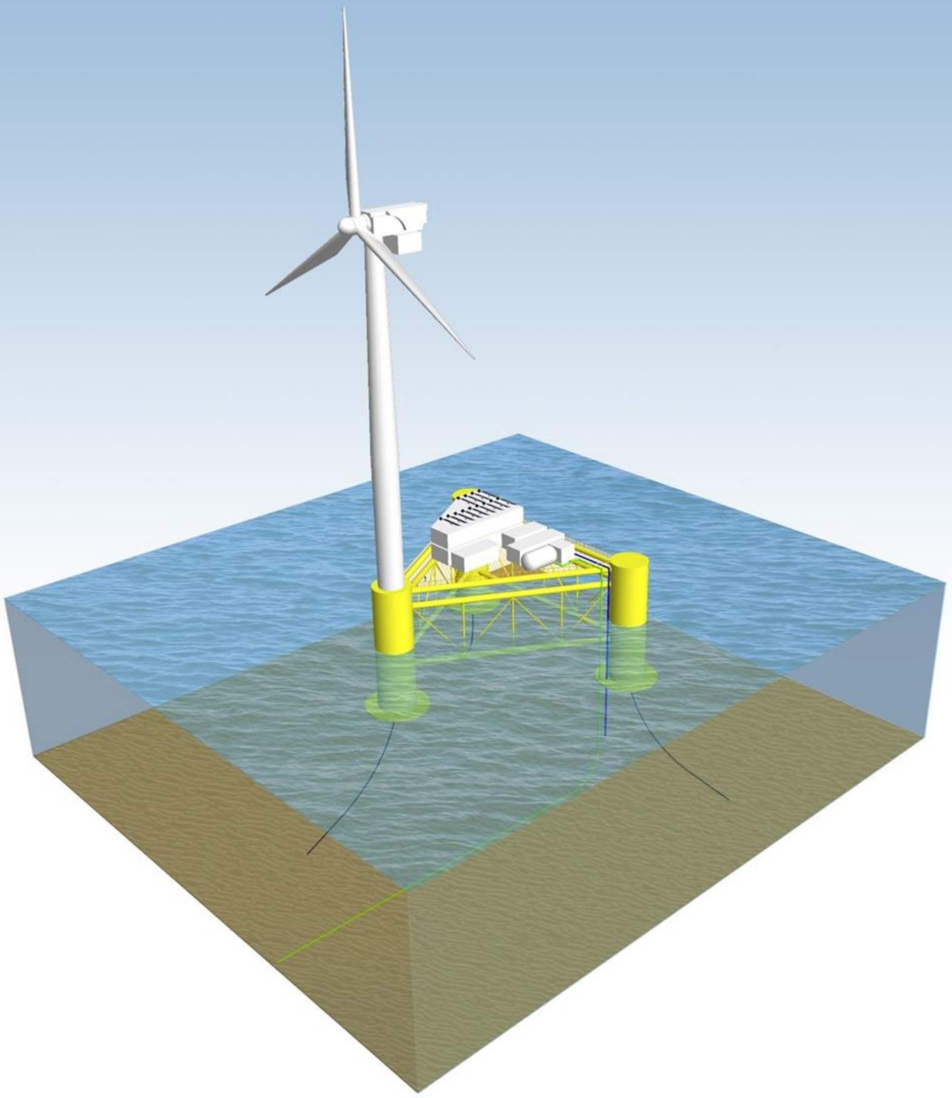


Large Scale Offshore Hydrogen Production

# ERM Dolphyn Hydrogen

## Phase 2 - Final Report

Comprising:
Detailed design for 2MW Scale Prototype
Pre-FEED for 10MW Commercial Scale Demonstrator

Public Report

2 July 2021

Project No.: 0536873

Department for
Business, Energy
& Industrial Strategy

*The business of sustainability*

ERM

| **Document details** | |
|---|---|
| Document title | ERM Dolphyn Hydrogen |
| Document subtitle | Phase 2 - Final Report |
| Project No. | 0536873 |
| Date | 2 July 2021 |
| Version | 1.0 |
| Author | David Caine, Widya Wahyuni, Ben Pizii, Molly Iliffe, Zoe Whitlock, Brett Ryan, Laura Bond |
| | Department for Business, Energy and Industrial Strategy |

## Document history

| | | | | ERM approval to issue | | |
|---|---|---|---|---|---|---|
| Version | Revision | Lead Author | Reviewed by | Name | Date | Comments |
| 1.0 | 00 | D. Caine | K. Kinsella | K. Kinsella | 02.7.21 | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

## Signature Page

2 July 2021

# ERM Dolphyn Hydrogen

Phase 2 - Final Report

Public Report

Dave Caine

Kevin Kinsella.

David Caine
Principal Consultant
Dolphyn Project Manager

Kevin Kinsella
Partner
Dolphyn Project Director

Environmental Resources Management
5 Exchange Quay
Salford
Manchester
M5 3EF
United Kingdom

## ABOUT ERM

Our work on low carbon energy transition and hydrogen covers many of the UK's leading projects (e.g.  H21, Hy4Heat, HyNet, H100, HyGen, Acorn).  We have extensive experience on leading renewable projects, including major wind farm projects both offshore and onshore.  We are the originators, developers and project manager for the ERM Dolphyn project, developing an innovative technical and economic solution for producing green hydrogen at scale from offshore wind.

ERM provides advice to our clients that improves their sustainability performance, including services such as:

### Response to Climate-Related Financial Impacts

ERM were the lead authors on behalf of the TCFD for the technical guidance for assessing climate-related financial risks and opportunities.  Recognising our TCFD expertise leading industrial companies, who are typically heavy emitters of CO2, have appointed ERM to work with them to assess the financial drivers on their business from the energy transition and to define strategic responses to mitigate risks and capture new growth opportunities.  Through the extensive work we have undertaken in the financial and corporate sectors, we understand both investors' key concerns and companies' potential challenges.

### Advice on Low-Carbon Business Growth

We help clients to shape their strategic response to the Energy Transition; this usually follows a detailed options appraisal that has assessed the techno- economic feasibility of different strategies and/or technologies.  ERM's expertise extends way beyond board rooms, we are fully equipped to support companies at a site-level delivering new innovative low-carbon projects, from advancing hydrogen and CCUS projects to supporting companies in reducing their overall product carbon intensity across their portfolio.  ERM has current insights into CCS / CCUS policy from our work with the CO2 Capture Project (CCP).  This presents a survey of CO2 storage regulations from a range of countries including the USA, Canada, UK, and Australia.

### Supporting Financial Resilience

Beyond implementation, a key part of our work is to measure and demonstrate a client's stated actions i.e. to demonstrate the positive impact of these low carbon advancements, and ultimately helping to support companies' reputations as responsible corporate citizens and retain their License to Operate.  We support companies in their reporting (e.g.  TCFD, CDP, corporate and sustainability reports), and engagements with investors, government and society more widely.

ERM works with the world's leading organizations, delivering innovative solutions and helping them to understand and manage their sustainability challenges.  ERM is a founder member of the WBCSD and has contributed to their publications including several sector SDG Roadmaps.  We have more than 5,500 people in over 40 countries and territories working out of more than 160 offices with London being our Global HQ.  www.erm.com

## CONTENTS

## List of Tables

## List of Figures

## Acronyms and Abbreviations

| | |
|---|---|
| ACC | Aberdeen City Council |
| ALARP | As Low As Reasonably Practicable |
| ATR | Auto Thermal Reformation |
| BEIS | Department for Business Energy and Industrial Strategy |
| BRAG | Black, Red, Amber, Green |
| BSC | Balanced Scorecard |
| CAPEX | Capital Expenditure |
| CCP | $CO_2$ Capture Project |
| CCS | Carbon Capture and Storage |
| CCUS | Carbon Capture, Utilisation and Storage |
| CDP | Carbon Disclosure Project |
| CES | Crown Estate Scotland |
| CfD | Contract for Difference |
| COMAH | Control of Major Accident Hazard Regulations |
| COPA | Control of Pollution Act |
| CSM | Construction Safety Management |
| DCR | Offshore Installation Design and Construction Regulations |
| DEA | Drag Embedded Anchors |
| DFIG | Doubly Fed Induction Generator |
| DLC | Design Load Case |
| DTM | Digital Terrain Model |
| EERA | Escape Evacuation and Rescue Analysis |
| EHS | Environmental, Health, and Safety |
| EIA | Environmental Impact Assessment |
| EPCI | Engineering, Procurement, Construction, and Installation |
| ESD | Emergency Shut-Down |
| ESSA | Essential Systems Survivability Analysis |
| ETZ | Energy transition Zone (Aberdeen – developed by Opportunity North East) |
| FCEV | Fuel Cell Electric Vehicle |
| FEED | Front End Engineering Design |
| FEHA | Fire and Explosion Hazard Analysis |
| GIS | Geographic Information System |
| HAZID | Hazard Identification |
| HAZOP | Hazard and Operability Analysis |
| HGE | Hydrogen Gas Embrittlement |
| HMB | Heat and Material Balance |
| HMPE | High Modulus Polyethylene |
| HPU | Hydrogen Production Unit |
| HSE | Health and Safety Executive |
| HSWA | Health and Safety at Work Act |
| HVAC | Heating, Ventilation, and Air Conditioning |
| IEC | International Electrotechnical Commission |
| IMO | International Maritime Organisation |
| KOWL | Kincardine Offshore Wind Limited |
| LCOH | Levelised Cost of Hydrogen |
| LER | Local Equipment Room |

| | |
|---|---|
| LOLER | Lifting Operations and Lifting Equipment Regulations |
| MAH | Major Accident Hazard |
| MARPOL | International Convention for the Prevention of Pollution from Ships |
| MBL | Minimum Breaking Load |
| MBR | Minimum Bending Radius |
| MHSWR | Management of Health and Safety at Work Regulations |
| MODU | Mobile Offshore Drilling Unit |
| NDA | Non-Disclosure Agreement |
| NTS | National Transmission System |
| NUI | Normally Unmanned Installation |
| OGA | Oil and Gas Authority |
| ONE | Opportunity North East |
| OPEX | Operating Expenditure |
| ORE | Offshore Renewable Energy |
| PEM | Polymer Electrolyte Membrane |
| PER | Pressure Equipment Regulations |
| PFD | Process Flow Diagram |
| PFEER | Prevention of Fire and Explosion and Emergency Response Regulations |
| PSR | Pipeline Safety Regulations |
| PSSR | Pressure System Safety Regulations |
| PWA | Pipeline Works Authorisation |
| RDS PP | Reference Designation System for Power Plants |
| SBRI | Small Business Research Initiative |
| SCR | Offshore Installation (Safety Directive) (Safety Case etc.) Regulations |
| SDG | Sustainable Development Goals |
| SECE | Safety and Environmentally Critical Equipment |
| SMR | Steam Methane Reformation |
| SOLAS | Safety of Life at Sea |
| SSSI | Sites of Special Scientific Interest |
| TCFD | Taskforce for Climate Related Financial Disclosures |
| UPS | Uninterruptable Power Supply |
| WBCSD | World Business Council for Sustainable Development |
| WTG | Wind Turbine Generator |

