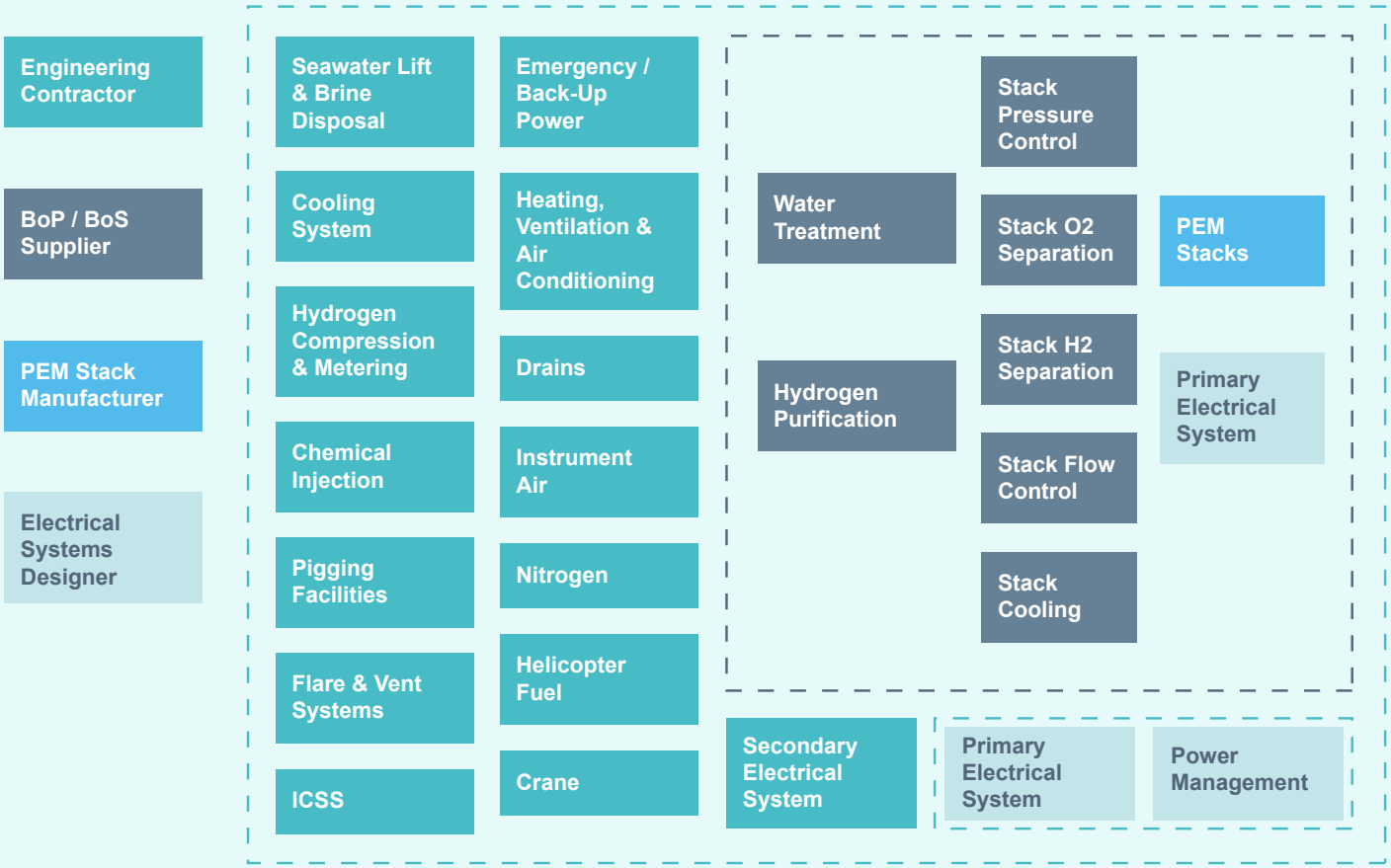
Concept Definition Study:
Topsides Integration: Development of the overall topsides facility design, the remaining utilities required to support offshore hydrogen production and integration of the electrolyser arrays, BoS and BoP and primary electrical systems into a single coherent production facility.

Each work package was undertaken by a specialist company (OEM, manufacturer, engineering consultant or contractor) to provide a fully integrated offshore hydrogen production concept. The boundaries of the Phase 2 scope split by work package is illustrated in Figure 1.

THE ENGINEERING DETAIL DEVELOPED ARE THOROUGH ENOUGH TO GIVE A CLEAR PICTURE OF THE POTENTIAL FOR HYDROGEN PRODUCTION



Figure 1: Phase 2 Scope Overview



03
Basis of Design

Host Facility

Four conceptual design options were developed during Phase 1 to host the offshore hydrogen production facilities. After high-level evaluation Option 1: Single Large Platform Asset was selected as the basis for the further study during the Phase 2 Concept Definition study. This option is based on the following details:

Basis
Repurposed single large asset

Asset
Ninian Central Platform

Location
Northern North Sea

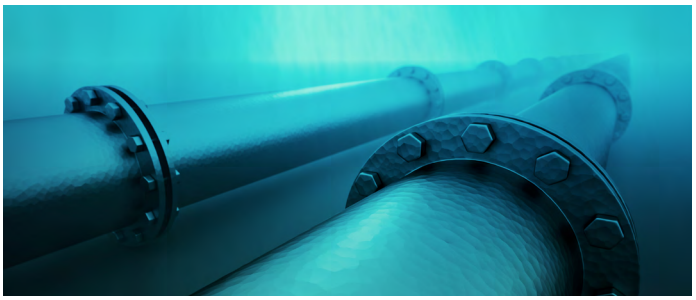
Substructure
Gravity Based Structure

Target Production Rate

A target peak hydrogen production rate of 10,000 kg/hr was carried forward from the Phase 1 Basis of Study. The annualised average production rate for the facility was estimated based on a typical NNS wind farm capacity factor, with the results shown in Table 1.

Table 1: Hydrogen Production Capacity

Rated Electrolysis Capacity (MW)	Peak Hydrogen Production Rate (kg/hr)	Annualised Average Production Rate (tonnes/annum)
500	10,000	40,800



Export Pressure

As established in Phase 1 Basis of Study, an export pressure of 100 barg was provisionally set at the interface with the export pipeline riser on the discharge side of the hydrogen export compressors.



Offshore Wind Farm

The study assumes a single offshore wind farm (OWF) connected to a local offshore substation (OSS), which will export via a single transmission circuit to the HOP2 facility.

04
Electrolyser Selection

Electrolyser Make & Model

The design of the hydrogen production facilities is fundamentally driven by the choice of electrolysis technology and the specific electrolyser model. As established during Phase 1, pressurised Proton Exchange Membrane (PEM) electrolysis was selected as the preferred technology.

While PEM technology is well established, performance characteristics can vary significantly between models. These variations influence key aspects of facility design, including:



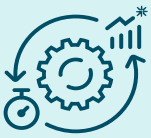
Feed water quality and specification



Oxygen and hydrogen production rates



Operating pressures for oxygen and hydrogen streams



Overall production efficiency



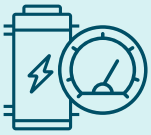
Operating temperatures and allowable anode temperature differential



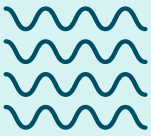
Turndown capability and dynamic response



Rated power and stack voltage



Current density and ramp rate



Power ripple tolerance



Physical footprint and weight



Operation and maintenance requirements

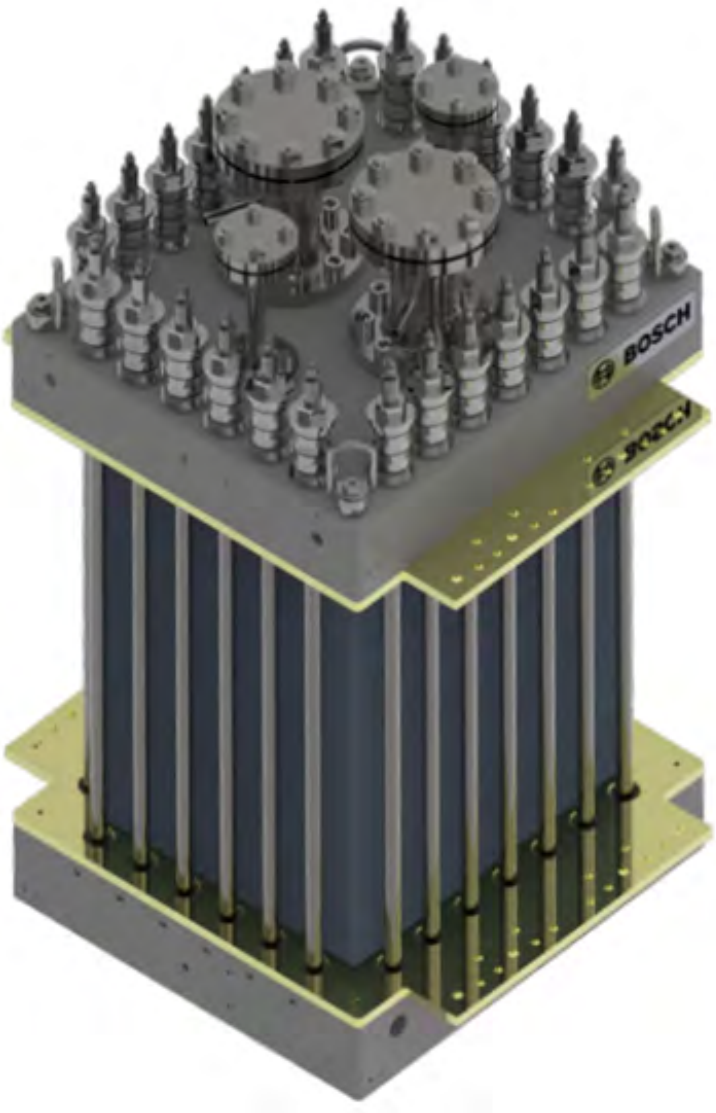


For the purposes of this study, the Bosch ELY1250 PEM stack was selected as the reference model (refer Figure 2). Bosch will supply standalone electrolysis stacks independently of a fully integrated electrolyser and BoS package, which provided the flexibility required for this project to develop a bespoke Balance of Stack design tailored to the HOP2 concept. This selection formed the technical basis for the Phase 2 Concept Definition study.

Environmental Requirement for PEM Stacks

PEM stacks that are commercially available, including the Bosch ELY1250 selected for this study, are typically designed for operation within controlled temperature and humidity environments. This characteristic introduces specific challenges when integrating the technology into an offshore setting. The implications of these environmental constraints are addressed within the Topsides Integration section of this report.