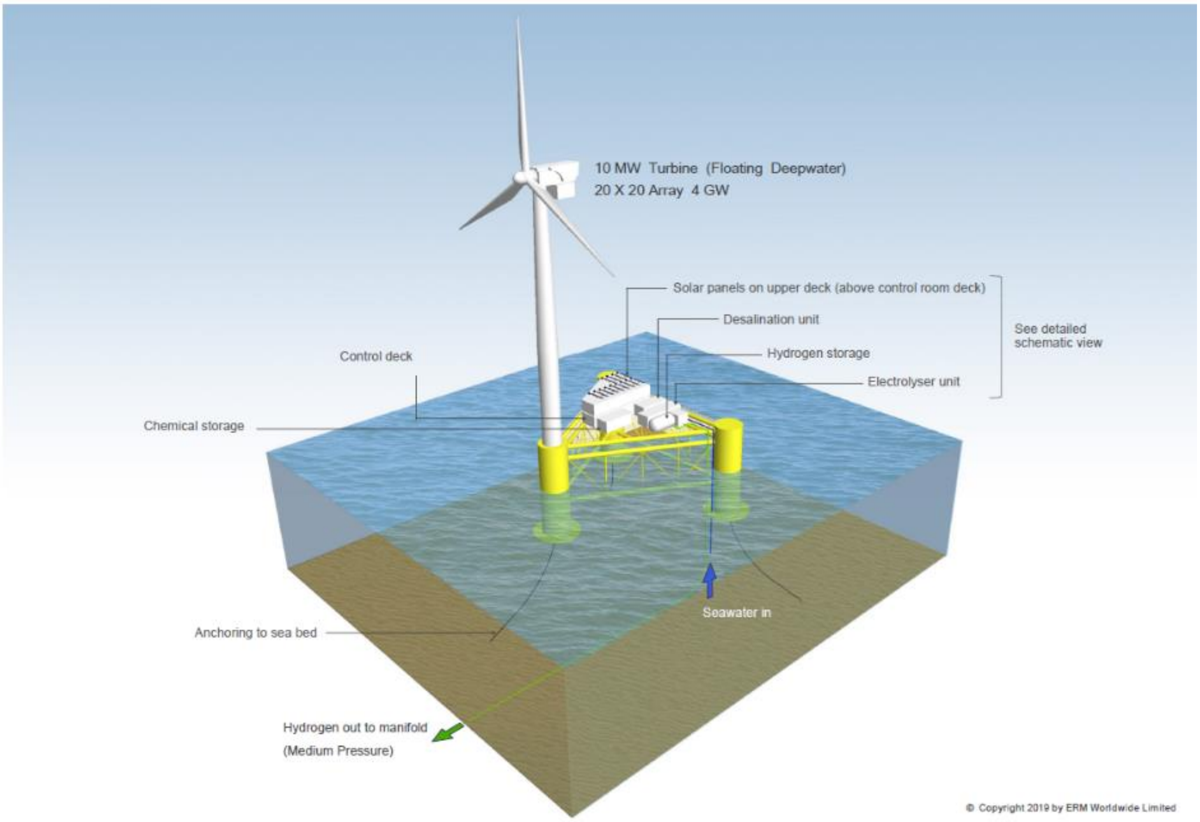
## EXECUTIVE SUMMARY

ERM has developed the Dolphyn concept for the production of ‘green’ hydrogen at scale from offshore floating wind. The Dolphyn concept has been developed by ERM over the last 4 years. This development has been accelerated under the Hydrogen Supply Competition, funded by the BEIS Energy Innovation Programme (2016-2021). During **Phase 1** of the programme, the concept was compared to alternative centralised and decentralised options both onshore and offshore and was found to be the most economically advantageous solution for generating hydrogen at multi-GW scale. Subsequently a prototype design solution for ERM Dolphyn was developed to FEED stage.

Through the work completed in this phase (**Phase 2**), the project has progressively de-risked the design to the extent that we can move forward confidently to a 10MW unit FEED from the previous 2MW unit. This will enable us to build the first 10MW unit more quickly and will result in the development pathway for the first commercial Dolphyn wind farm (typically 100-300MW) being accelerated by up to 4 years. The project aim is to construct and operate the first 10MW unit by the end of 2024. The first commercial scale farms (100-300MW) are currently being planned and are expected to be operational from the late 2020s.

### Producing Green Hydrogen at Scale from Offshore Floating Wind

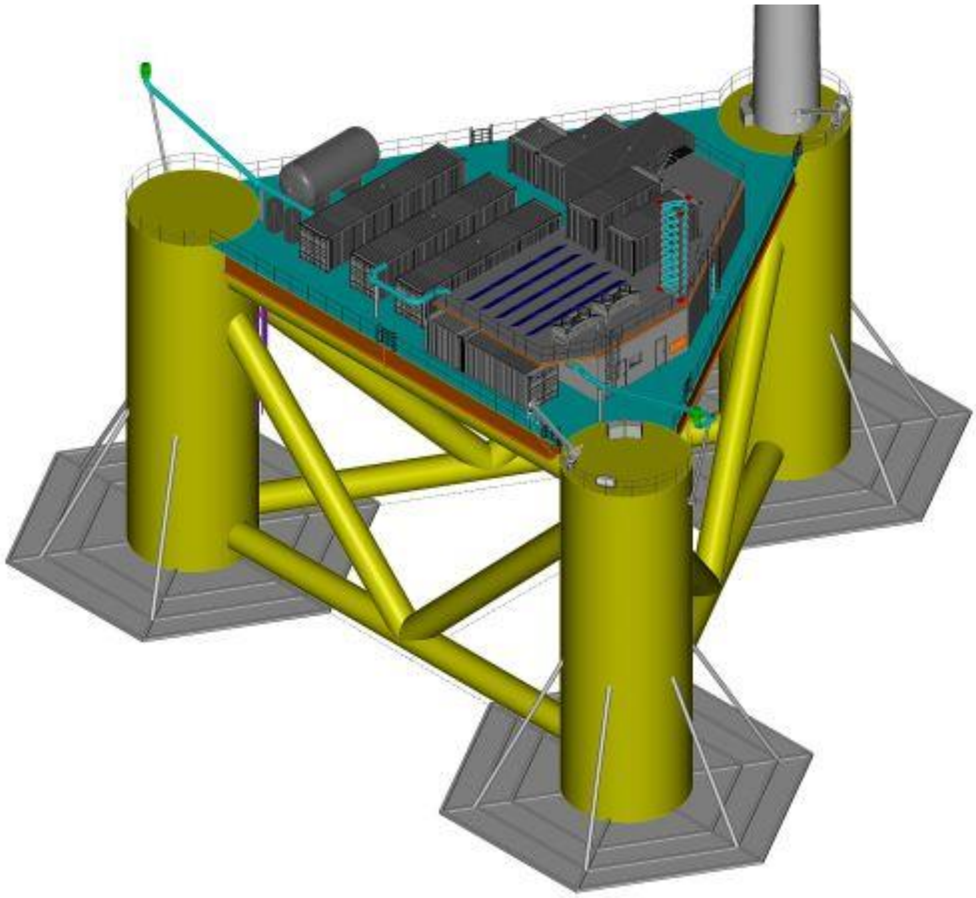
The Dolphyn concept employs a modular design, integrating electrolysis and a wind turbine (nominally 10MW) on a moored floating sub-structure to produce hydrogen from seawater using wind power as the energy source. The component parts of the concept, whilst emerging technology, are all at a high ‘technology readiness level’ providing a good degree of confidence that the solution will work at scale.



## Development of the 2MW Prototype has De-Risked the Project

The design activities for the 2MW Prototype have been successfully completed, resulting in more than 300 engineering deliverables being produced, including a wide range of studies and engineering drawings such as layouts, 3-D models, Process Flow Diagrams (PFDs), Piping and Instrumentation Diagrams (P&IDs) and Single Line Diagrams (SLDs). Key documents required for the next stage of the project (e.g. testing, procurement, installation, commissioning and operation) have also been developed. These include equipment datasheets and specifications, offshore testing plans, installation plan and the process control philosophy.

Development of the Detailed Design for the Dolphyn 2MW unit has enabled engineering activities to focus on de-risking the project, which has been highly successful. The work focussed on providing the necessary evidence needed to deploy all of the primary systems on a full-scale unit. There are now no significant technical barriers remaining that prevent the development and deployment of the concept considered.



## An Accelerated Timeline to Commercial Scale Demonstration

During the course of delivery of Phase 2, the project team were able to successfully identify and evaluate a low risk route to accelerated deployment at scale. A number of smaller scale offshore trials focussed on the key systems (e.g. power, electrolysis, desalination) will be conducted to suitably demonstrate the effectiveness of the overall system. This will negate the requirement for the smaller scale 2MW prototype planned under Phase 1. This enables the project to proceed directly with the development of the first 10MW commercial scale unit around 4 years faster than originally planned. The decision was taken midway through the delivery of this Phase to finalise and close out of the 2MW prototype development activities early and switch directly to the pre-FEED for the 10MW unit. This has now been completed in addition to the successful finalisation of the 2MW engineering activities.

The outputs of the pre-FEED design activities for the 10MW commercial scale demonstration unit have provided confirmation that the Dolphyn concept is technically and economically robust at the larger scale. It has also provided clarity over the likely design, procurement, and construction challenges to be faced, enabling a clear risk-based development plan.

The pre-FEED design activities for the 10MW commercial scale demonstrator have been successfully completed resulting in more than 20 engineering deliverables and studies, including key deliverables such as preliminary layout, Process Flow Diagrams (PFD) and Heat and Mass Balance (HMB), equipment list and electrical load list.

## The Design has been Independently Verified and is aligned with Regulatory Expectations

The ERM Dolphyn Project is an innovative project looking to produce hydrogen offshore at scale from floating wind technology. A regulatory framework does not currently exist specifically for the development of offshore hydrogen production facilities. Therefore, the Dolphyn project has had to work with regulatory bodies to 'borrow' best practise from two existing industries for combined experience of best safe practice and risk management:

1. Offshore renewables (offshore floating wind in particular); and
2. Offshore oil and gas (flammable gas production and control).

The ERM project team has regularly liaised with the UK HSE to understand the latest thinking in safe hydrogen project development, and to share our view of ensuring a safe design. Offshore hydrogen development is a new area and ERM are keen to contribute to the development of a clear and safe approach to offshore hydrogen development. We are confident that the approach adopted is in line with the highest standards of technical safety design and safety management.

The design process for the Dolphyn project has been critically reviewed and independently verified by Lloyd's Register to provide confidence that a robust hazards management process is being followed during the design. Lloyd's Register have had unrestricted access to all design documentation developed by the project team.

## The Optimal Site has been selected with a Roadmap to Consenting

Site selection exercises were completed for both the offshore and onshore components of the Project to identify sites that will be consentable, and are least constrained by technical, safety, environmental and commercial considerations.

Broad search areas were initially identified in the North Sea considering a range of factors including access to an onshore hydrogen market, and wind and wave characteristics. Within the zones under consideration, the area south-east of Aberdeen city close to the existing Kincardine offshore wind farm was identified as the most advantageous. The Kincardine field offers a number of project similarities to Dolphyn; it is a floating wind farm, with 10 MW units, and utilises a similar substructure and mooring design.

ERM Dolphyn is a novel green hydrogen project and will require a variety of consents for the different components. The consenting route is uncharted and the existing regulatory regime is not entirely fit-for-purpose for this kind of technology. Although a consenting strategy has been devised within the existing regulatory regime, the Project team is still seeking formal agreement on the requirements for the project.

Project engagement with the regulators (OGA, CES and MS) has been proactive and positive, and the Project team will continue to work collaboratively to navigate the regulatory system as it develops. The pragmatic approach followed by all parties so far, provides confidence in the successful offshore consenting of the commercial scale unit.

At this stage of the development process, the onshore site selection and preliminary survey work conducted has confirmed a number of onshore sites and pipeline routes that have the potential to site the hydrogen receiving facility and associated infrastructure. This provides sufficient confidence that a technically feasible pipeline routing and onshore site exist, close to suitable offtakes. The likely development risks and cost implications to the project are understood and have been taken forward into the development plan. Following detailed feasibility and engineering assessments at the next stage of the Project a technically feasible site for the onshore facilities will be selected.

### The Complete Supply Chain is in place and ambitions are well aligned with ERM Dolphyn

To date, the project has recorded more than 150 equipment providers, 200 Service providers and more than 30 manufacturing facilities with capacity to support the project. The project has developed an extensive Supplier Management Register and has developed a good understanding of the supply chain readiness for Dolphyn. The register forms the project database of supply chain contacts as well as keeping a record of engagement and screening activity progress and therefore of evolving supply chain risk identification.

Engagement with suppliers of equipment and services to date has proven extremely useful to the project. Based on these discussions and coupled with the work undertaken by the engineering teams, there appears to be minimal supply risk for the major components and services to support development of the ERM Dolphyn 10WM unit.

The assessment work completed has shown that platform fabrication, assembly and WTG integration activities for the 10MW Dolphyn unit can all occur within a single facility, with suitable facilities located in the UK. However, there is a potential to reduce the platform fabrication cost by as much as 20% if the platform is fully fabricated at an experienced port site outside of the UK. The ERM Dolphyn project is committed to maximising UK content as far as is economically practicable. The project team have an existing relationship with a suitable deep-water port facility in the UK and are keen to continue working with wider UK facilities during the next phase to explore options for fabrication optimisation.

### A Rapid Route to Deployment at Scale to meet Society’s Ambitions

The Commercial Development Plan represents a rapid and efficient means of quickly moving to at-scale deployment, while incorporating learnings and aligning with the UK Government’s objectives on decarbonisation and the development of a hydrogen economy.

The plan has been developed incorporating feedback from potential investors and offtakers, which has been extremely positive about the potential for rapid deployment at scale. A phased approach to build out will enable learnings from the project, and from the sector more widely, to be incorporated to reduce costs and optimise performance.

The Commercial Development Plan assumptions align with the UK Government's goals and objectives on decarbonisation and the development of a hydrogen economy as detailed in the Government's 10 Point Plan, enabling ERM Dolphyn to make a significant contribution to meeting these national objectives.

Our financial assessments, which are continually being refined with suppliers as the project progresses, suggest that the project can achieve all of its financial targets for hydrogen production costs. These are forecast to reduce considerably in line with technological development and efficiencies in manufacturing process and scale-up. By 2040, we are forecasting that hydrogen at a price of around £1.50/kg would be available from large-scale ERM Dolphyn projects, and that UK deep-water areas of the North Sea and Celtic Sea have the potential to provide 10's of GW capacity providing a security of supply. This level of UK green hydrogen production can make a significant contribution to large-scale decarbonisation of UK transport, industry and heating, whilst also facilitating the potential to export large volumes of green hydrogen to Europe.

| | Operational from | Location | Hydrogen production rate (tonnes/yr) | Development status |
|---|---|---|---|---|
| **Small scale hydrogen performance demonstration trials** | 2022 | UK (near shore) | n/a – short duration performance trials | Project defined |
| **Commercial scale demonstrator unit (10MW)** | 2024 | Aberdeen | 900 | Project defined |
| **Deployment of multiple commercial fields 100-300 MW** | Late 2020s onwards | UK (North Sea and Celtic Sea) and global locations | 9,000 – 27,000 | Pipeline of sites, 2 at advance stage of development |
| **GW scale large commercial projects** | Early 2030s onwards | UK (North Sea and Celtic Sea), other sites globally | ~360,000 | Site identification underway |

During the next phase of the project, work will be undertaken to overcome the remaining technical, commercial and financing challenges, and realise opportunities to optimise the project that have been identified during the work so far. Public funding will be critical to achieve this.

In order for the rapid deployment of ERM Dolphyn to be successful, and for the UK to achieve the economic and decarbonisation benefits of green hydrogen, UK Government support is required. In particular, revenue and/or grant funding support for early stage projects like ERM Dolphyn, the removal of regulatory barriers, and the stimulation of market demand for hydrogen, will be key to success.

A number of commercial offtake agreements have already been developed for ERM Dolphyn. Certainty over the level of government support will be key to concluding these discussions and formalising any future offtake pricing structure.

## Supported by World Leading Organisations

The ERM Dolphyn project has been developed with input from a wide variety of organisations with relevant experience and knowledge across a range of established sectors including oil and gas, renewables, chemicals, hydrogen production, energy, construction, trading, and marine operations. ERM is extremely grateful for the support and input from all organisations and in particular, we would like to acknowledge the considerable support, knowledge and expertise provided by our project sub-contractors, namely:

Doosan Babcock

Nel Hydrogen

Principle Power

Lloyd’s Register

ODE

Tractebel

# 1. INTRODUCTION

ERM has developed the Dolphyn concept for the production of large-scale ‘green’ hydrogen from offshore floating wind. Dolphyn aims to deliver large scale zero carbon hydrogen at a competitive price, thereby making a significant contribution toward accelerating the UK’s path to Net Zero as outlined in the Governments ten point plan for a green industrial revolution. The Dolphyn concept has been developed by ERM for a number of years. This development has been accelerated under the Hydrogen Supply Competition, funded by the BEIS Energy Innovation Programme (2016-2021). During Phase 1 of the programme, the concept was compared to alternative offshore options, and a prototype design developed to FEED stage with a final report developed by ERM [1]. Phase 2 of the programme has developed the prototype design (2MW) sufficiently for a final investment decision to be made, additionally the first commercial scale unit (10MW) has been developed to a Pre-FEED level. This report summarises the work completed under Phase 2.

## 1.1 BEIS Hydrogen Supply Programme

The aim of the Hydrogen Supply Programme is to identify and test approaches to supplying bulk low carbon hydrogen; either to the gas grid, or for industry, power, or transport applications. However, for a market to grow, potential users (in any application) need to be confident in the supply of sufficient hydrogen at a competitive price. By supporting innovative pilots to help develop the process and technologies required to supply bulk low carbon hydrogen, this Programme seeks to address the supply and cost differential between natural gas and low carbon hydrogen.

The Programme seeks to identify and demonstrate bulk low carbon hydrogen supply solutions, which have the potential to be replicated at significant scale in identical or similar applications, that can meet the challenges of supplying the gas grid, industry, power, transport and upgrading our import terminals to be able to handle hydrogen (or hydrogen carrier). The Programme is technology-neutral; however, it takes a portfolio approach to funding a range of solutions.

The proposed bulk low carbon hydrogen solutions include: low carbon production (through fossil fuel reformation with CCS), zero carbon production (using zero carbon energy such as electrolysis, nuclear, or biomass with CCS), the import infrastructure for hydrogen, the storage of hydrogen, or the bulk provision of hydrogen closer to the end user. These solutions could also include the use of a hydrogen carrier, such as ammonia, methanol or LOHC.

A two-stage Small Business Research Initiative (SBRI) pre-commercial procurement process has been used to evaluate these innovative large-scale hydrogen production options:

**Phase 1, Feasibility studies**. Project teams undertook feasibility studies comprising:

- An assessment of the market size and export opportunities for the technology for bulk low carbon hydrogen supply.
- A detailed engineering design for each hydrogen supply solution, against which an assessment could be made on a number of metrics. These are likely to include: capital and operating costs, process risks (reliability), the availability and the impact of variable demand, the hydrogen quality, the

potential to mitigate greenhouse gases, the build rate, and how the process could be scaled. Process modelling or small-scale trials could be used to verify the design.

- A detailed development plan for each solution describing the key development steps to commercialisation, including the key barriers and risks. This included a detailed focus on the component(s) to be piloted in Phase 2.
- A detailed assessment of the business plan on how the process will continue to be developed after the funding for the pilot ends.

**Phase 2** is for projects that have been down-selected from Phase 1, based on the information contained in their Feasibility Study. This phase will result in the implementation and demonstration of a hydrogen supply solution and will consider applications to pilot key components or further develop the design of the new hydrogen supply solutions. A pilot demonstration is not limited to a physical demonstration and may only be for part(s) of the process. This could include detailed process modelling or engineering design. The Phase 2 demonstration projects were selected based on the feasibility studies submitted for Phase 1. ERM Dolphyn was one of the projects selected and this report presents the work completed under Phase 2.

## 1.2 Dolphyn Concept

The Dolphyn concept employs a modular design, integrating electrolysis and a wind turbine (nominally 10MW) on a moored floating sub-structure to produce hydrogen from seawater using wind power as the energy source. The component parts of the concept, whilst emerging technology, are all at a high ‘technology readiness level’ providing a good degree of confidence that the solution will work at scale. An illustration of the ERM Dolphyn concept is shown in Figure 1.1 and Figure 1.2:

**Figure 1.1 Dolphyn Concept Overview**

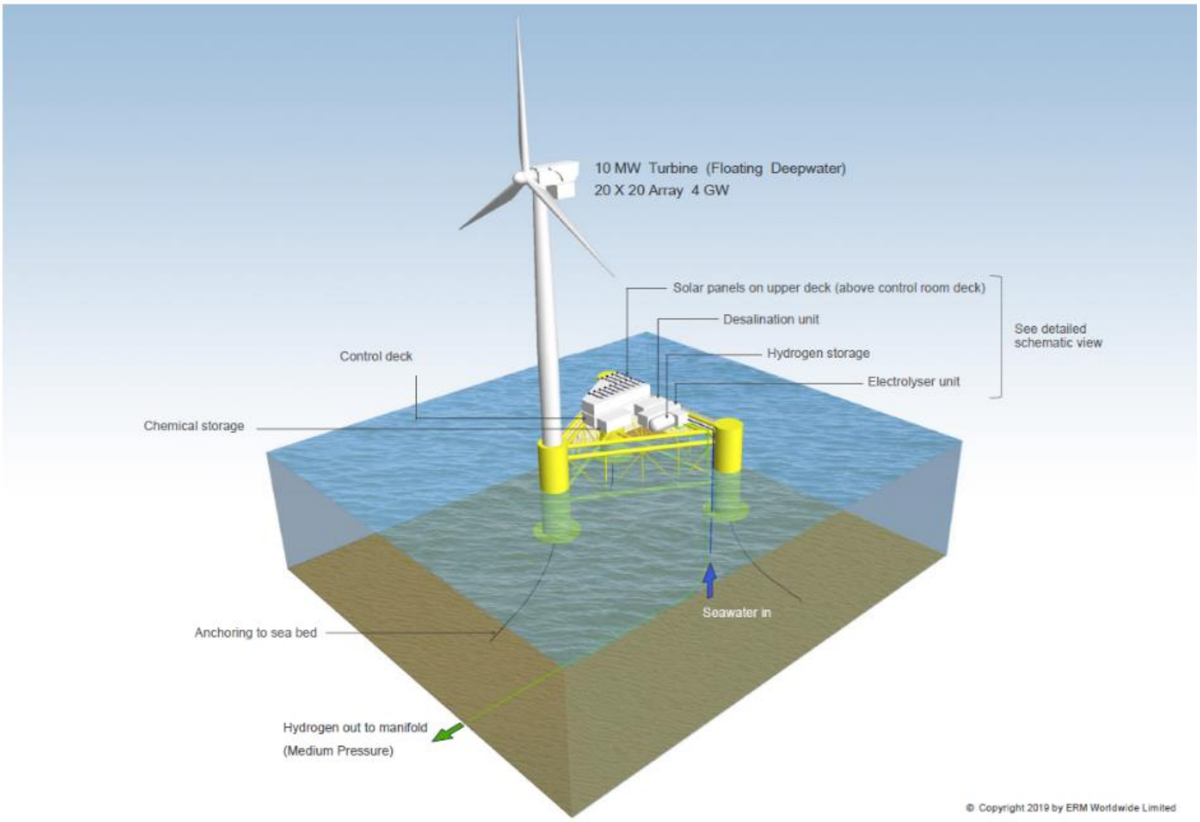
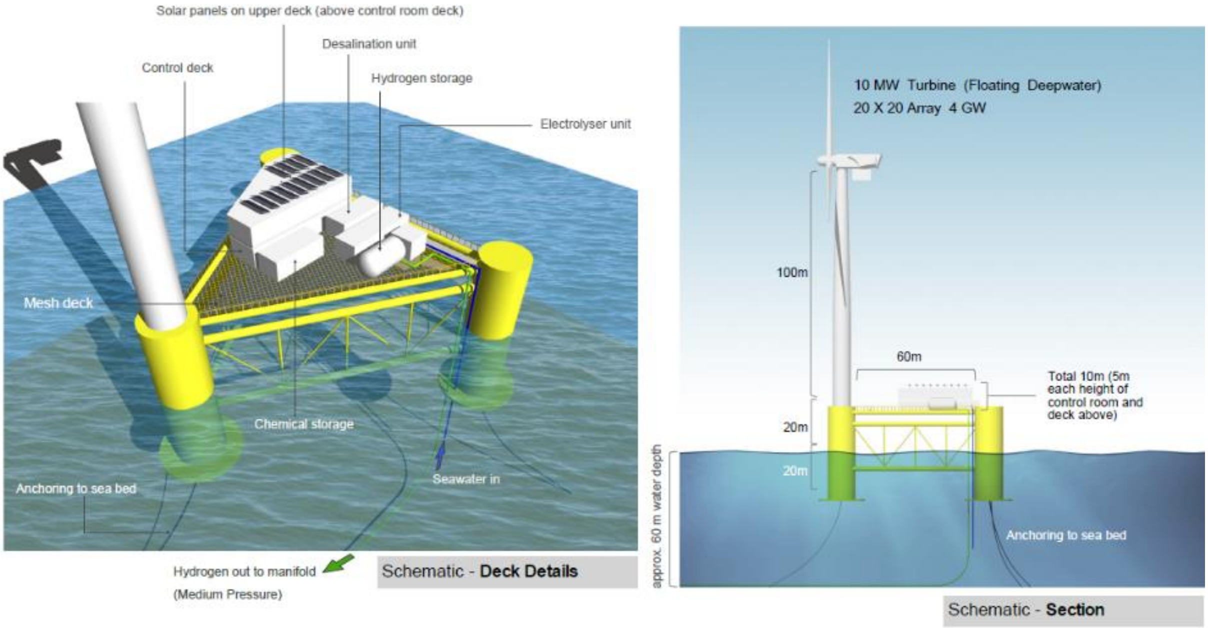