Figure 2: Bosch ELY1250 PEM Stack (Source: Bosch)



05
Balance of Stack & Balance of Plant

Overview

Balance-of-Stack (BoS) and Balance-of-Plant (BoP) are terms used to refer to the systems required to support electrolysis of water by providing feedstock and processing the outlet streams of the electrolysis process. Figure 3 provides an overview of the BoS and BoP operations.

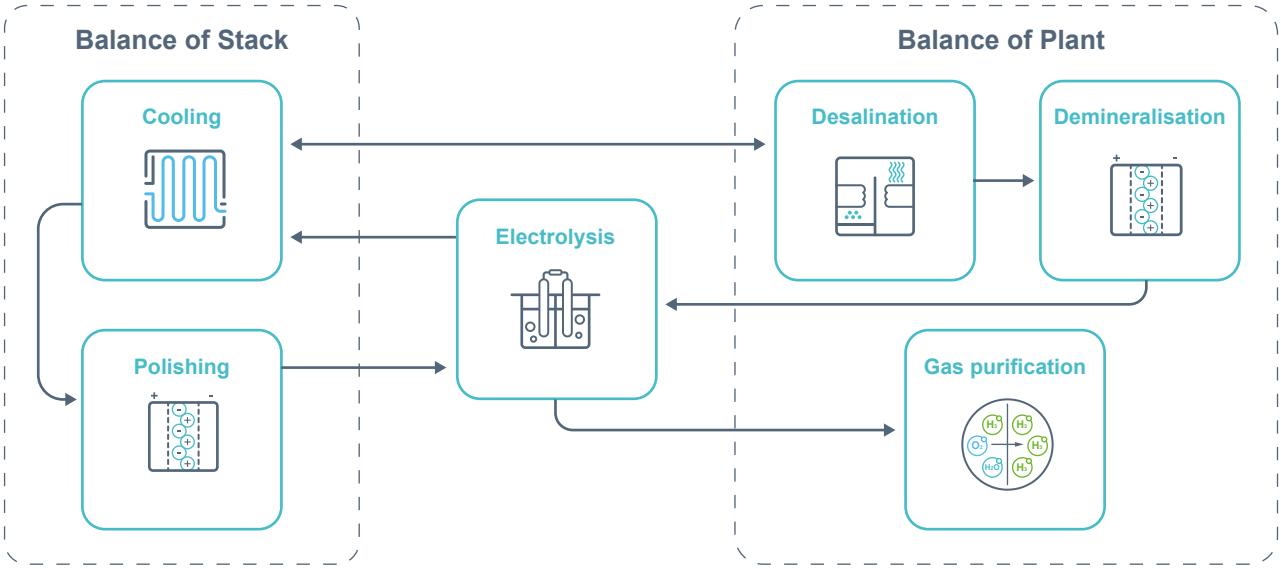
BoS describes the unit operations associated with:

- **Gas / liquid separation:** Directly downstream of the PEM stacks
- **Anode water treatment:** Also referred to as water polishing
- **Electrolyser cooling.**

BoP describes the unit operations associated with:

- **Water treatment:** For provision of ultra-pure water to electrolysis (desalination and demineralisation)
- **Gas purification:** For removal of trace water and oxygen content from the hydrogen product stream to meet pipeline export specifications.

Figure 3: Overview - BoS and BoP (Source: VWS Westgarth - Veolia)



For Phase 2, the design of the BoS and BoP systems was undertaken by VWS Westgarth (part of the Veolia group), who have proprietary technology for both the water treatment and hydrogen purification unit operations required for the BoP.

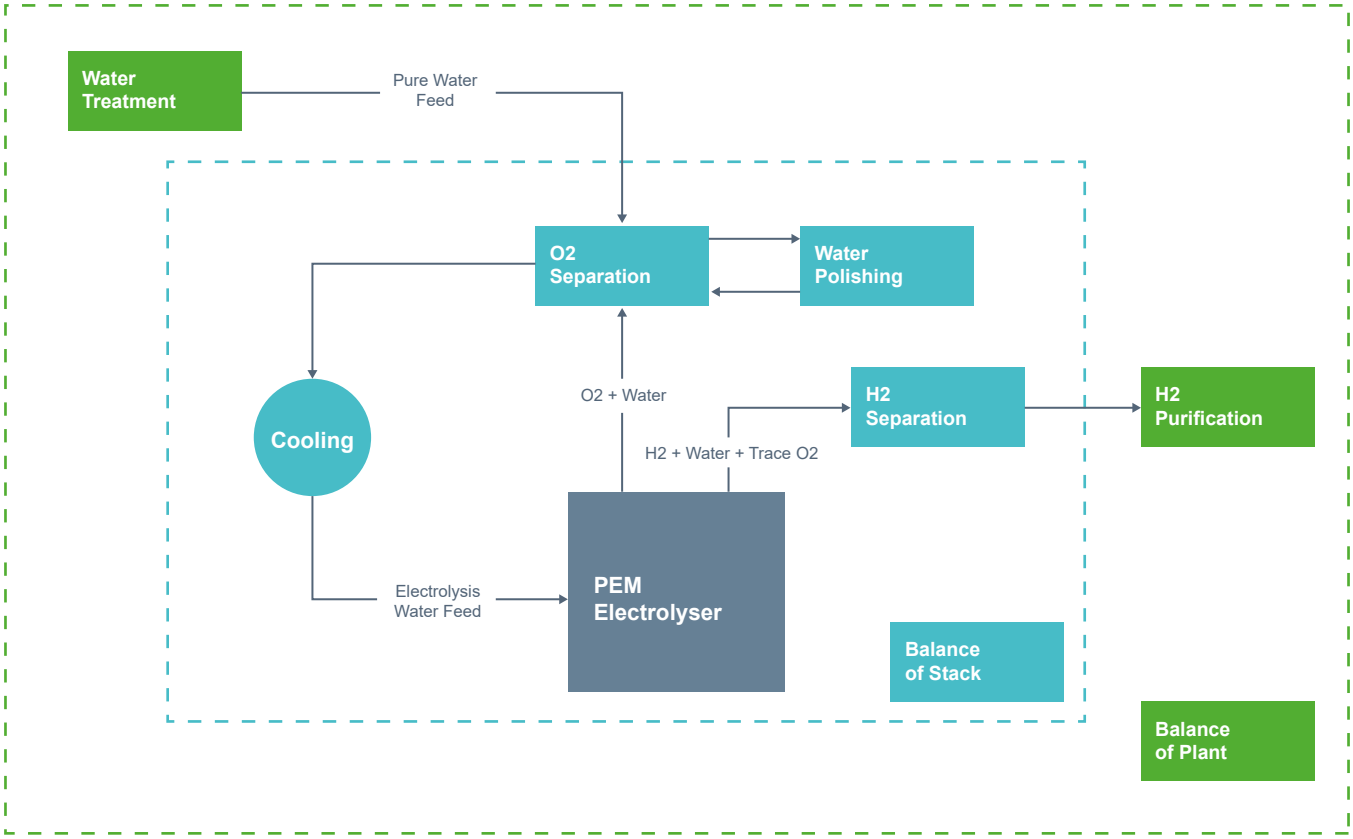
The overall objective of the VWS Westgarth scope was to develop a custom design for BoS that is fully integrated with the electrolysers, coupled with use of their proprietary technology for the BoP. The aim was to optimise the overall design for:

Footprint and weight: Minimising space and weight requirements by leveraging 'economies of scale' for a custom-designed electrolyser array.

Energy efficiency: Maximising synergies between unit operations (e.g. utilisation of reject heat from electrolysis).

Operability: Including maintainability, turndown and safety.

Figure 4: Block Flow Diagram - BoS and BoP



The scope was required to confirm the technology selection for water treatment and hydrogen purification unit operations (e.g. thermal desalination, mol sieve TSA etc.).

Balance of Stack

Balance of Stack systems for PEM electrolysis are commonly packaged into 'arrays' consisting of a number of electrolyser stacks (up to a pre-determined capacity) alongside the BoS equipment required to support electrolyser operation (gas / liquid separation, anode water treatment, electrolyser cooling etc.). The existing supply chain typically produces electrolyser arrays consisting of stacks and associated BoS equipment with capacities of between 5MW and 20MW that are skid mounted and packaged for road transportation.

Therefore, a key objective of this scope was to design an electrolyser array tailored to offshore deployment at a more substantial scale, with the BoS equipment centralised, consolidated and sized accordingly. The design and configuration of this system is detailed in the following section.

Gas / Liquid Separation

In a PEM electrolyser, hydrogen gas is generated on the cathode side through the electrochemical splitting of water. As the hydrogen exits the electrolyser stacks, it carries with it a small amount of entrained water. This mixture is directed into a separator vessel, where the water is removed, leaving behind hydrogen gas.

On the anode side, oxygen gas is produced. Water is continuously circulated through the electrolyser stacks, entering and exiting the anode side. The oxygen generated is carried within this circulating water flow. This water flow is passed through a separator vessel to extract oxygen gas from the liquid stream.

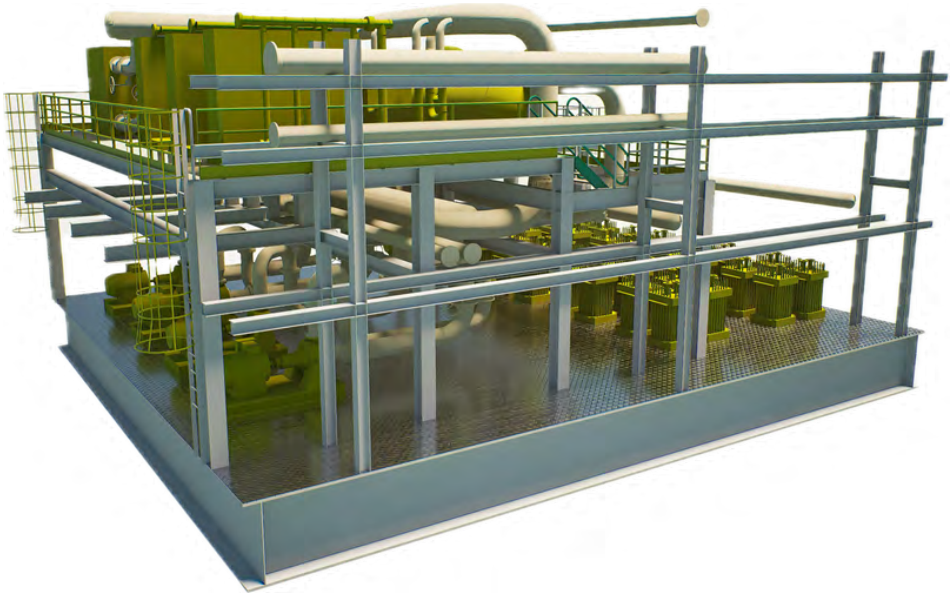
Anode Water Treatment and Cooling

PEM electrolysers operate within strict parameters to ensure safe and efficient performance. One key requirement is that the temperature of the circulating anode-side water must remain below 70 °C, while its electrical conductivity must stay below 0.1 µS/cm.