**Figure 1.2 Dolphyn Close-up Schematic**

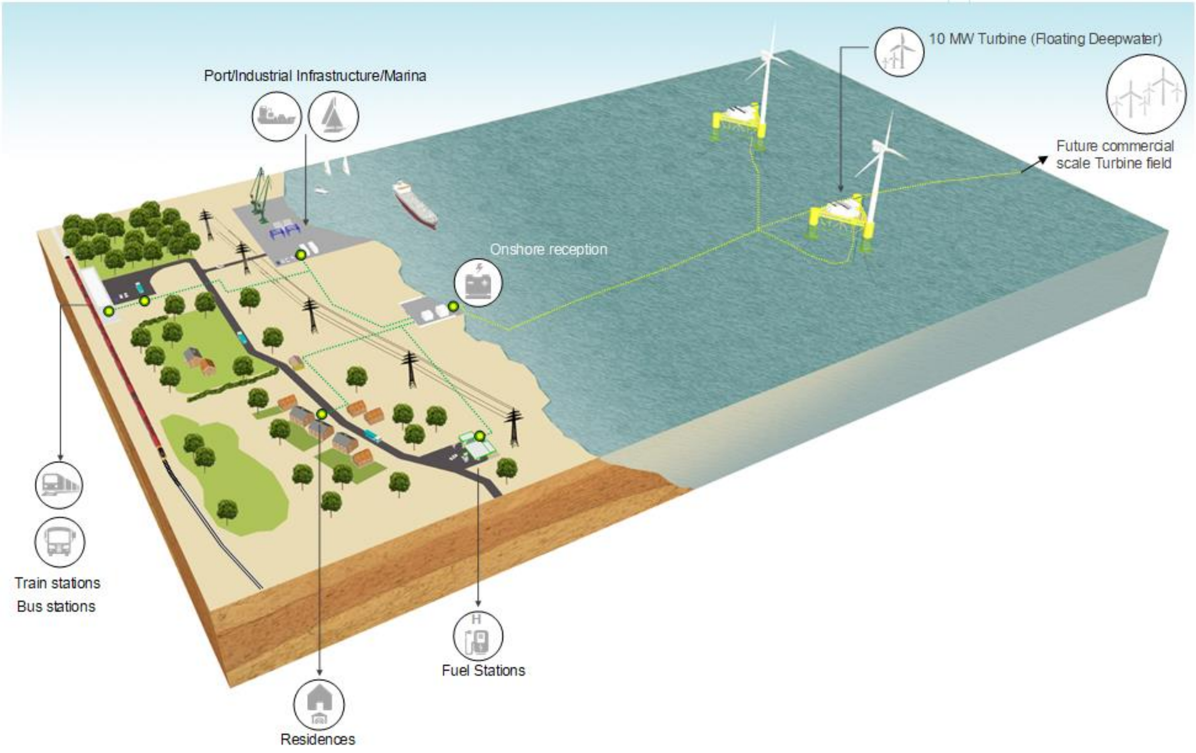


The ERM Dolphyn Concept can be deployed in any number of units enabling significant flexibility of deployment. The optimal deployment configuration is expected to be large-scale windfarms to maximise the efficiency of shared infrastructure. The base case for deployment is a 20 x20 array configured to provide a hydrogen production wind farm of 4GW capacity. A 4GW windfarm would supply sufficient green hydrogen to heat around 1.5 million homes.

## 1.3 Dolphyn Development Background

The ERM Dolphyn concept has been developed with the objective of supplying green hydrogen at a sufficiently low cost to be used for heating or transport applications. On the road towards large-scale deployment the Dolphyn project will initially be deployed at lower scale, supplying hydrogen into a local geography. These smaller scale ‘stepping stone’ projects have a significant role to play in establishing local hydrogen markets. The Dolphyn project is engaging with the local supply chain and collaborating with local operations support specialists to maximise local content. The hydrogen produced can be used in a variety of applications including fuel for heavy vehicles, rail, light transport, industrial processes, domestic heating, or marine activities. The potential interface with local markets and facilities is outlined in Figure 1.3.

**Figure 1.3 Dolphyn Interface with Local Infrastructure**



The ERM Dolphyn concept’s value is particularly demonstrated at larger scale deployments further from shore. It is able to operate in deep-water and the efficiency of hydrogen pipelines as an energy transmission method enable economic operations to be conducted long distances from shore. The UK is blessed with some of the highest quality offshore wind resources in the world, which is illustrated in Figure 1.4 showing the power density distribution of UK offshore wind [2]. The highest quality wind resources are located long distances from shore in deep water.

Globally there is estimated to be over 12,000 GW of Floating Wind Capacity, the majority of which is located in Europe, China, Japan and US. Combined, this is the equivalent of over a billion tonnes of hydrogen production per year. Whilst the full development of these areas will be shared with offshore floating wind power production, the enormous scale of suitable quality wind gives confidence in the scalability of the Dolphyn technology for hydrogen production beyond just the UK, Figure 1.5.

**Figure 1.4 Offshore Wind Power Density Distribution**

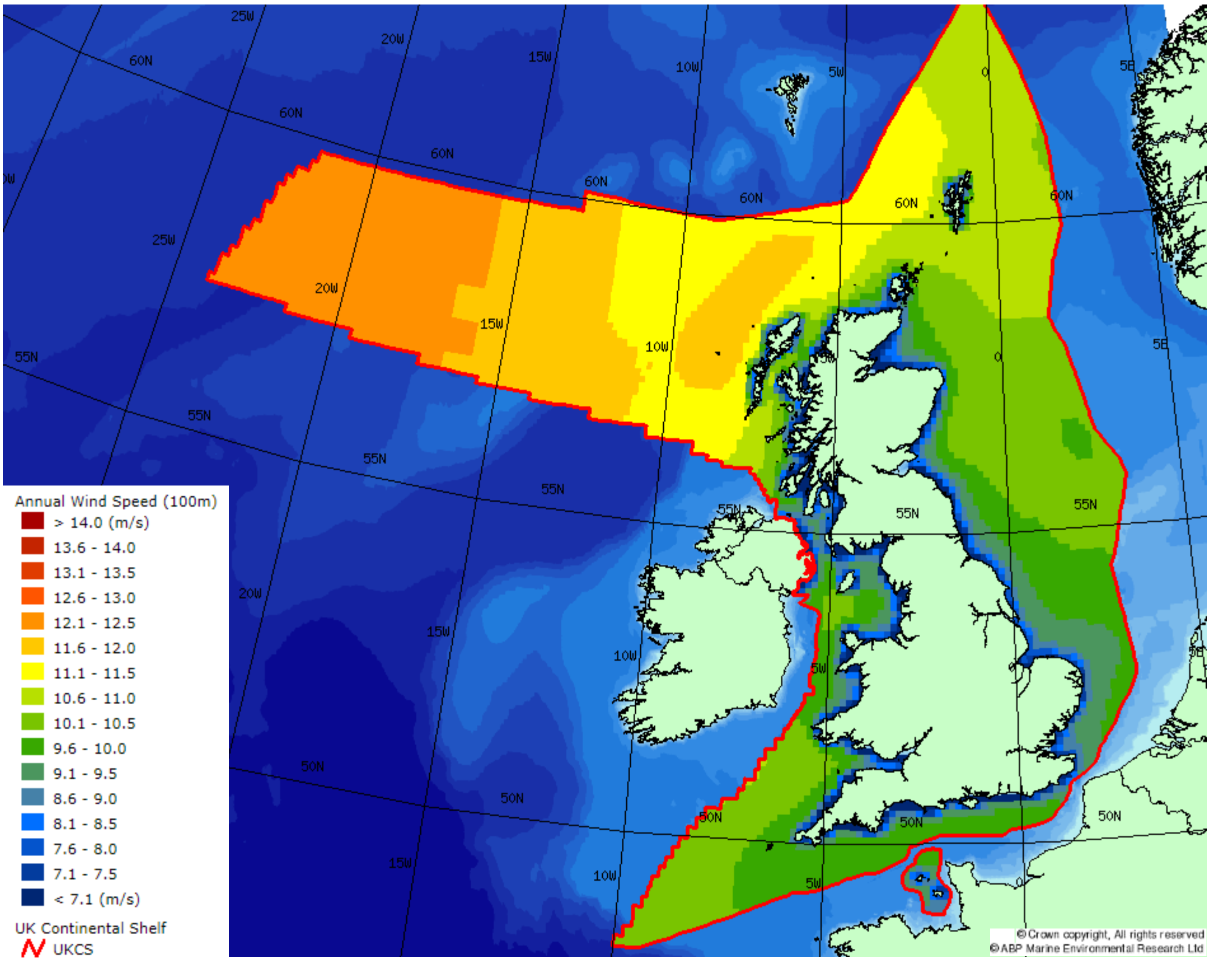
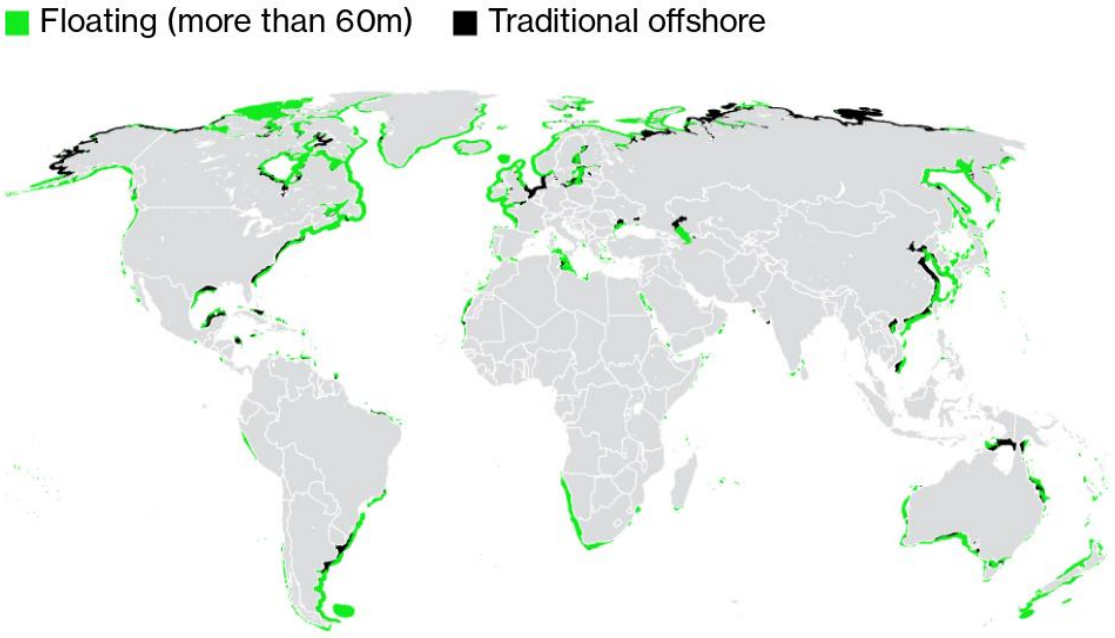