During operation, the electrolysis process generates heat within the anode water loop. To maintain the required temperature, a dedicated cooling system is used to remove excess heat and keep the water within the specified temperature limit.

Additionally, the anode water can absorb dissolved ions from the electrolyser stacks over time. To preserve water purity and meet conductivity requirements, a polishing system is employed to continuously remove these ions, ensuring the water remains within specification.

Figure 5: Bespoke Electrolyser Array and BoS (Source: VWS Westgarth - Veolia)



Array Design

To achieve the functionality described above, the following process equipment is required as part of each electrolyser array:

- PEM Electrolyser Stacks
- Electrolyser Feed Pump
- Cathode Water Pump
- Electrolyser Cooler
- Electrolyser Water Polishing Package.

To improve platform space and weight utilisation, the design approach focused on consolidation of the BoS equipment with the goal of reducing the number of electrolyser arrays required in the Phase 1 design, where 50 x 10MW arrays were required to provide the target production capacity of 500MW. The sizing of the arrays and resulting number required was determined based on:

- Anode water handling capacity, including limitations related to process equipment and piping sizing for large water recirculation flowrates
- Available footprint and layout/spatial constraints
- Operations and maintenance requirements.

The final design concluded on the use of 12 Electrolyser Arrays, each supporting 33 x 1.25MW Bosch PEM electrolyser stacks with integrated BoS as depicted in Figure 5.

This configuration delivers a nominal power rating of approximately 41.5MW per array at Beginning-of-Life (BOL) condition, which is closely aligned with the target production capacity of 500MW. As the system ages and stack efficiency declines towards End-of-Life (EOL), each array may require up to 50MW to maintain full hydrogen production output. Refer to Figure 6 for more details.

Figure 6: Degradation of Electrolyser Performance with Time

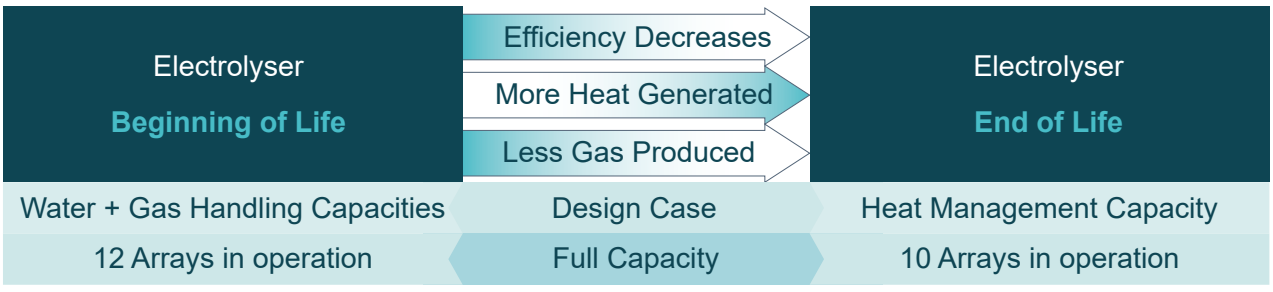
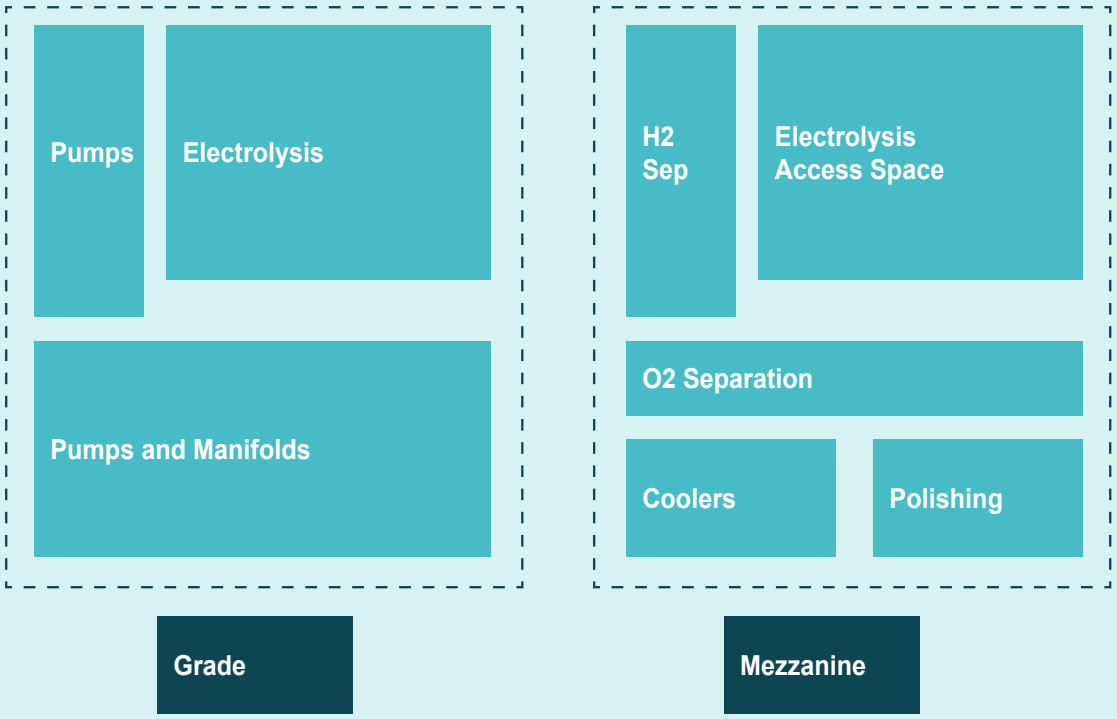


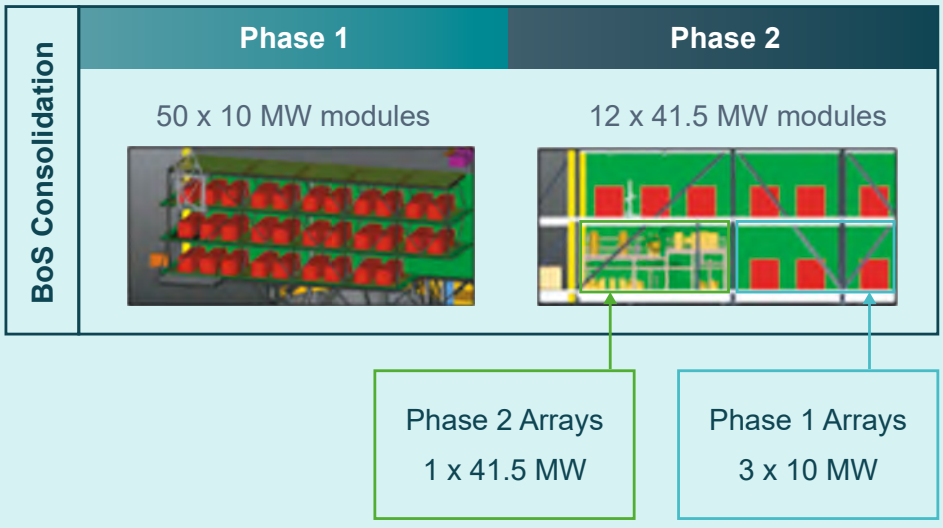
Figure 7: Conceptual Array Layout



Consolidated BoS equipment was designed for each array to support this scale of operation and associated layouts were developed. The array design arranged equipment at two elevations: a grade deck level and a mezzanine level. A high-level overview of the equipment arrangement in each array is shown in Figure 7.

Consolidation of the stacks into larger arrays with bespoke BoS design allows 1 x 41.5MW Phase 2 array to fit within the footprint previously required for 3 x 10MW Phase 1 arrays, as represented in Figure 8. Therefore, an increase of nearly 12MW production capacity was achieved with no increase in real estate required.

Figure 8: Comparison of Phase 1 & 2 Array Layouts



Balance of Plant – Water Treatment

The water treatment system plays a critical role in supplying ultra-pure water to the electrolysis process. Feed water is lifted from the North Sea, passed through coarse filtration and then treated in two key stages to meet the high purity standards required by the electrolysers.

Stage 1:
Desalination: Seawater is processed using desalination technology to produce potable-quality water.

Stage 2:
Demineralisation: The feed water is further treated using advanced demineralisation techniques to achieve ultra-pure water quality, suitable for use in PEM electrolysers.

Technology Appraisal and Selection

Two desalination technologies were evaluated for ultra-pure water production. This section compares these options for application in the HOP2 context:

Multi-Effect Distillation (MED):
A thermal process that uses waste heat to evaporate seawater in a series of pressure-reduced stages, producing distilled water.

Seawater Reverse Osmosis (SWRO):
A membrane-based process that uses high-pressure pumps to force seawater through semi-permeable membranes, separating salt and impurities.

Both technologies are well-established, but their suitability for offshore hydrogen production was assessed across several criteria:

Key Evaluation Criteria

Energy Efficiency:
MED leverages waste heat from the electrolysis process, thereby significantly reducing electrical power demand. SWRO, by contrast, relies entirely on electrically driven pumps and requires additional booster stages to meet purity requirements.

Chemical Usage and Maintenance:
MED systems are more tolerant of feed water variability and require fewer chemical treatments. SWRO systems require extensive pre-treatment, regular chemical dosing, and more frequent cleaning to prevent membrane fouling.

Footprint and Weight:
MED units are more compact and lighter than equivalent SWRO systems, which is a critical advantage for offshore installations where space and weight are constrained.

Operational Simplicity:
MED can integrate directly with the thermal loop of the electrolyser, reducing the requirement for a separate cooling water system. SWRO systems require dedicated cooling and more complex operational management.

Water Recovery and Flexibility:
SWRO offers better recovery of reject water from downstream polishing systems, which can improve overall water efficiency. However, this benefit was not considered sufficient to outweigh the broader advantages of MED.

Based on the comparative assessment, MED was selected as the preferred desalination technology for this project. The ability to utilise waste heat from the electrolysers aligns well with the offshore concept, offering:

- Lower energy consumption
- Reduced chemical and maintenance requirements
- Smaller footprint and weight
- Simplified integration with the overall system.

To address MED's reliance on electrolyser heat - particularly during start-up - a dedicated feed water storage tank is included in the design. This tank ensures a continuous supply of ultra-pure water until the MED units reach operational temperature.

Regardless of the desalination method, a final polishing stage is required to meet the ultra-pure water specification for PEM electrolysers. This is achieved using Electrodeionisation (EDI) units, which remove residual ions through electrically driven ion exchange. The EDI system ensures water conductivity remains below 0.1 µS/cm, as required by the electrolyser manufacturer.

Equipment Requirements

Using these selected technologies the following BoP water treatment equipment is required for the facility:

- MED Package (depicted in Figure 9)
- Array Feed Water Tank
- Array Feed Water Pumps
- Array Feed Water EDI Unit.



Balance of Plant – Gas Purification

The gas purification system conditions the hydrogen gas produced by the electrolysers. The main function is to remove trace amounts of water and oxygen, ensuring the hydrogen meets the required purity standard before it is compressed and exported. The system receives hydrogen directly from the BoS and treats it through a series of steps to deliver clean, dry hydrogen suitable for downstream handling and use.

Hydrogen produced by the PEM electrolysers enters the purification system as a water-saturated vapour containing trace levels of oxygen, though the gas is free from particles and harmful contaminants.

Process Description

In the first stage, the hydrogen gas is heated in a feed heater. This superheated gas then flows into a deoxygenation reactor containing a noble metal catalyst. Within the reactor, the residual oxygen reacts with hydrogen to form water, reducing the oxygen content to below 10 ppmv. The resulting gas stream is a hydrogen-water vapour mixture.

The second stage targets the removal of water vapour. The gas is first cooled in a shell-and-tube heat exchanger. This cooling promotes condensation of water vapour, which is then separated in a dedicated vessel. The condensed water is drained from the system.

The remaining hydrogen gas is directed to silica gel dryer vessels, which operate in a cyclic mode:

- **Adsorption:** Silica gel captures residual water molecules
- **Regeneration:** A portion of purified hydrogen is heated and passed through the gel to release the absorbed water, followed by cooling.

Any fine particles from the silica gel beds are removed by a downstream dust filter, ensuring the hydrogen meets the required purity standard.

A slipstream of purified hydrogen is used to regenerate the silica gel beds. This stream is heated, passed through the gel to desorb moisture, and then cooled. Condensed water is separated and drained, while the hydrogen is recompressed and recycled back into the system.

Equipment Requirements

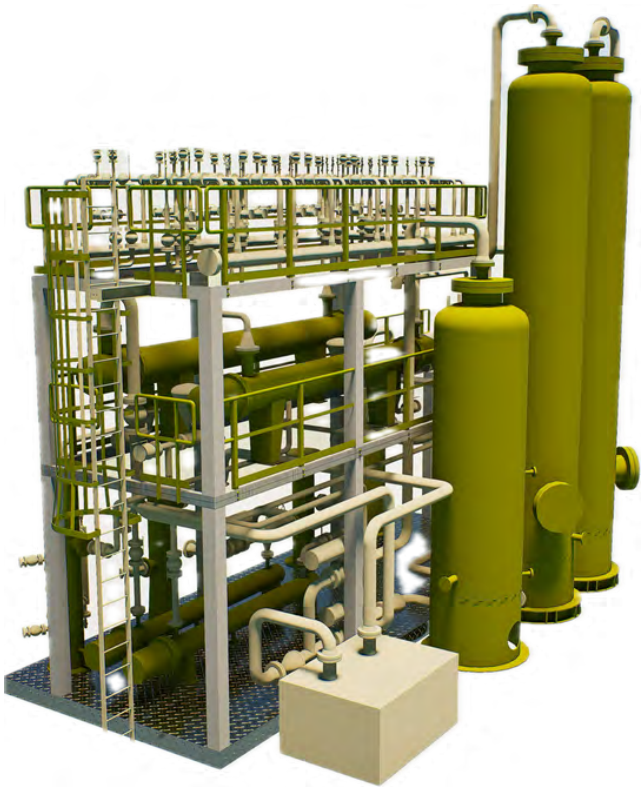
The main hydrogen purification equipment required based on technology of this type is listed below:

- Deoxygenation Reactor
- Dryer Vessel
- Regen Gas Compressor.

Figure 9: MED Unit (Source: Entropie - Veolia)



Figure 10: Gas Purification Unit (Source: Veolia Energy and Process Systems)



06
Primary Electrical Systems

Overview

For the HOP2 offshore hydrogen production facility, the electrical systems required can be broadly categorised as primary and secondary systems.

The primary electrical system is required to interface with the wind farm HV-AC offshore substation and transform / convert / condition the power for the electrolyser arrays. It will also provide HV / MV power distribution for Balance of Plant and utilities systems equipment.

The secondary electrical system is required to support the platform operation, including UPS, LV power distribution, lighting and small power, supplementary bonding, lightning protection, etc. The secondary electrical systems were not fully defined and sized at this stage of the project.

For Phase 2, the design of the primary electrical systems was undertaken by Petrofac. The overall objective of the Petrofac scope was to develop the primary electrical system architecture for a 500MW offshore hydrogen production facility covering:

- Definition of key working assumptions, including wind farm interface, distance from the hydrogen production platform and transmission voltage.
- Vendor engagement with primary electrical equipment manufacturers to establish equipment ratings, footprints, heights, and weights for the primary electrical equipment, to cover:
  - High Voltage Alternating Current (HV-AC) power import, transformation, and distribution
  - Medium Voltage Alternating Current (MV-AC) to Medium Voltage Direct Current (MV-DC) conversion for PEM equipment
  - Reactive power compensation / filters.
- Definition of electrical control / power management system architecture and requirements for equipment cabinets, operation stations, etc.

In common with the BoS and BoP scope, the aim was to optimise the design for space and weight by centralisation / commonality of transformers and rectifiers where possible. The design was developed to sufficient detail to provide input to the Topsides Integration scope for 3D modelling and layouts, and to support a preliminary cost estimate.

Centralised Concept

Electricity generated by a single offshore wind farm (OWF) will be connected to a local offshore substation (OSS) which will export power via a single transmission circuit to the HOP2 facility. The power will be converted from alternating current (AC) to direct current (DC) via rectifiers, with onward supply of DC power to the electrolyser arrays for hydrogen production.

Electrical Power System Design

Transmission from OWF to HOP2
Transmission distances of 50 km and 100 km were considered, with 275 kV selected as the optimal voltage level due to stability and capacity benefits.

HV-AC Distribution
The HV-AC system proposed includes:

- 275/66/66 kV three-winding transformers (likely configured as 2 x 400 MVA units)
- Gas-insulated switchgear (GIS)
- Shunt reactors
- Subsea cable reception facilities.

The 66 kV system primarily supplies power to electrolyser transformers, while 11 kV transformers support auxiliary loads such as hydrogen compression, heating ventilation and air conditioning (HVAC), and seawater lift pumps.

Rectifier Design for Electrolyser Arrays
The key considerations for the design of the rectifiers required to convert MV-AC to MV-DC for supply to the electrolyser arrays were:

- Power required.
- Voltage level required by the PEM electrolysis stacks (which in turn introduces a limitation on how much rationalisation of MV-AC and MV-DC equipment is practicable).
- Voltage range required by the PEM electrolysis stacks during their start-up and normal operation.

These three key aspects informed the development of the preliminary primary electrical system architecture. Several MV-AC / MV-DC voltage conversion and control topologies were considered and a combination of two rectifier types were selected to convert the power to the PEM electrolysis stacks as follows:

- **Thyristor Rectifiers:** These are designed for on/off control only. These rectifiers are efficient and compact but produce high harmonics at partial loads. They also cannot provide reactive power support to the grid.
- **Hybrid Rectifiers:** These combine IGBT and thyristor rectifiers to enable a more precise control method of the power supply. The IGBT units provide fine control and reactive power support but have a relatively large footprint and weight (compared with thyristors). The thyristors units within the rectifier provide on/off control to handle the bulk load. Therefore, the rectifier can therefore be operated from 0 – 100%.

The hybrid rectifiers would require significantly more space and be more expensive than the thyristor rectifiers, so a balance of controllability versus space and cost was required. The final design selected a combination of 9 thyristor rectifiers with 3 hybrid rectifiers for supply of DC power to the 12 electrolyser arrays.

Preliminary Control Philosophy

The primary aim of the power system control philosophy was to match the electrical load demand of the HOP2 facility to the OWF generation profile, ensuring that the power system remains balanced and stable. This will be achieved by using a combination of thyristor and hybrid rectifiers as discussed above. The thyristor rectifiers will be used at full load to consume the bulk of the load, with the IGBT rectifier load varied to match the remainder of the generation profile.

The capability of all OWF generation sources will be continually monitored and the load will be controlled accordingly. Typically, this will involve ramping the electrolyser arrays up or down to match the OWF generation profile.

As the electrolyser arrays cannot be entered straight into service from cold, a forecasting system will be used to ensure that the arrays are available when required. An accurate forecast will help to minimise curtailment of the OWF. Electrolyser arrays will be kept in standby based on the forecast generation profile, ready to be entered into service when required.

On this basis, a preliminary control system concept was developed to better understand how hydrogen production could be matched with the variable output of the OWF, with key elements included as follows:

- Load Management: Thyristor rectifiers will be provided to handle bulk load with IGBT rectifiers adjusting dynamically to match OWF generation.
- Forecasting: Electrolyser arrays will be pre-heated and kept in standby based on wind forecasts to avoid curtailment.
- Energy Storage Integration: Storage systems can buffer fluctuations, reduce curtailment, and extend equipment life (further details below).

A Power Management System (PMS) was proposed to coordinate array operation, energy storage and emergency diesel generators (EDGs). An Electrical Control System (ECS) will provide monitoring, alarms, and manual override capabilities.

Power System Analysis

Preliminary electrical power systems simulation was performed including Load Flow, Short Circuit, Transformer Energisation and Harmonic Penetration. Reactive Power Compensation was also considered but due to limitations of the ETAP software and the preliminary nature of the system design this is recommended for further review. Among the key findings were:

- **Transformer Energisation:** Due to the HOP2 facility being islanded from the grid and the large transformer size required for the main incoming transformer, it will not be possible to energise this transformer by traditional means. Therefore, it is proposed to use point-on-wave switching or pre-magnetisation to minimise in-rush current.
- **Reactive Power Compensation:** Shunt reactors were sized for various transmission distances. It was found that 275 kV systems provided better voltage stability than 220 kV, especially at longer distances.

Optimisation

OWF Sizing and Capacity Factor

An OWF rating equivalent to the HOP2 capacity would be required to provide generation at the rated load at its full output. Therefore, an OWF capacity of 540MW was assumed, composed of 495MW production and 45MW base load.

It is assumed that the base load would consume the “first” 45MW of OWF generation, and therefore any OWF output of 45MW and below would result in no hydrogen production. This equates to a wind speed of around 4.8m/s. Similarly, any wind speed of 25m/s and above would require turbine shutdown to protect the machines.