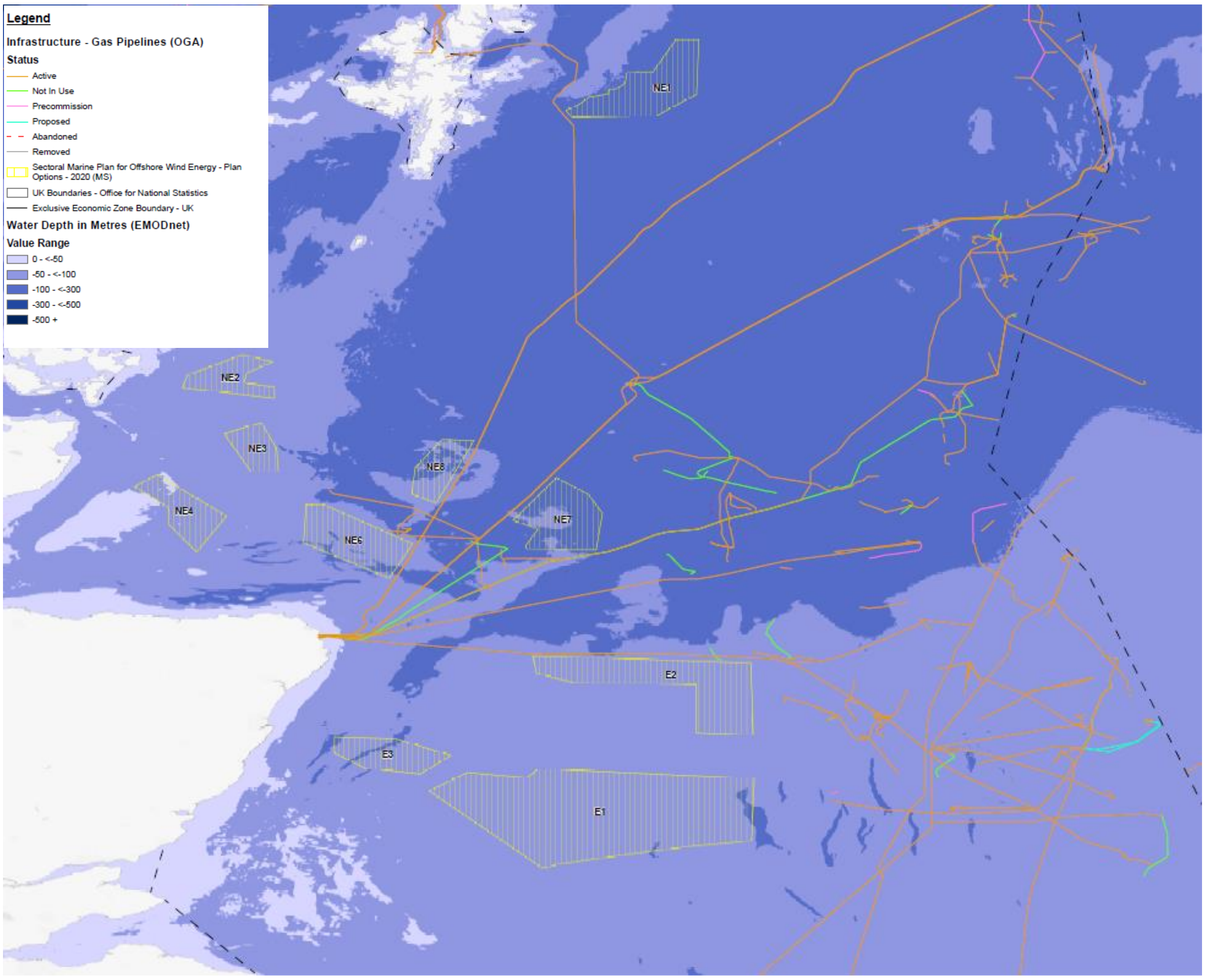
**Figure 1.5 Global Nearshore Deep Water Wind Resource Distribution**



British Oceanographic Data Centre [3].
Areas considered are between 55 and 200km from shore with >7m/s wind speed.

The Dolphyn solution is being developed with the understanding that infrastructure will be required for large-scale deployment. However, the UK has significant high quality infrastructure deployed for the oil and gas industry some of which could be repurposed. Figure 1.6 shows a large portion of the northern North Sea in deep water which already has existing pipeline infrastructure in place. Not all of this infrastructure is expected to be directly suitable for hydrogen service, with studies ongoing to understand the potential suitability based on the grade of steel used and overall condition. It is reasonable to expect that some upgrade activities will be required for conversion if a suitable pipeline can be identified and that this will require careful planning and coordination with the pipeline owners.

**Figure 1.6 North Sea Water Depth, Scotwind Licencing Rounds, and Pipeline Infrastructure**



EMODnet [4], OGA [5], Marine Scotland [6], Flanders Marine Institute [7], Office for National Statistics [8].

## 1.4 An Accelerating Programme

The detailed engineering activities for the development of the 2MW prototype unit were commenced in January 2020. The primary objectives of the project were to:

- Demonstrate the ability of all technological components to perform together in an offshore environment to reliably produce hydrogen at the specified rate and pressure through a pipeline connected to shore;
- Evidence the performance of the floating facility to offshore wind and wave conditions, with ongoing remote monitoring all of key process parameters;
- Provide confidence that the facility can be scaled up to 10 MW capacity pre-commercial project without any major technology changes required;
- Demonstrate that green hydrogen from offshore floating wind can be generated at a cost as estimated from our financial model and can be competitive compared to other technologies;

- Identify opportunities for design optimisation at a commercial scale including; design simplification, constructability, and operational efficiency improvement;
- Identify the optimal operating parameters for a commercial scale project, considering the project drivers to; maximise production rates, minimise construction cost and time, minimise scheduled and unscheduled maintenance activities, maximise system autonomy, minimise shut-down time, and minimise risk from identified hazards;
- Promote the Dolphyn technology, and engage and prepare the supply chain required for commercial scale development.

During the course of delivery the project team were able to successfully demonstrate a low risk route to deployment at larger scale (i.e. 10MW), which is discussed in further detail in Section 2 of this report. As a result of this de-risked development process the project has been able to accelerate its deployment timeline. A number of smaller scale trials focussed on the key systems will be required to suitably demonstrate the effectiveness of the overall system. This will enable the 2MW prototype to be by-passed and enable the project to proceed directly to a 10MW unit. This enables the project to proceed directly with the development of the first commercial scale unit around 4 years faster than originally planned. The decision was taken to commence the development of the commercial scale system alongside the finalisation and close out of the 2MW prototype development activities. The commercial scale unit (nominally 10MW) has now been developed to a Pre-FEED stage. This has been conducted in addition to the successful development of the 2MW engineering activities.

The project development is now focussed on the following target areas:

- Cost drivers towards specific levelised cost of hydrogen
- Ensuring the accuracy of cost estimates
- Promoting ease of operability and maintainability
- Proof of key systems and targeted approach to innovation involving offshore testing
- Ensuring supply chain readiness for deployment at scale
- Optimising British content of early project phases
- Zero carbon at the point of production
- Reduction in lifecycle emissions

In total, over 650 deliverables have been generated as part of the delivery of the Phase 2 work. The key findings from those studies is summaries in the following sections of this report, and a selected summary of the document titles provided in Appendix A.

The project was impacted by the COVID pandemic. The majority of design activities were desk based and all project organisations were able to move to remote working. This disruption did introduce some challenges and short-term inefficiencies whilst organisations and individuals redeployed. Activities such as site survey work were still able to proceed and have been completed safely and successfully. All travel had to be scheduled around COVID restrictions in place and additional precautionary measures taken to protect the project team. All activities on the project have been completed safely, on time, and to a high quality enabling the project to remain fully on track during a challenging year. This performance is an enormous credit to the individuals and organisations involved.

## 1.5 Project Organisations

The project has been developed with input from a wide variety of organisations with relevant experience and knowledge from a range of established sectors including oil and gas, renewables, chemicals, hydrogen production, energy, construction, trading, and marine operations. ERM is extremely grateful for the input from all organisations, in particular the core project delivery has been completed with the support of the following sub-contractors:

**Offshore Design Engineering** – Designing the top-sides including desalination unit, electrolyser interface, hydrogen storage, stand-by power unit and export pipeline

**Principle Power** – Technology provider of the sub-structure system based on the proven Wind Float Atlantic design

**Tractebel** – Designing the sub-structure deck, wind turbine generator integration, and mooring and anchoring system. Working with Principle Power.

**NEL** – leading European Electrolyser Technology company developing electrolysis using their experience of electrolysis at sea (ships, submarines)

**Doosan** – Leading integration and marinisation engineering for the PEM electrolyser working alongside NEL

**Lloyd’s Register** – Independent 3rd party verification of the design

## 2. THE 2MW SCALE PROTOTYPE

Following on from the FEED stage of the 2MW prototype successfully completed in Phase 1, the Detailed Design for the system has now been completed as part of Phase 2a of the project.

The design activities for the 2MW Prototype have resulted in more than 300 engineering deliverables being produced, including a wide range of studies and engineering drawings such as layouts, 3-D models, Process Flow Diagrams (PFDs), Piping and Instrumentation Diagrams (P&IDs) and Single Line Diagrams (SLDs). Key documents required for the next stage of the project (e.g. testing, procurement, installation, commissioning and operation) have also been developed. These include equipment datasheets and specifications, offshore testing plans, installation plan and the process control philosophy. Many of these studies were completed in parallel with site selection and consenting activities, supply chain engagement, financial modelling, and particularly safety design and independent verification activities.

Development of the Detailed Design for the Dolphyn 2MW unit has enabled engineering activities to focus on de-risking the project, which has been highly successful. The work focussed on providing the necessary evidence needed to deploy all of the primary systems on a full-scale unit. There are now no significant technical barriers remaining that prevent the development and deployment of the concept considered.

Key parameters and aspects of the Detailed Design for the 2MW prototype are highlighted in this section.

### 2.1 Overview of Design

The Dolphyn prototype unit employs a modular design, integrating electrolysis and a 2 MW wind turbine on a moored floating sub-structure to produce hydrogen from seawater using wind power as the energy source. The prototype unit is designed to export dry hydrogen (minimum purity of 99.97%) at medium pressure (~25 barg) to shore, with maximum production rate of ~800 kg/ day, suitable for blending or injection into the natural gas grid as well as for a variety of alternate uses including transport use.

The design is split into primary modules as follows:

- Floating substructure; based on a semi-submersible type of floater of proven WindFloat® design comprising of three vertical stabilizing columns that are supported on submerged horizontal water entrapment plates.
- Topside structure and facilities; including design of global deck, rooms its auxiliary systems
- Topside equipment, including:
    - ✓ Seawater lift system; provided to supply seawater for fresh water production and for ancillary purposes e.g. cooling.
    - ✓ Desalination system and fresh water buffer storage.
    - ✓ Hydrogen production system (electrolyser unit) and storage, based on PEM (Polymer Electrolyte Membrane) technology.

  - ✓ Standby and back-up power generation system; provided to supply power to (safety or production) critical systems during low/ no wind condition where there is less available power from the wind turbine. For the Dolphyn prototype unit, this system consists of hydrogen re-conversion and battery back-up/ Uninterruptable Power Supply (UPS) system.
  - ✓ Frequency Control/ Power Imbalance system, provided for power balancing and grid forming.
  - ✓ Power distribution system; covering medium voltage (1000 V < Voltage < 35 kV) and low voltage (< 1000 V) systems.
  - ✓ Auxiliary systems and facilities (e.g. chemical injection system, drain system, venting, etc.).
- Mooring and anchoring, which uses catenary mooring system composed of six mooring lines.
- Export riser and pipeline, which uses flexible riser connected to a rigid pipeline.

The onshore tie-in and reception facility were outside the scope of the design for this phase, although some feasibility activities were undertaken in parallel to the project to support site selection activities (Section 4) and further de-risk the project development.

The site selection process identified that the optimum location for the Dolphyn prototype unit is off the coast of Aberdeen, Scotland, located at the existing Kincardine windfarm site.

## 2.2 Objectives

The Detailed Design for the prototype unit was focusing on proof of all main systems for deployment on a full-scale unit as well as de-risking the project. From an engineering design perspective, this was successfully achieved by carrying out the following activities.

- Key interfaces were identified and incorporated into the design.
- Key operating requirements were identified (i.e. de-risk the OPEX for the full field development).
- Key construction stages and methods that can be adapted for the later stage of the project (i.e. during commercial demonstrator through the full field development) were developed.
- Identifying potential optimisations in the systems that should be explored in the larger scale unit.

See Section 2.7 to Section 2.9 for further details.

## 2.3 Philosophy

The following main philosophies were adopted into the design of the Dolphyn prototype.