Therefore, a 540 MW OWF (without any intermediate energy storage) would result in:

- No hydrogen production for ~20% of the year i.e. significant downtime for the facility.
- No power generation for ~5% of the year.

To improve capacity factor for the HOP2 facility, options could include:

- Oversizing the OWF
- Integrating energy storage (refer below for further details)
- Installation of a grid connection.

Energy Storage Options

Energy storage could be beneficial to maintain a more stable hydrogen production regime. Two main options were considered:

- **Battery Energy Storage Systems (BESS):** Small scale buffer storage to smooth short-term fluctuations in the OWF output and to provide instant response to the power system.
- **Long-term storage:** Such as subsurface compressed hydrogen gas storage if local reservoir geology permits.

No storage option was implemented during the Concept Definition phase.

07
Concept Definition: Topsides Integration

Overview

The Topsides Integration scope included development of the overall topsides facility design, the remaining utilities required to support offshore hydrogen production and integration of the electrolyser arrays, BoS and BoP and primary electrical systems into a single coherent production facility.

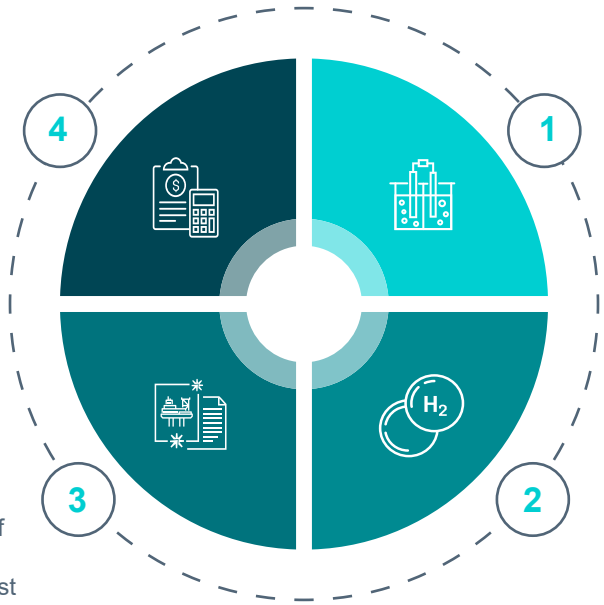
For Phase 2, the Topsides Integration scope was undertaken by Apollo Engineering, who had previously performed the Topsides Layout and Design scope as part of the Concept Development phase.

Ultimately, the key objective was to demonstrate overall technical feasibility of the 500MW centralised offshore hydrogen production facility concept hosted on a repurposed substructure.

A summary of the main design elements of the Topsides Integration scope is presented in Figure 11.

The objectives of the scope were to:

To develop a high-level cost estimate for the facility covering the full development lifecycle.



To integrate the electrolysers, BoS, BoP and primary electrical systems into the overall topsides facility design based on output from the Vendor Engagement activities detailed in previous sections.

To further develop the single platform option from the Concept Development phase with the aim of optimising the design of the facility for space, weight and ultimately cost - taking into account the output from the Vendor Engagement activities.

To further define the other process and utilities systems required to support offshore hydrogen production and export.

THE TOPSIDES INTEGRATION SCOPE INCLUDED DEVELOPMENT OF THE OVERALL TOPSIDES FACILITY DESIGN

Figure 11: Main Design Elements of Topsides Integration Scope (Source: Apollo Engineering)

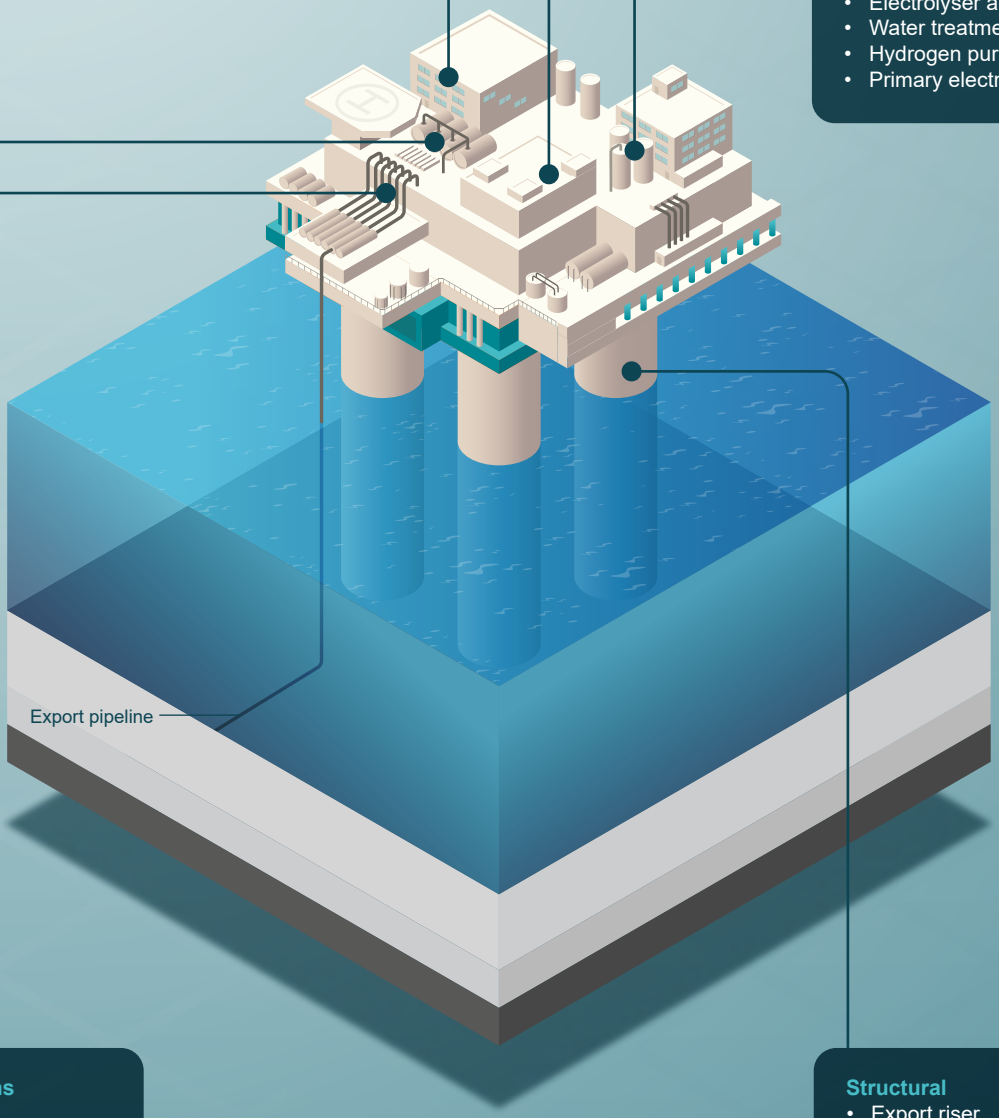
Process Equipment
- Cooling medium cooler (30%vol TEG)
- Hydrogen intercooler per train (3 x 50%)
- Hydrogen export cooler per train (3 x 50%)
- Seawater lift pumps (5 x 25%), demin water charge pumps (2 x 100%)
- Cooling medium pumps (5 x 25%) and expansion vessel
- Oxygen KO Drum Sump Pump
- Water tanks
- Flare KO Drum and package
- Oxygen Vent KO Drum, cooler and vent
- Flare, chlorination, dechlorination packages
- Coarse seawater filters

Combined topsticks weight ~35,000 tonnes (~9000 tonnes accounted for electrolysers)

Accommodation
- 1250 tonne allowance made for 68-bed living quarters
- Helideck (100 tonne)

Electrical
- MV and HV switchboards
- Emergency switchboards
- Switchgear
- Power distribution systems and transformers in climate controlled enclosures

By Others
- Electrolyser arrays
- Water treatment
- Hydrogen purification
- Primary electrical systems



Auxiliary systems
- Drains
- Instrument air
- Nitrogen package
- Helicopter fuel
- ICSS
- Firefighting
- HVAC

25 year design life

Structural
- Export riser
- Seawater lift and disposal caissons
- Electrical supply cable & control umbilicals
- Structural steelwork and module support frame

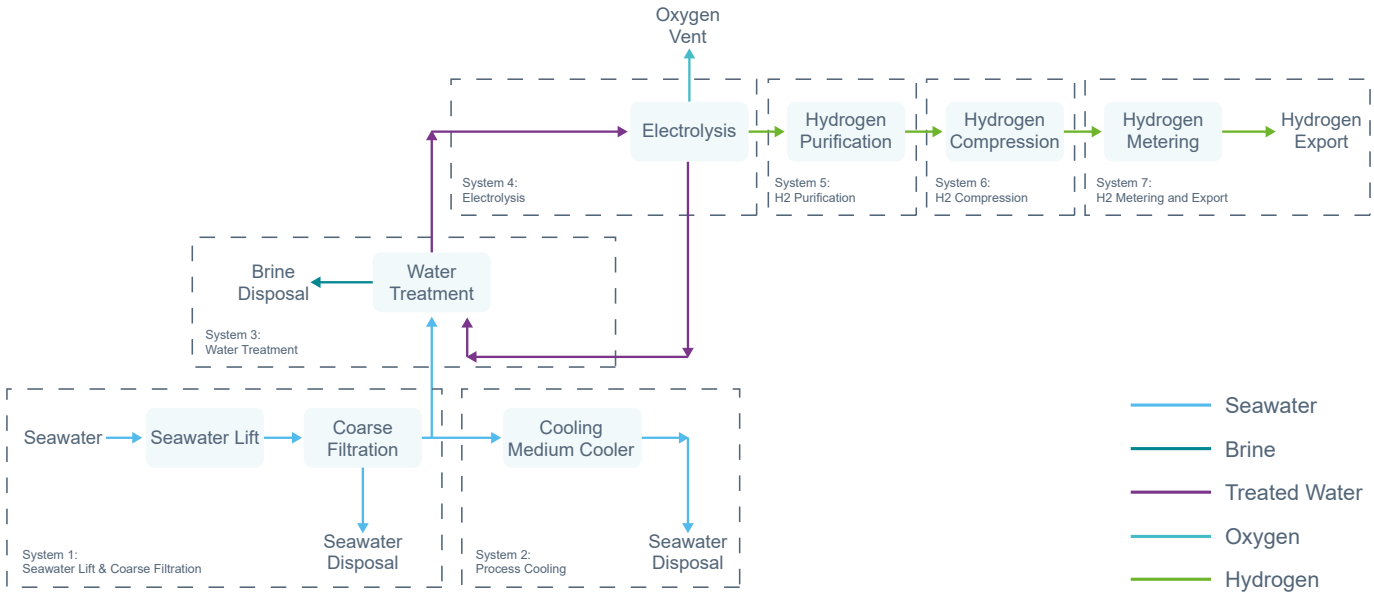


Facilities Design

The process design for the topsides facilities was developed further from the Phase 1 design based on the revised electrolyser array concept of 12 x 41.5MW modules instead of 50 x 10MW modules.

An overview of the process unit operations required to support hydrogen production is shown in Figure 12. The battery limit pressure for the hydrogen export was provisionally set as 100 barg at the interface with the pipeline riser downstream of hydrogen metering.

Figure 12: Facilities Block Flow Diagram



Seawater System

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.

The system was composed of 5 x 25% seawater lift pumps submerged in existing NCP caissons which will supply seawater via coarse seawater filters for water treatment and cooling. Seawater will be chlorinated within the caissons to prevent marine growth within the downstream system. However, the seawater stream to desalination (stage 1 of water treatment) will be dechlorinated by injection of sodium bisulphate solution to prevent rapid corrosion of downstream equipment which is subject to high temperatures.

Balance of Plant – Water Treatment

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

Balance of Plant – Gas Purification

The hydrogen produced by the electrolyser arrays is saturated with water vapour and contains trace amounts of oxygen. The hydrogen purification system conditions the hydrogen gas to meet the required purity standard before compression and export.

Hydrogen System

Dry hydrogen from the purification process will be compressed in two stages to achieve the required discharge pressure of approximately 100 barg. High-pressure hydrogen will then be sent to a metering package which measures the export flow rate to fiscal metering standard as well as quality control of oxygen and Wobbe Index specifications. A pig catcher is provided to enable pipeline commissioning and maintenance.

The specified compression design comprises three vertical, non-lubricated reciprocating compressors, delivered as fully skid-mounted units for ease of integration. Designed for high-pressure hydrogen service, the system will provide 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.

A hydrogen flaring and venting system will be provided for safe disposal of hydrogen from the process in the event of process upset, maintenance and/or other process depressuring requirements. The system is composed of a knock-out drum and flare stack. The electrolyser arrays will each be provided with a secondary small hydrogen vent (directed away from sources of ignition) to discharge small amounts of low-pressure hydrogen.

Process Cooling

Following selection during the Concept Development phase of indirect seawater cooling for the electrolyser arrays to minimise corrosion / material selection and fouling issues, further refinement of the cooling system was undertaken to segregate cooling users in hazardous and non-hazardous designated areas.

Cooling to users in hazardous areas (electrolyser arrays, hydrogen compressors, gas purification) will be provided by an indirect 30 vol% tri-ethylene glycol in water (TEG) closed loop, which will enable the detection and segregation of hydrogen (or oxygen) leaks. The system is composed of circulation pumps, a main cooler, and a trim cooler to provide additional cooling to the TEG for compression and purification users. A vertical expansion vessel will also be provided for thermal expansion within the system.

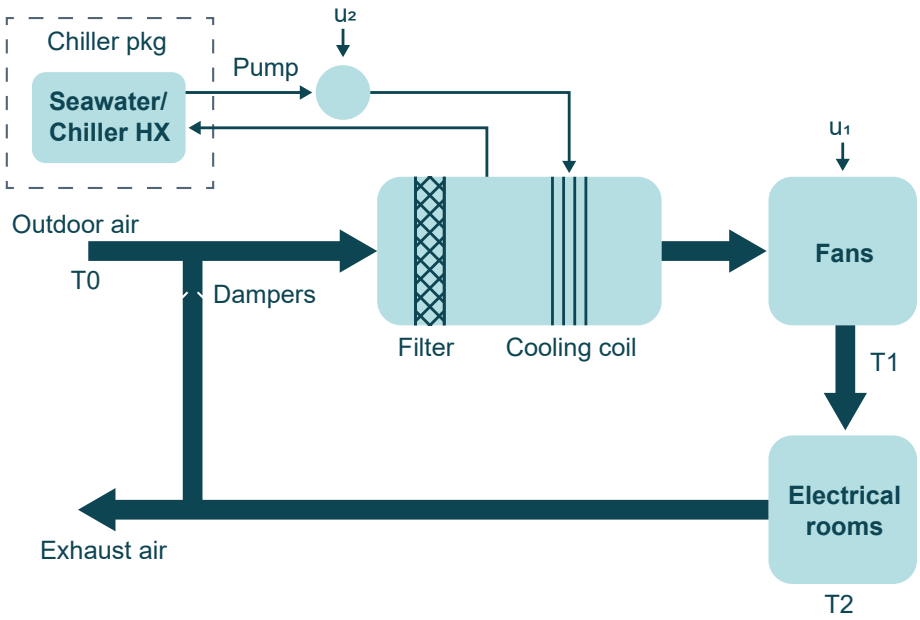
Direct seawater cooling was adopted for the non-hazardous Heating, Ventilation and Air-Conditioning (HVAC) system, as titanium options are readily available for HVAC chillers.

HVAC System

The topsides HVAC system was developed to manage significant thermal loads generated by high-capacity electrical equipment required to transform / convert / condition the power for the electrolyser arrays, including transformers, rectifiers, and harmonic filters. The design was based on detailed thermal load assessments and airflow modelling to ensure optimal room temperature for the electrical equipment performance, while accounting for the platform's spatial constraints.

This resulted in five large chillers and a network of high-capacity air handling units. Modular ducting strategies, airflow optimisation, and the recommendation to externally install transformer radiators further optimised the HVAC design, thereby reducing HVAC demand and lowering the platform's weight and ultimately CAPEX.

Figure 13: HVAC Block Flow Diagram



Secondary Electrical System

The secondary electrical system supports HOP2 facilities operation and habitation. Power for the secondary electrical system is derived from the primary electrical system.
The proposed system was composed of:

- MV and HV switchboards, emergency switchboards, switchgear, power distribution systems and transformers
- Back-up and emergency power systems.

The design of the Secondary Electrical System was found to be readily achievable using standard commercially available and proven equipment. With the HVAC load approximately 40% of the overall secondary electrical system power requirements (excluding the primary electrical system), this should be a focus for optimisation during subsequent engineering phases.

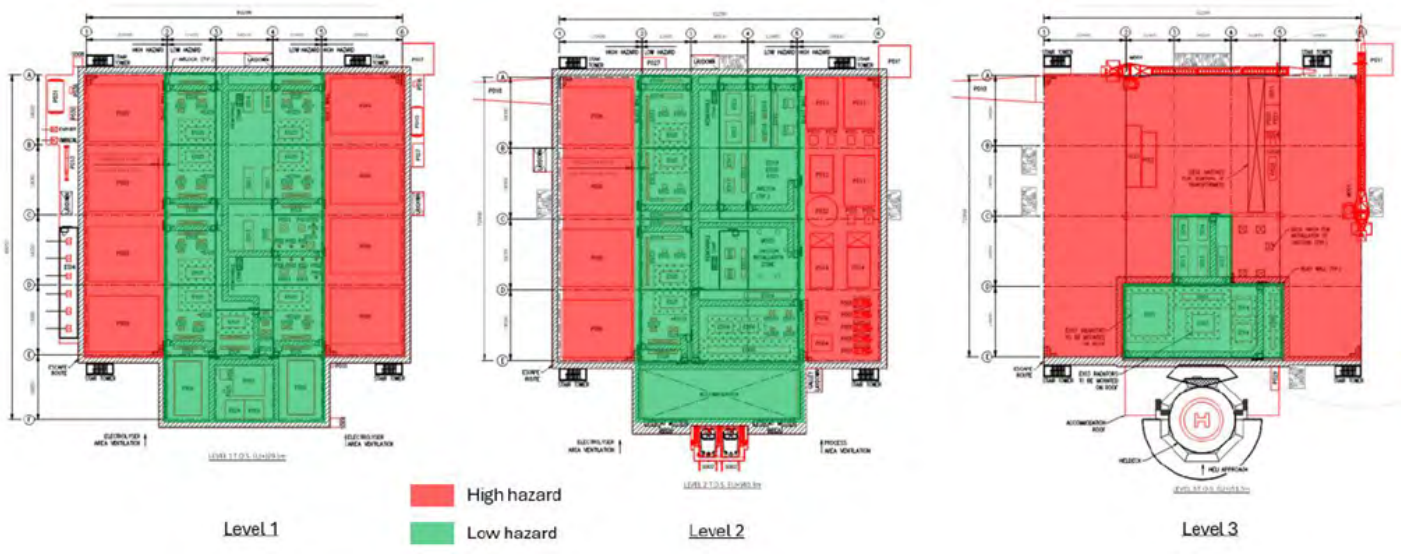
Layouts

Layouts for the topsides facilities were developed further from the Phase 1 design based on:

- Revised electrolyser array concept of 12 x 41.5MW modules instead of 50 x 10MW modules (including BoS).
- Revised design for the Gas Purification unit
- Revised design for the Water Treatment unit
- Revised design for the primary electrical systems.

The more compact arrangement of the electrolyser arrays allowed the overall topsides footprint to be consolidated over 3 deck levels instead of 4 deck levels required in Phase 1, as shown in Figure 14.

Figure 14: Centralised Platform Deck Levels (Source: Apollo Engineering)



The topsides layouts maintained the philosophy developed in Phase 1 of a central low-hazard zone for utilities and electrical equipment (shown in green in Figure 14), flanked by high-hazard zones to the east and west of the platform for the electrolyser arrays and other hydrogen-related process equipment (shown in red).

This design takes advantage of the southerly / south westerly prevailing winds at the NCP location to disperse any hydrogen that may leak in the high-hazard zones, with grated decks provided within these zones. High and low hazard areas will be separated with fire/blast walls.

With respect to the prevailing wind directions, the accommodation module and temporary refuge (TR) were retained at the southern end of the platform in the upwind location, with cranes located on the north and east faces to facilitate supply boat operations downwind. In order to keep the northern and eastern faces of the platform clear for supply vessel operations, it was proposed that flexible risers for the power import cables, the hydrogen export riser, and the control and telecoms umbilical will approach the platform from the west. This also kept the southern face of the platform clear for the freefall TEMPSC/lifeboats to launch.

Air handling units make up the majority of the HVAC equipment required for cooling of electrical equipment rooms. Given the size of these units, it was necessary to distribute these units throughout the electrical compartments.

To facilitate supply boat operations, a tower was proposed (instead of a boom) for the hydrogen flare given its downwind location on the northeast corner of the platform. The oxygen vent was positioned at the northwest corner, ensuring a safe distance from both the hydrogen flare and helicopter operations.