- Modular design approach to simplify the interface requirements and reduce the requirements for novelty;

- Autonomous system, with remote operations possible from shore;
- Selecting technology/ equipment for sufficient level of reliability and availability and low maintenance requirements;
- Implementation of inherent safety design principles, as far as reasonably practicable, and limit the dependency on mitigation measures;
- The design follows UK legislation and internationally recognised codes and standards.

## 2.4 Team Members

ERM is the project developer, supported by a number of sub-contractor organisations providing the technical engineering support in the design development of the Dolphyn prototype. The ERM team manages and works with the main subcontractors who are listed below:

- Offshore Design Engineering (ODE), leading the design of the topside process equipment (including the auxiliary systems), riser and pipeline.
- Tractebel Engineering, leading the design of topside facilities (including rooms and auxiliary systems). Tractebel works closely with Principle Power.
- Principle Power, technology provider of WindFloat®, the semi-submersible type of floater used for Dolphyn prototype. Principle Power works closely with Tractebel to deliver the design of the floating foundation and mooring system.
- Doosan Babcock, leading the design of the electrolyser system. Doosan is working closely with NEL Hydrogen.
- NEL Hydrogen, technology provider of the electrolyser system.

## 2.5 HSE in Design

### *2.5.1 Legal Framework*

The Dolphyn Project is an innovative ‘first of a kind’ project looking to produce hydrogen offshore from floating wind technology. A regulatory framework does not currently exists specifically for the development of offshore hydrogen production facilities and therefore the Dolphyn project, working with UK regulators, has taken learnings from two other related industries in relation to best practise in both technical design and safety and risk management. These are:

1. Offshore renewables (offshore floating wind in particular); and
2. Offshore oil and gas (flammable fluid production and control).

The ERM project team has regularly liaised with the UK Health and Safety Executive (HSE) to enable the highest standards in safe design and safety management to be followed on the project. Offshore hydrogen development is a new area and ERM are keen to contribute to the development of a clear and safe approach to offshore hydrogen development. In agreement with the UK HSE, the project is generally following the requirements of the legislation and regulations presented in Table 2.1 below:.

The following UK legal framework and regulations have been used as reference.

**Table 2.1 UK Legislation and Regulations**

| Legislation/ Regulation | Note |
|---|---|
| The Health and Safety at Work etc. Act 1974 (HSWA) | This act provides the overarching legal framework for health and safety; it imposes general duties for protection of the health and safety of those who may be affected, so far as is reasonably practicable. |
| The Management of Health and Safety at Work Regulations (MHSWR) 1999 | This regulation introduces the requirement for Risk Assessment. |
| The Construction (Design and Management) Regulations (CDM), 2015 | The regulations applies to all construction projects in the UK and sets out the requirements for safe construction. |
| Merchant Shipping Act 1995 | Principal maritime regulations, which also apply to offshore renewable developments; these regulations impose the duties for common standards of health and safety. |
| International Convention for the Safety of Life at Sea (SOLAS), 1974 | |
| International Convention for the Prevention of Pollution from Ships (MARPOL) 1983 | |
| The Offshore Installation (Offshore Safety Directive) (Safety Case etc.) Regulations (SCR) 2015 | Principal regulations for offshore oil & gas installations, ensuring that the associated major accident hazards are identified and managed adequately. |
| The Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations (PFEER) 1995 | |
| The Pipeline Safety Regulations (PSR) 1996 | |
| Lifting Operations and Lifting Equipment Regulations 1998 (LOLER) | |
| The Offshore Installations and Wells (Design and Construction, etc.) Regulations (DCR) | |
| The Pressure Equipment Regulations (PER) 2016 | |
| Control of Major Accident Hazards (COMAH) Regulations 2015 | Principal regulations for onshore facilities, requiring operators to take all measures |

| Legislation/ Regulation | Note |
|---|---|
| The Pressure Systems Safety Regulations (PSSR) 2000 | necessary to prevent major accidents and to limit their consequences for human health and the environment. These are applied to the section of hydrogen export pipeline associated with, or from which a release could affect any onshore reception facilities. |

Whilst the Dolphyn Project is not legally required to meet all of the above regulations, the project is following these as representative of good industry practice for safety management.

### *2.5.2 Key HSE in Design Objectives*

The Dolphyn 2MW prototype is to be a normally unattended installation (NUI). Any visit to the floater introduces the personnel to the facility hazards and transportation hazards. In addition, due to the small footprint of the floater, there are relatively small distances between the hazardous facilities and non-hazardous areas.

The key design objective was therefore to minimise personnel intervention at the floater. This is to be achieved by:

- Minimising the equipment and the inventory of hazardous substances on the floater;
- Selecting equipment for sufficient level of availability and reliability and low maintenance requirements;
- Use of only proven technology for Dolphyn project to provide confidence in the reliability and availability of the relevant equipment/ component, preferably those with a sound track record from previous use;
- Minimising requirements for local intervention;
- Designing a facility with full remote operation from an onshore control room.

Focus has been given on implementing the inherently safer design principles, as far as reasonably practicable, and limit the dependency on mitigation measures. This focus will continue throughout the design process. The recommended guidelines provided by Energy Institute for unmanned installation, Ref [9] have be adopted.

The design had used a ‘safety gradient’ to the development of the Dolphyn layout in order to keep high risk areas segregated from low risk and vulnerable areas required for muster and evacuation form the platform, as far as practicable.

### *2.5.3 Hydrogen Safety Characteristics*

The major hazards associated with hydrogen are as follows:

- Producing a flammable or explosive mixture with air;
- Physiological (asphyxiation);
- Physical (embrittlement and component failures); and

- Mechanical explosion of hydrogen vessel (when exposed to high temperatures or thermal radiation).

Flammability characteristics of hydrogen and their implications to fire and explosion hazards are summarised in Table 2.2.

**Table 2.2 Characteristics of Hydrogen and their Implications to Fire/ Explosion Hazards**

| Characteristics | Implications |
|---|---|
| Hydrogen is colourless, odourless and insipid | Leaks of hydrogen can be difficult to detect |
| The flammability range of hydrogen is wider compared to most hydrocarbons, approx. 4% to 75% by volume in air | In the event of leak to the atmosphere and mixed with air, hydrogen could easily ignite, resulting in fire/ explosion, at these wide range of concentrations |
| Hydrogen has high buoyancy characteristics, supported by low molecular mass and low density | In the event of hydrogen leak to an open area, hydrogen has the ability to rapidly flow out of the source, and mix with the ambient air to a safe level below the lower flammability level of 4% by volume in air. However, if hydrogen is leaked onto a congested or confined area, it can easily form flammable mixtures resulting in explosion. |
| Hydrogen has low ignition energy (0.019 mJ) | Hydrogen is very easily ignited, even by weak ignition sources |
| Hydrogen burns with an invisible (non-luminous) flame | Hydrogen flames are difficult to detect visually |
| Premixed hydrogen-air combustion can be aggravated by heavy sprays or water due to induced turbulence and the ability of mixture to burn around the droplets | The most effective way to respond to hydrogen fire is to limit the inventory, which means activation of emergency shutdown valves (ESDVs) to limit the inventory of hydrogen in a fire is more effective compared to the use of firefighting system to extinguish the fire. |
| Hydrogen is more susceptible to Deflagration to Detonation Transition than other gases such as natural gas | Detonation of a gas cloud has the potential to result in much higher overpressure than a deflagration of the same cloud, even in the absence of congestion or confinement. |

### *2.5.4 Major Accident Hazard Management*

The ERM project team have developed the Dolphyn prototype in line with the stringent requirements of the Safety Case Regulations [10] have been implemented, namely:

- All hazards with the potential to cause a major accident have been identified;
- All major accident risks have been evaluated; and
- Measures are taken to control the major accident risks in compliance with the relevant statutory provisions (i.e. a compliance demonstration) and to a level that is As Low As Reasonably Practicable (ALARP).

It should be noted that Dolphyn does not strictly come under the provisions of the SCR, however broad adherence to these Regulations is being undertaken as representative of good practice.

A key requirement of effective hazard management is to be able to demonstrate that a structured, formal process has been adopted specifically including the identification and assessment of all potential hazards, consequences and adequacy of controls. A formal hazard identification and assessment process has been carried out for Dolphyn to demonstrate that all potential hazards and consequences have been identified, risks assessed and understood, and the controls to manage the causes and consequences are provided. These formal assessment studies include the followings.

- Hazard Identification (HAZID) study
- Hazard and Operability (HAZOP) study
- Fire and Explosion Hazard Assessment (FEHA)
- Escape, Evacuation and Rescue Analysis (EERA)
- Emergency System and Survivability Analysis (ESSA)

The project has conducted a formal hazard identification (HAZID) process in line with the definitions of hazards commonly used for the development of offshore projects. A total of nine hazards have been identified with the potential to cause a major accident. The focus of the HSE in design activities have been on removing, avoiding, controlling, and mitigating these hazards.

It should be noted here that the Dolphyn 2MW prototype involves minimum storage of hydrogen on board and within the export pipeline. The mass of hydrogen is comparable to that stored on a FCEV bus, and at considerably lower pressure. As such, the effects from fires are typically short duration, and shorter still when factoring for the activation of emergency depressurisation.

### *2.5.5 Safety and Environmentally Critical Equipment*

The major accidents identified as being potentially associated with the development of the Dolphyn project have been analysed to identify the specific mechanisms by which these accidents could be realised. Equipment which is critical to prevent, control, mitigate, or recover from the effects of major accidents is considered to be safety or environmentally critical. The safety and environmentally critical equipment (SECE) items have been given particular attention to provide confidence in the correct performance of this equipment in the event of a major accident. Performance standards have been developed to provide a clear set of performance criteria for all SECEs in terms of functionality, availability, reliability, survivability and interdependence with other SECEs to be able to perform their role in the event of a major accident.

### *2.5.6 Independent Verification*

The design process for the Dolphyn project has been independently verified by Lloyd's Register to identify areas of potential safety improvement, and provide confidence that a robust hazards management process is being followed during the design. Lloyd's Register have had unrestricted access to all design documentation developed by the project team. The work completed by Lloyd's Register has shown that through the work completed during this phase, the Dolphyn 2MW prototype is expected to be successfully concluded in line with a robust safety design process.

## 2.6 Approach to Technology Selection

The component parts of the Dolphyn concept, whilst emerging technology, are all at a high 'technology readiness level' providing a good degree of confidence that the solution will work at scale. The design is based on proven technologies, which are tested at scale, and the operational characteristics are understood. Where different choice of technologies are viable for the relevant system, an evaluation of potential technologies was carried out, taking into account different aspects including:

- the costs of CAPEX and OPEX;
- safety implications;
- operational aspects (e.g. additional utility required for the system, system efficiency, maintenance requirements, etc.); and
- associated project risks (e.g. impacts to project schedule, contractual management, etc.).

The Dolphyn prototype unit uses a proven semi-submersible floating foundation design of WindFloat®. This technology, of similar capacity as Dolphyn prototype unit, has been deployed and installed in Europe (Portugal) and in the UK, off the coast of Aberdeen on Kincardine site.

With regards to desalination technology, two options of desalination technologies were considered for the Dolphyn prototype unit namely reverse osmosis and thermal desalination technologies. These technologies are viable options for Dolphyn application, as they only require electrical energy without any need of thermal energy (heating system); hence reducing the process systems required and the physical footprint required on board Dolphyn. Reverse osmosis was selected as the desalination technology for Dolphyn prototype unit. This technology is selected for Dolphyn prototype unit due to its lower capital expenditure, smaller equipment footprint, lower weight and lower energy requirement compared to alternative technologies (e.g. thermal desalination) considered. Reverse osmosis technology is a proven desalination technology and already applied in offshore environment in modular units. It was noted, that the reverse osmosis technology requires more regular maintenance visits that the thermal desalination technology, which implicates a significantly higher OPEX requirements for full field scale development that is envisaged to be located further away from shore. Therefore, the technology selection should be re-assessed for large field development.

The prototype unit uses PEM electrolyser technology, which is a proven technology. This technology has compact design (small footprint), high efficiency and fast response to fluctuations in power input. The latter means it is suitable for Dolphyn application where there is fluctuations in available power from the wind turbine depending on wind conditions. Its compact design is an advantage considering limited deck space available on the Dolphyn floating unit. A systemic review of the NEL electrolyser package identified that some modifications are required to address issues of operating electrolyser in an offshore marine environment on a floating semi-submersible platform. These modifications are relatively minor in nature and there are examples of suitable technology solutions that have already been deployed at scale in other industries. The systematic review of the electrolysis system provides a high level of confidence that the package is suitable for deployment at scale with minor modification. To demonstrate its performance, the proposed system will be tested under offshore conditions as part of the next phase of the project.