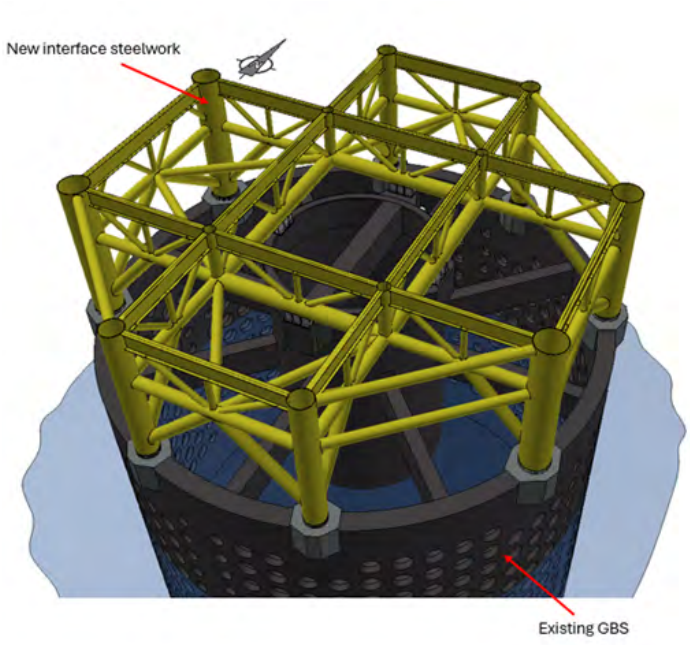
It was proposed that the free areas on the upper deck are provided with open grated steel deck to mitigate against the risk of dropped objects when using the cranes while still providing good ventilation to the lower levels. Main escape routes were provided around the perimeter of the platform and also through the central low-hazard core to allow good access back to the TR from all areas of the platform in the event of an emergency.

Maintenance Philosophy

Access to PEM electrolysis stacks will allow use of a manual or powered truck, similar to a forklift, to transport the stack units to the east or west laydown areas of the platform. Local runway beams can be provided to aid lifting of the electrolyser stacks from their in-situ position to the trucks.

The weights of some primary electrical equipment items (e.g. main 275kV/66kV transformer) significantly exceed what could be reasonably expected of a platform crane. Therefore, these items have been located on upper Level 3 of the platform so that a Heavy Lift Vessel (HLV) can be employed to remove and replace these items in the rare event of a catastrophic failure.

Figure 15: Proposed HOP2 topsides / GBS interface steelwork (Source: Apollo Engineering)



Structural Design

Development of the primary framing of the topsides was driven by two main factors:

- Requirement for new interface steelwork between the new-build topsides and the repurposed existing GBS.
- Topsides layout development to suit the revised electrolyser array concept and primary electrical systems.

Interface Steelwork

Development of the interface steelwork was based upon the driving principal of maintaining the existing load paths for the topsides load into the GBS. Altering these load paths significantly could present a substantial risk to the project. Any requirement to modify the GBS would likely be a significant and costly engineering challenge. However, the existing interface between the GBS and existing NCP topsides does appear to lend itself to re-use for a new-build topsides.

Conceptual drawings for the proposed new HOP2 interface steelwork were developed and a 3D model screen shot of the interface steelwork design is shown in Figure 15.



Topsides Layout Development

In relation to the layout development, the main change to the proposed topsides structural framing results from the increased size (and reduced number) of the electrolyser arrays. The increased electrolyser array bay length has led the overall width of the integrated deck primary frame to increase by ~8.4m compared with Phase 1, as shown in Figure 16.

Appurtenances

The general principle for appurtenances was 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. Phase 2 addressed the conceptual design of the following appurtenances required for operation of the HOP2 facility:

- Electrical supply cables
- Hydrogen export riser
- Control and telecoms umbilical
- Seawater lift caisson/s
- Seawater and brine disposal caisson/s.

A riser hang-off balcony was proposed at Level 1 to facilitate the support of the risers required.

Weight Estimation

Given the early stage of project development, a volumetric norm approach was adopted for weight estimation.

A dry weight of 31,600 tonnes was calculated for the HOP2 topsides, with the operating weight estimated as 35,000 tonnes. This weight estimate assumes integrated deck construction and includes an allowance for interface steelwork. This is a substantial topsides weight, and although not unprecedented in the North Sea, it would represent a significant technical and cost challenge to the project. However, the weight estimate is expected to fall within the limit of the existing NCP GBS substructure. Future engineering phases could consider reducing the overall weight by decreasing the target production capacity of the facility.

The optimised arrangement of the electrolyser arrays with more efficient use of space over 3 deck levels (instead of 4 levels in Phase 1) achieved a reduction in the topsides loading for these systems. However, this was partly negated by an increase in weight of the primary electrical systems, as better definition was achieved in this area.

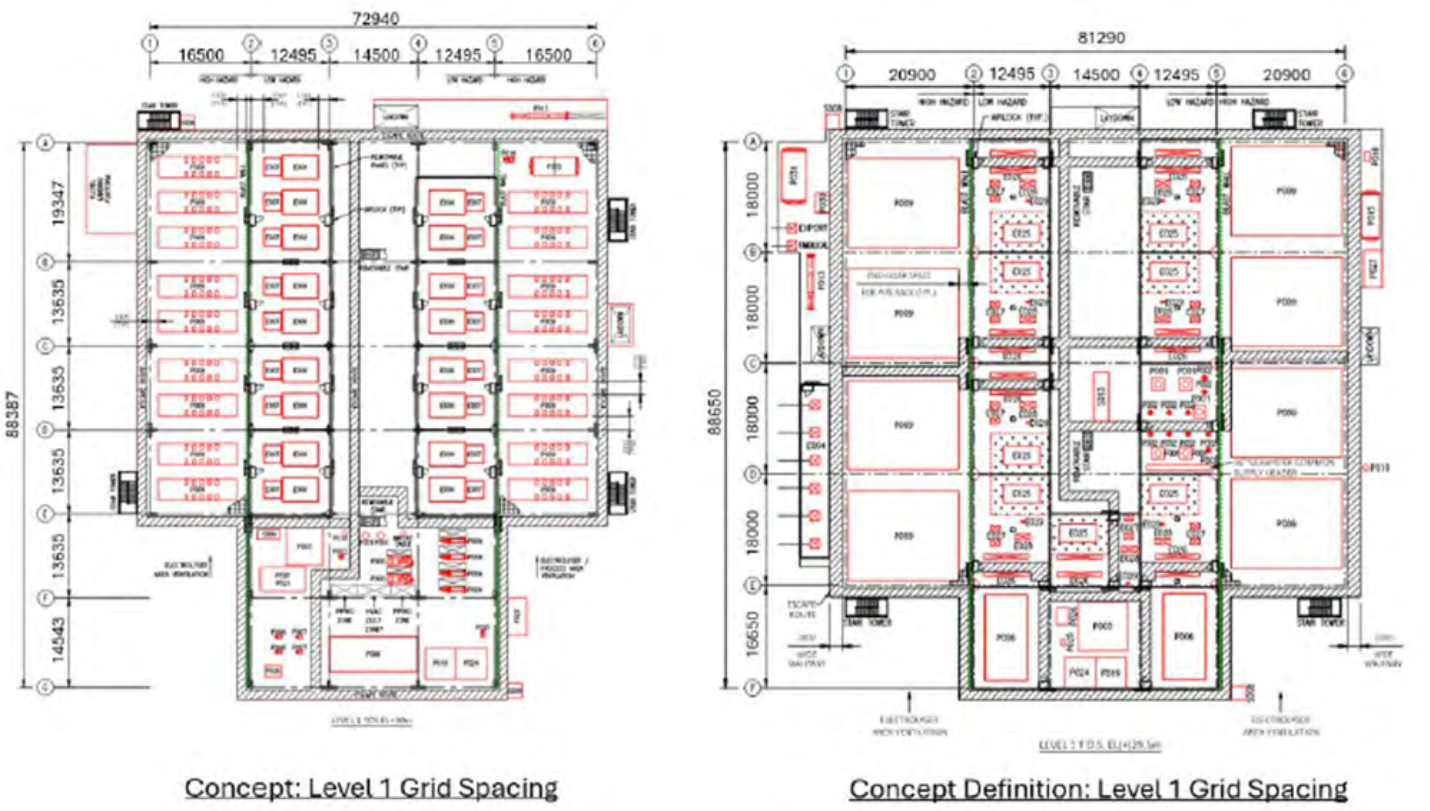
Construction

The base case for the platform installation is an integrated deck design, as this would prove most efficient in terms of weight and overall cost. However, at present the only HLV that could install a topsides of this magnitude in a single lift is the Allseas Pioneering Spirit. This has a stated lifting capacity of 48,000 tonnes (for topsides) and it is believed the vessel has adequate width between its hulls to straddle the existing NCP GBS for a float-over installation. However, further engagement would be required with Allseas to develop the lifting concept and confirm the feasibility of such an installation.

An indicative installation sequence is depicted in Figure 18.

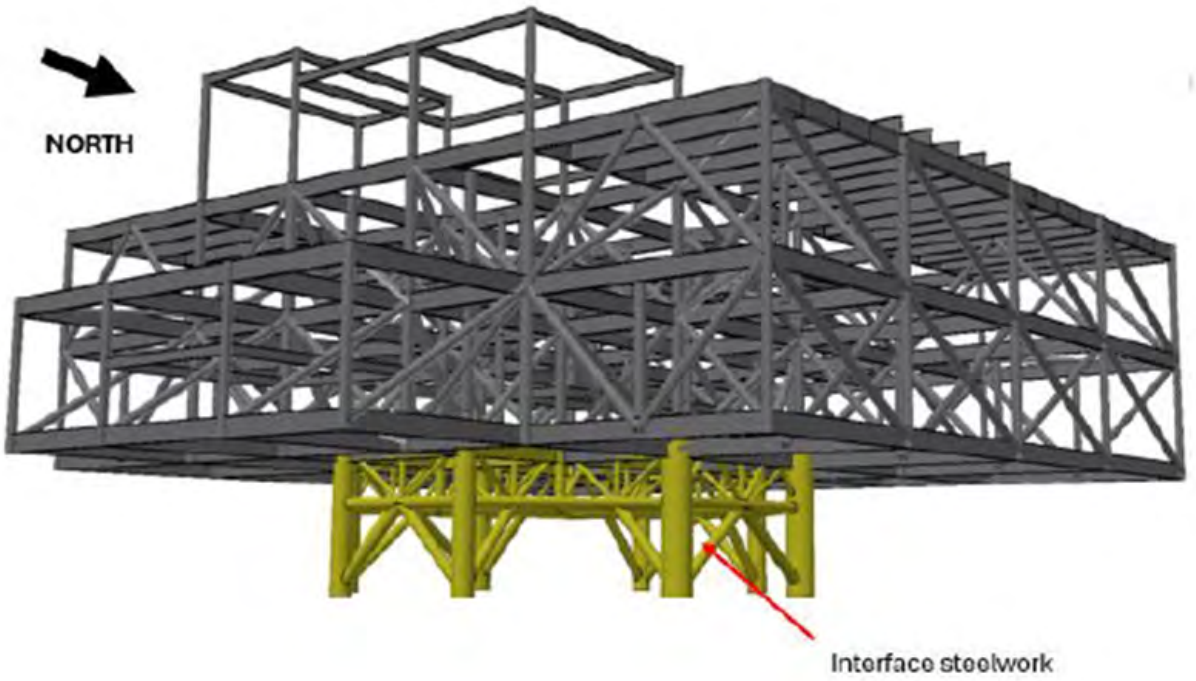
To provide some flexibility in the installation method, the study also considered the feasibility of a more traditional modular installation concept. This would allow use alternative installation contractors with more common dual crane type vessels where there is greater market availability. It was concluded that a modular installation similar to that undertaken for the existing NCP topsides is potentially feasible. However, this may increase the operating weight of the platform close to the GBS substructure loading limit.