Dolphyn uses electricity generated by a wind turbine that operates automatously (i.e. no grid connection) to power the topside process equipment. To enable successful operation, a Frequency Control/ Power Imbalance system is required for power balancing and grid forming.

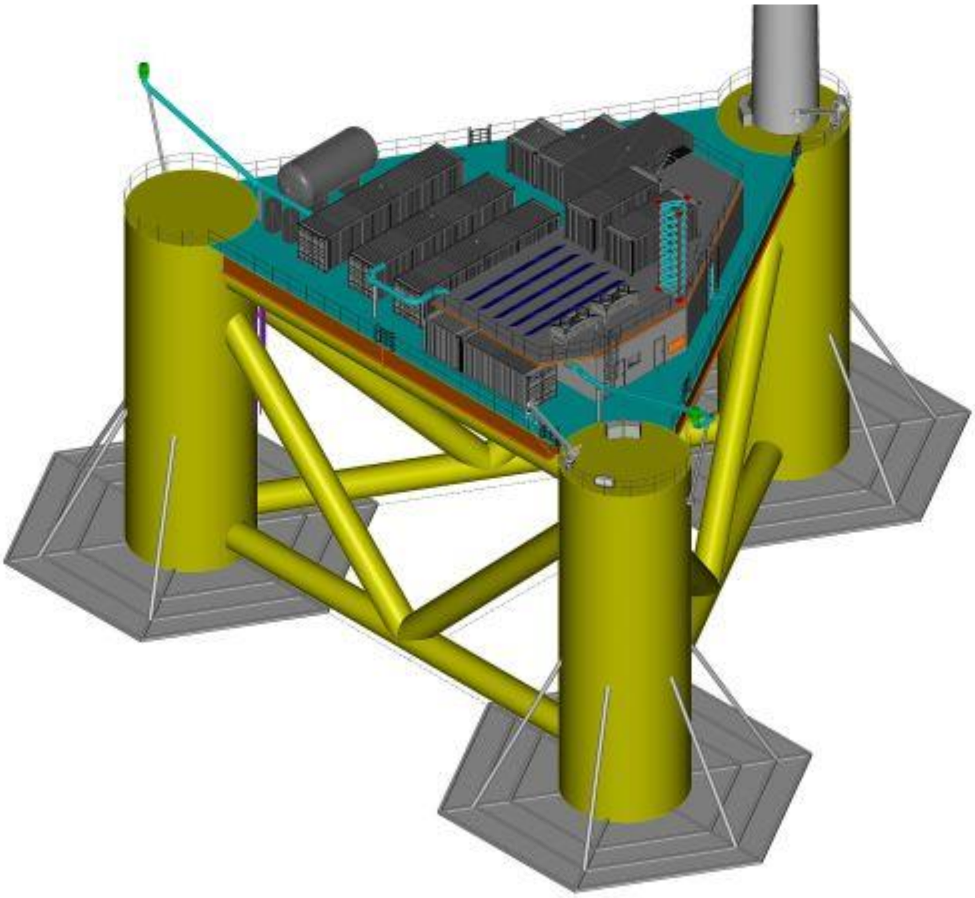
A standby power generation system is provided on board Dolphyn, in order to supply power to (safety or production) critical systems during low/ no wind condition where there is less available power from the wind turbine. On the prototype unit, this system is based on fuel cell technology; using hydrogen stored on-board Dolphyn to generate electricity. Fuel cells with suitable capacity for the Dolphyn prototype unit are readily available on the market. Fuel cells, along with a number of emerging technologies, are still developing and the project is interested to see and support the development of these technologies as potential suppliers for future developments.

For the hydrogen pipeline to shore, two options were considered, namely rigid steel pipeline and flexible pipeline. Both technology options are suitable for the Dolphyn project, and both provide benefits in various situations. The rigid pipeline is more established technology and there are a large number of suppliers offering this option. There is a relatively limited number of suppliers for the flexible pipeline technology, although the technology readiness and supply chain capacity both provides confidence in the future development. Existing flexible risers have not been formally certified for use with pure hydrogen duty. However, a review of the technology and materiality have not identified any concerns over the ability to support hydrogen duty, although a formal verification and certification is considered beneficial by the project team.

## 2.7 Key Design Outputs

Design activities started with the detailed design of the topside process equipment and their auxiliary systems (including electrical), as well as topside facilities (including rooms and its auxiliary systems). This activity provides input into the layout development and structural design of the global deck, which was subsequently used as one of the inputs into the design of the floating foundation. A 3D visualisation of the Dolphyn prototype unit is presented in Figure 2.1.

**Figure 2.1 3D visualisation of Dolphyn 2MW Prototype Unit**



Key interfaces between different systems/ modules were identified and incorporated into a cohesive integrated design. Key interfaces are listed in engineering interface registers.

### *2.7.1 Codes and Standards*

In general, the Dolphyn project follows the regulations, codes and standards commonly applied to the UK Offshore Oil & Gas Industry in combination with those applied to the floating offshore wind industry.

No regulatory framework exists specifically for the development of offshore hydrogen production facilities. The main UK legal framework and regulations are identified; these includes the overarching legal framework for health and safety, principal regulations for offshore oil & gas installations, as well as principal maritime regulations which applies to offshore renewable developments. Whilst the Dolphyn project is not legally required to meet the specified regulations, the project is following the specified regulations as industry good practice for safety management.

A register of codes and standards applied for the design was developed. This covers different elements of the design, including mechanical, piping materials and valves, pipeline, electrical, instrumentation and control, etc. In general, the floating substructure and mooring system are designed under the overarching frame of IEC standards, supported by guidelines issued by verification bodies. The codes and standards have been reviewed by the Independent Verification body for consistency with expectations of good design practice.

### 2.7.2 Uniform Coding and Numbering System

For efficient project planning, development, construction, operation and maintenance of offshore wind and process units, it is essential to structure and assign clear and unambiguous alphanumeric codes to all systems and equipment. The existing coding and numbering systems are design for application to either offshore renewables or offshore process design. To prevent any inconsistencies in codification, a standardised coding approach is used across the Dolphyn project. Following a review of the currently available numbering systems the Reference Designation System for Power Plants (RDS PP) developed by VGB has been selected and applied. This is a globally proven identification system which is already applied across the offshore wind industry and can be used for codification of all systems on Dolphyn, including the wind turbine generator, the floating substructure, process units, electrical system, supporting facilities, etc.

### 2.7.3 Fully Autonomous System

The overall systems were designed for isolated operation (i.e. no grid connection), keeping the process systems in safe and healthy conditions during no/ low wind conditions and being able to re-start when the wind returns.

The system is designed to be fully autonomous, with remote operations from shore. The prototype was designed for full automation between generation phase and standby mode as it is designed to be not normally attended by personnel, with process power off and start-up mode being actioned via an onshore control room. This is similar to the future full field scale design, is inherently safer, and minimises operating costs.

A Process Control Philosophy was developed to provide an operating and control description aligned with the P&IDs, including details of interfaces, auxiliary systems and start-up and shutdown for different operating modes. Different operating modes identified for the Dolphyn prototype are presented below. Operating modes (1) to (4) are all deemed normal operating, where different process systems will be in either operation or standby depending on available power from the wind turbine.

**Table 2.3 Operating Modes for Dolphyn Prototype**

| Ref. | Mode | Description | Power Output | | |
|---|---|---|---|---|---|
| | | | Wind Turbine | Standby Power (Fuel cell) | Emergency Power (UPS) |
| 1 | Normal Production Mode | Continuous maximum hydrogen production. All process are operational, with continuous export of hydrogen to shore. | Nominal power | 0 | 0 |
| 2 | Turndown Mode | Continuous reduced hydrogen production with intermittent operation of fresh water production system. Continuous hydrogen export to shore. | Variable | 0 | 0 |

| Ref. | Mode | Description | Power Output | | |
|---|---|---|---|---|---|
| | | | Wind Turbine | Standby Power (Fuel cell) | Emergency Power (UPS) |
| 3 | ECO Mode | No hydrogen production. Electrolyser in standby mode. Fresh water production system is operating until the fresh water storage tank is full. | Variable | 0 | 0 |
| 4 | Full Standby Mode | No hydrogen production. All process equipment in standby mode. Back-up system in operation mode when the available power from the wind turbine is not sufficient for standby and safety critical power users. | Variable | Nominal power | 0 |
| 5 | Emergency Mode | No hydrogen production – emergency shutdown conditions. Depending on the Emergency Shutdown (ESD) level, the fresh water production and electrolyser system will be in standby, idle or shutdown. Power is supplied from emergency battery back-up (UPS). | 0 | 0 | Nominal power |

In terms of emergency mode, at the highest level of ESD (i.e. ESD Level 0 – Total Platform Shutdown), the overall process systems will be in shutdown condition with hydrogen systems being depressurised (removal of flammable inventories on board Dolphyn). Following this type of emergency mode, the process system would need to re-start-up in a black start mode. This represents a start-up mode after a platform blackout, where there is no power available from the wind turbine in combination with depleted hydrogen storage on board.

The black start mode has not been fully defined at the current project phase; hence, its start-up philosophy needs further definition during the next design stage. It is envisaged that the black start mode will be mostly determined by electrolyser unit power requirements during platform blackout conditions and in the event of the unit starting up after a platform blackout.

### 2.7.4 Electrical System

The preferred prototype design uses a 2 MW WTG of a VESTAS V80 DFIG (Doubly-Fed Induction Generator) turbine due to its design compatibility with the proven WindFloat® platform, as used on the Kincardine site. However, due to the prototype design requiring the WTG to operate in ‘island’ mode with no grid connection, there are additional design considerations for generator selection. Choice of generator will affect the required frequency and reactive power management provisions from auxiliary systems. The anticipated conversion and optimisation of the wind turbine shall be assessed further with the wind turbine manufacturer during the next phase of the project.

Medium voltage (MV) cable will run from the transformer in the WTG nacelle to the tower to MV switchgear located on the floating substructure. The MV switchgear will be located inside a dedicated switchroom, distributing power to the electrical equipment for hydrogen production and utilities, directly or via step-down transformers. A frequency control/ power imbalance system will be connected directly to the MV switchboard. A main low voltage (LV) switchboard shall be located in a containerised Local Equipment Room (LER), distributing power to electrical equipment at low voltage level. An emergency LV switchboard will also be provided.

When using a WTG of the envisaged type in isolated operation to power process systems as is intended on board Dolphyn, provision of a frequency control/ power imbalance system is required for power balancing and grid forming. The system will be experiencing imbalances between the power generated by the wind turbine and the power consumed by the electrical users; hence maintaining of power balance between the wind turbine, the electrolysers and the rest of the system loads is required during normal operation. In terms of a grid forming function, the system needs to generate a stable voltage waveform, so the wind turbine can maintain synchronism. A number of design solutions exist for the formation of such a frequency control system, with a preferred and viable solution selected. The design of frequency control/ power imbalance system shall be further refined in the next phase of the project. This system is highly dependent on the wind turbine choice and therefore requires full engagement with a turbine manufacturer. Development of ‘off-grid’ ready generators offers a potential future benefit to the project.

Standby power (hydrogen storage, fuel cell and battery) is provided to supply power for the process equipment to run in standby mode when there is insufficient power from the WTG. The stand-by power system is sized to provide power at full standby operating mode in line with the expected equipment performance and the site-specific environmental conditions

Uninterruptible Power System (UPS) is provided for emergency conditions to enable the main safety features on Dolphyn to be able to bring the platform to be brought to a safe and stable condition when the electrical power generation on the platform fails, or during no-wind condition.