Figure 16: Structural grid spacing changes between Phase 1 (left) and Phase 2 (right) (Source: Apollo Engineering)



An indicative framing concept for the integrated deck, including the interface steelwork, is shown in Figure 17.

Figure 17: Indicative Concept for Primary Framing (Source: Apollo Engineering)



Technical Safety

The study considered a range of hydrogen leak scenarios for the HOP2 facility, and high-level consequence modelling was performed. The impact of gas dispersion, explosion and jet fire was 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 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 were not found to cause potential for steel failure due to the limited inventory.

However, since the Technical Safety work performed at this stage was primarily consequence based, it did not take into account that in an emergency scenario the topsides would be shutdown and rapidly depressurised (to flare) to mitigate fire effects. The total hydrogen inventory stored on the topsides is relatively low at approximately 1300kg and, therefore the associated contained energy is also low. On this basis it is expected that the fire escalation risks from hydrogen hazard events will be low.

It is recommended that further assessment is conducted on explosion risk, particularly around the electrolyser arrays which will have many potential leak points such as flanges, valve stems etc. Due to the propensity of hydrogen to leak and its low ignition energy, the risk from explosion overpressure in these areas may potentially be significant.

HOP2 WILL PREDOMINATELY CONSIST OF MODIFYING THE EXISTING SUBSTRUCTURE OF NCP ACCOMPANIED WITH NEW-BUILD TOPSIDES.

Environmental

A preliminary review of the key environmental and consenting risks was undertaken, and actions presented to mitigate impacts where necessary. The environment around NCP where HOP2 is located for the purposes of this study 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 NCP. Socioeconomic considerations highlighted evidence of commercial fishing activity, moderate vessel traffic primarily from service vessels, and proximity to several other oil and gas platforms.

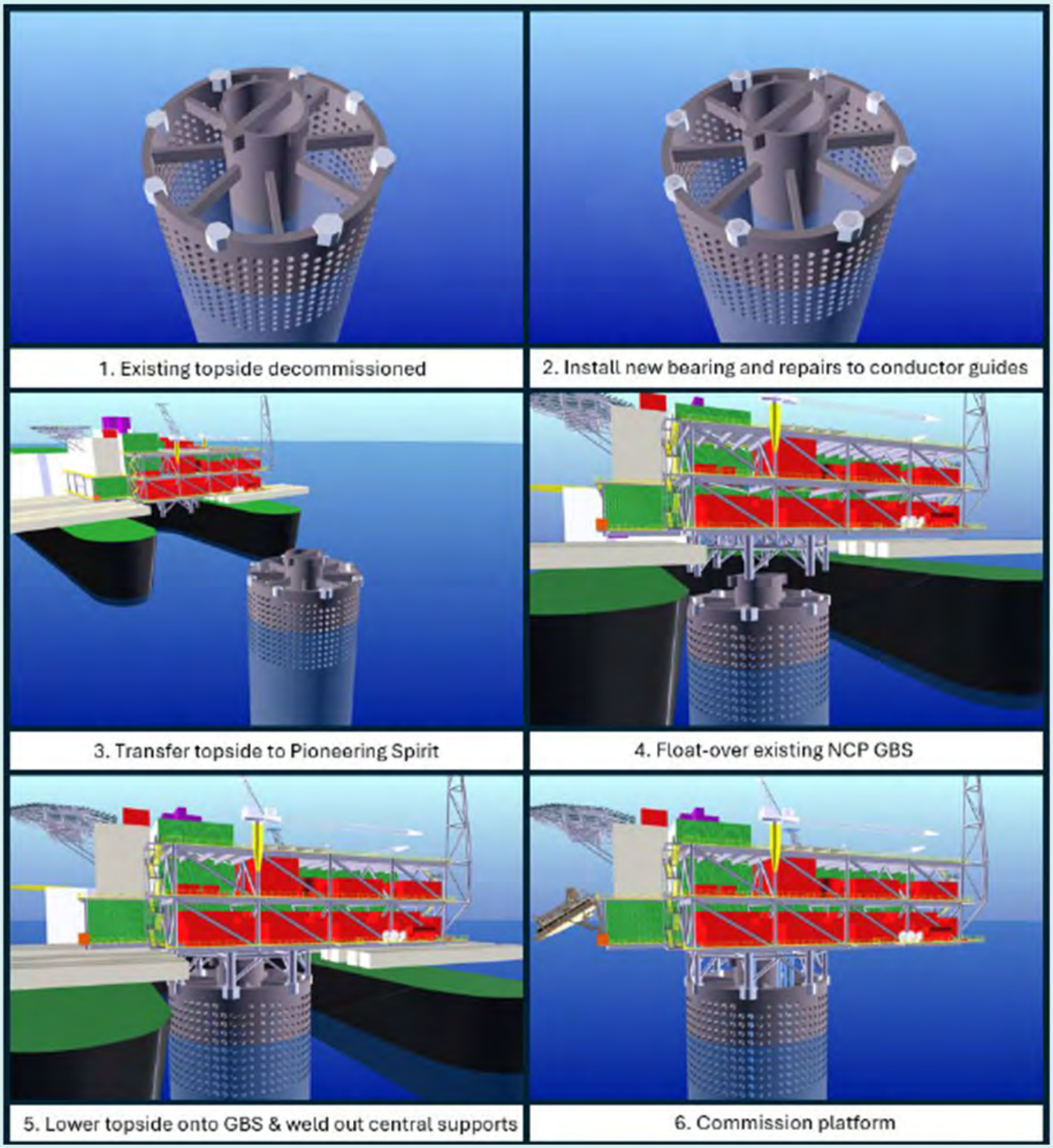
Potential impacts from the construction and operation of the HOP2 facility identified include seabed disturbance, discharge to sea, atmospheric emissions, underwater noise, and accidental events such as chemical spills and vessel strikes. These impacts could affect water quality, benthic organisms, fish, marine mammals, seabirds and other sea users.

HOP2 will predominately consist of modifying the existing substructure of NCP accompanied with new-build topsides. This will include installation of a hydrogen export pipeline, subsea electrical and telecommunications cables, and a seawater lift caisson. 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. However, repurposing of the existing NCP substructure is expected to omit the need for activities such as pile driving or drilling which would cause greater damage to the seabed and benthic habitat.

Operation of the HOP2 facility will require some discharges to the sea; primarily seawater (used as cooling water) mixed with small quantities of brine (<0.25% by mass) from the desalination process and other cleaning chemicals. An appropriate discharge permit will be required through the UK Energy Portal Environmental Tracking System (PETS) in accordance with the Offshore Chemical Regulations 2002 or other appropriate regulations.

The ultimate end use of the repurposed HOP2 facility will limit further carbon emissions and impacts to environmental sensitivities in comparison to its 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.

Figure 18: High-Level Installation Sequence for an Integrated Deck (Source: Apollo)



08
Cost Estimation

Basis of Estimate

A Class 4 cost estimate (+50% / -30%) has been prepared to cover the costs associated with the engineering, design, procurement (equipment and materials), fabrication, site construction, installation and third party vendors required to execute the scope detailed in Figure 1. Costs for the OWF, OSS and subsea cables were excluded.

The following allowances have been applied in the estimate:



Client costs based on 15-20% of estimated costs (including hire of heavy lift vessel)



20% contingency on the bottom line



Where budget quotes have been received in Euro, an exchange rate of 0.85 has been applied



Insurance and bonds have been excluded.

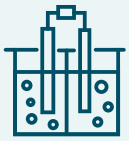
Preliminary CAPEX Estimate

Cost Element	CAPEX £MM RT 2025
Equipment – Electrolysis Stacks	160
Equipment – BoS & BoP	120
Equipment – Primary Electrical Systems	260
All other costs for integration, topsides, substructure and engineering	590
Client Costs	175
Sub-Total	**1,300**
Contingency	260
TOTAL	**1,560**

09
Conclusions & Next Steps

Phase 2 Conclusions

The following conclusions can be drawn from the Phase 2 activity:



Electrolyser Selection:
Further work is needed to address the environmental requirements for PEM stacks in offshore settings, particularly marinisation and integration into topsides design.



Balance of Stack and Balance of Plant:
Consolidation significantly improves space/weight efficiency versus modular arrays and MED technology is optimal for offshore due to waste heat integration. Bespoke large-scale arrays designed for offshore deployment are strongly preferred over adapted standard modular units.



Primary Electrical Systems:
A review of reactive power compensation and energy storage options like batteries and subsurface hydrogen should be considered.



Concept Definition: Topsides Integration:
Focus should remain around safety, particularly regarding hydrogen leak and explosion risks with further assessment of explosion risk around electrolyser arrays advised. Installation contractors should be engaged with early to confirm feasibility of heavy lift or modular installation approaches.



Cost Estimation:
Continue to refine cost estimates as engineering definition improves.



Outcomes and Next Steps

Phase 2 of the project produced a topsides design that makes efficient use of space, weight, and plant balance for offshore hydrogen production by converting an existing offshore platform. The engineering detail developed are thorough enough to give a clear picture of the potential for hydrogen production in this scenario.

Further conceptual design work should be completed when a potential owner, operator, or developer is found to take the concept forward. Considering how the hydrogen market is expected to develop, it's likely that offshore hydrogen development will only begin once the onshore market is more established.

Given this, and the general parallel deceleration of the offshore wind sector build out, Phase 3 will pivot to focus on what could be possible for offshore hydrogen production in the future. It will incorporate "the art of the possible" and focus on a future vision for offshore hydrogen production, maximising use of digital technologies and emerging electrolysis technologies that would be well suited to the offshore environment.

Net Zero Technology Centre

Technology Driving Transition

Net Zero Technology Centre
20 Queens Road, Aberdeen AB15 4ZT

Contact number:
+44 (0)1224 063200

Media enquiries:
pressoffice@netzerotc.com

www.netzerotc.com



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