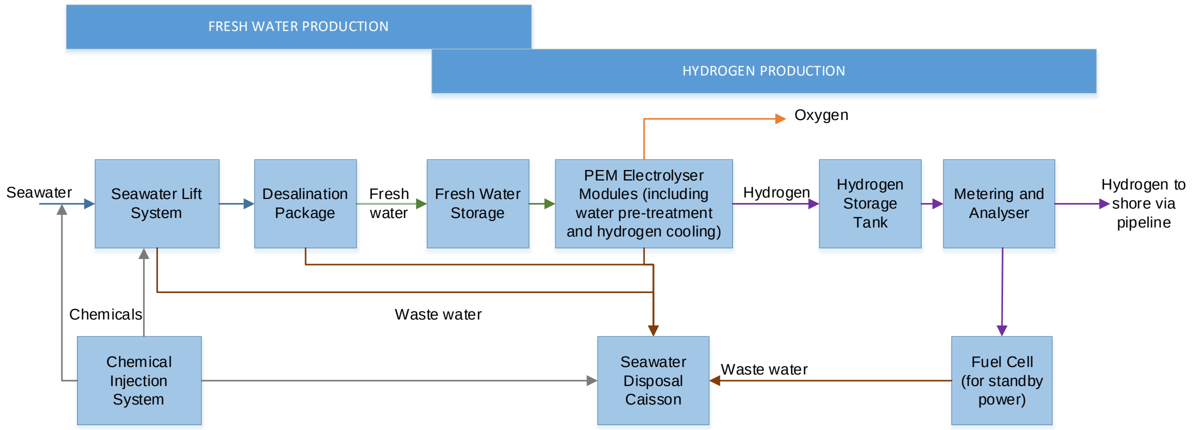
In terms of electrical system, the engineering design activities have produced a wide range of deliverables, including key electrical documents such as single line diagrams, electrical equipment list, load list, schedules and material take-offs for equipment and cables, etc. Datasheets and specifications for electrical equipment and cables were also produced, in order to support the next phase of the project (i.e. procurement). A start-up philosophy document, which establish a high-level strategy for starting up the process system from a state where all power generation has been shut down or tripped, was produced, in order to support the next phase of the project (i.e. operational phase).

The design activities have provided sufficient confidence that the overall electrical system will work as intended. A number of potential optimisations within the energy generation and storage system were identified and will be explored further in the next design stage (refer to Section 2.9).

### *2.7.5 Process Equipment*

The topside process equipment is designed to produce hydrogen, powered by a wind turbine, with oxygen as a by-product and wastewater. An overview of the major process equipment is shown below.

**Figure 2.2 Dolphyn Process Schematic**



The process starts with Seawater Lift System, pumping seawater from a sea chest inside one of the floating substructure's columns. The seawater is routed to desalination package, with reverse osmosis as the selected technology for Dolphyn prototype unit (due to its relatively small scale).

A fresh water storage tank is provided downstream of the desalination system to store potable water from the desalination unit. The electrolyser package includes water pre-treatment and hydrogen post-treatment, delivering dry hydrogen.

Minor modifications to the NEL electrolyser package are required to address issues of operating electrolyser in an offshore environment on a floating semi-submersible platform. These modifications have been explored and demonstrated to be minor in nature. The project team is confident in the technical and economic solution of the modifications and their practical implementation shall be finalised as part of the system procurement. A series of tests involving the system in offshore conditions is planned in the next phase of work.

A number of systems ancillary to the electrolysis package present opportunities for close integration with the topside process; further efficiencies expected to be realised. These areas of design integration will be taken forward for consideration during the commercial scale development of the system.

Hydrogen is stored on board Dolphyn in a pressurised vessel at medium pressure (~30 barg) and ambient temperature. The amount of hydrogen stored is kept at minimum, as storing of hydrogen (flammable gas) has safety implications.

The hydrogen product from the electrolyser package shall pass through the metering system before being exported to shore via a flexible riser and export pipeline. Oxygen produced from the electrolyser is emitted to the atmosphere.

In terms of topside process equipment, the engineering design activities have produced a wide range of deliverables, key process, piping and instrumentation documents such as Process Flow Diagrams (PFDs), Piping and Instrumentation Diagrams (P&IDs), cause & effect diagrams, system architectural diagram, instrument block diagrams, instrument cable schedule, piping list/ class, etc. Datasheets and technical specifications for process equipment (including packaged equipment and mechanical equipment), piping and control and instrumentation equipment were also produced, in order to support the next phase of the project (i.e. procurement). Process control philosophy and start-up philosophy documents were produced, in order to support the next phase of the project (i.e. operational phase).

As part of the design activity, a Hazard and Operability (HAZOP) review study was carried out in order to identify potential hazards and operability issues due to deviations from normal process or operating conditions or intended design. The study resulted in a total of 77 actions. Immediate design actions were considered and incorporated into the design. Some actions are relevant to future phases of the project. These recommendations were carried forward to the next design stage when the procurement process will begin and further discussions can be held with vendors. HAZOP actions relevant to the operational phase were also deferred to the next project phase.

The design activities have provided sufficient confidence that the overall topside process system will work as intended. There are some potential optimisations identified within the overall process system that should be explored further in future phases of development (refer to Section 2.9). It is envisaged that a value engineering exercise be carried out prior to procurement to identify equipment which may be surplus to requirements.

### 2.7.6 Riser and Pipeline to Shore

Hydrogen will be exported to shore via pipeline. The pipeline is designed to transport hydrogen product from the Dolphyn prototype, with provisions of tie-in spools/ connection for future pipeline connections at the seabed. The pipeline is comprised of the following components:

- Flexible riser between the Dolphyn substructure and the seabed
- Spool piece tie-in from the riser to the pipeline. This spool has the facility to later attach future pipeline connections
- Pipeline to nearshore tie-in point.
- Landfall/ cliff section. This section runs from the nearshore tie-in point (of the offshore pipeline) to the cliff top through Directionally Drilled (DD) tunnel. It is envisaged that this section will be a rigid steel pipeline. This section of the pipeline was out of scope of the current design phase, but has been developed sufficiently to provide confidence in the feasibility of a solution. It will be further developed at the next design stage.

A flexible riser shall connect the floater to the pipeline in a lazy S configuration, similar to the configuration used for the electrical power export cable from the adjacent Kincardine site. Discussion with existing equipment vendors indicates that the material offered for the flexible riser is suitable for hydrogen use. Preliminary assessments carried out by the vendor for various inner liner materials indicates that hydrogen permeation issue is not expected. However, it is envisaged that formal certification would be beneficial to confirm the suitability of such material for hydrogen use on Dolphyn.

As the riser shall interface with the mooring system, a preliminary configuration assessment was carried out to check the riser flexibility, which resulted in a defined maximum motion envelope allowed for the riser without damaging its integrity. The motion limits were defined considering the value of the Minimum Bending Radius (MBR) recorded along the riser. The MBR is a typical key parameter that is monitored during flexible riser system analysis to determine the integrity of the actual riser during service life. The riser maximum motion envelope is a key interface point with the mooring design for safe operation.

The hydrogen export pipeline will be of 3” internal diameter with approximately 16 km length. The pipeline shall be constructed of materials that are compatible with hydrogen service at the pressure required to avoid any issues such as Hydrogen Gas Embrittlement (HGE).

The main materials for the pipeline are specified in the material take-off listing. Basic analysis for the pipeline was performed in support of the use of line-pipe of specified thickness. This included assessment of on-bottom stability and free-spans, which needs refinement at the next design stage to fully specify the local details for the pipeline with input from marine surveys. Datasheets have been developed for the main pipeline elements.

### 2.7.7 Auxiliary System

The floater will be provided with shelters to facilitate local control function (during maintenance visits), local equipment room and the relevant auxiliary systems. The shelter will consist of MV/ LV Room, Control/ UPS Room, HVAC/ Workshop Room and a welfare room. The basic specification for these rooms has been defined. The fire protection and architectural treatment for each room was specified based on best practice with A60 ratings. A Fire and Explosion Hazard Assessment carried out as part of the design activity indicated no significant harm expected to personnel inside the shelters for accidental fire cases; hence the need for a specific fire protection system for the shelter was not identified. These requirements will be reviewed and confirmed at the next design stage in line with good engineering practice.

The sizing and specification for the HVAC system serving the shelter area are defined, and a Duct and Instrumentation Diagram (D&ID) developed. Given the containerised nature of many process areas, these were specified with standalone HVAC systems. However, integration into a single HVAC system is expected to offer improvement to the system efficiency, which would reduce the equipment size and minimising the amount of power used for HVAC system. This potential optimisation shall be taken forward to the commercial scale unit.

The provisions for mechanical handling for the prototype unit were based on handling and lifting of small equipment items. The Dolphyn prototype is provided with a small crane. Basic mechanical handling principals and handling techniques have been defined. The mechanical handling provisions will be reviewed for the larger scale unit, and definitions of the loads to be lifted and the required lifting equipment will have to be further detailed in the mechanical handling plan. This would be affected by available space onboard the floater for equipment handling as well as laydown area. It should include an assessment of which cases require lifting by a positioning vessel with crane (if any).

### *2.7.8 Topside Structure*

Structural design drawings for deck structures and supporting points have been developed. A global structural analysis has been performed, considering the size, weight, and operating conditions. The structural analysis indicates that the structural strength of the global deck is sufficient for the intended purpose. Further refinement on the structural design is required during the pre-procurement phase to optimize the structural design in line with the construction process. A 3D model has been developed for the topsides modules.

### *2.7.9 Floating Substructure*

The final dimensions of the floating substructure were selected via iterative stability assessment on different dimensions for optimised sizing taking into account the overturning moments and operational conditions of the Wind Turbine Generator (WTG), as well as inclusion of the topsides. An intact stability analysis, performed against IMO MODU Code stability criteria, shows that the designed floating foundation configuration passes the intact stability criteria. The intact stability is analysed by form of a reserve factor, which is the ratio between the righting energy and the greatest overturning energy. The reserve factor should be greater than one, which was comfortably exceeded in all cases considered.

The expected motions and loads performance were derived in accordance with standard industry practices and based on selected sets of design load cases (DLC). The minimum air gap requirement was met in all cases.

### *2.7.10 Station Keeping System*

The mooring system consists of clusters distributed around the substructure. The platform heading is aligned to allow for a better sharing of the site specific wind loads. The mooring line arrange and specification has been optimised to the installation campaign requirements. Each line has a top section of High Modulus Polyethylene (HMPE) rope, connected to chain sections (with clump weights fitted near the touchdown point) and then to the anchor. A wide mooring radius of is applied to prevent uplift at the anchor, one of the requirements for the drag embedment anchors (DEA) considered for the system.

The mooring line elements were designed and sized to cope with the required safety factor. The mooring system restrains the platform offsets under the specified met-ocean condition and is designed to be fully redundant; a failure of one mooring line does not lead to failure of other lines and does not compromise the integrity of the riser under any conditions. In practice, this means that a breakage of one mooring line does not lead to exceedance of minimum breaking load (MBL) on the remaining lines and the platform excursion is kept within a targeted allowable motions envelope to protect the riser integrity.

## 2.8 Construction and Installation

A high-level construction and installation plan has been developed incorporating the methodology, schedule and potential locations for fabrication of a single 2MW floating substructure, integration of WTG and offshore installation. Potential sites/ ports for the construction and installation activities both in the UK and in the European region were assessed from a technical and economic viewpoint. Detailed assessment on a number of ports located on the eastern coast of Scotland was carried out to determine their suitability to support different construction and installation activities. These ports were assessed based on their existing infrastructure and characteristics to support different construction and installation activities, including the quayside properties (e.g. water depth, quay length), access channel properties (e.g. water depth, channel width and restrictions), available space, load bearing capacity, etc. The assessment confirmed that Scotland has the capacity to support the fabrication of the platform; hence a fully fabrication of the platform local to the project site in Scotland can be carried out. This would support the local supply chain in its evolution towards the commercial scale field of Dolphyn units. The assessment work completed has shown that platform fabrication, assembly and WTG integration activities for Dolphyn prototype can all occur within a single facility, with suitable facilities located in the UK. However, there is a potential to reduce the platform fabrication cost by ~20% if the platform is fully fabricated at an experienced port site outside of the UK and subsequently transported to Scotland. The ERM Dolphyn project is committed to maximising UK content as far as is economically practicable. The project team have an existing relationship with suitable port facilities in the UK and are keen to continue working with UK facilities during the next phase to explore options for fabrication optimisation.

The hydrogen export pipeline will be installed on the seabed; hence the pipeline installation will involve trenching, pipeline laying and backfilling. A pipeline construction philosophy was developed, identifying the methodology for pipeline laying, riser and spool piece tie-in installation. A high-level methodology for pipeline pre-commissioning activities was also developed.

There are two options of pipelay, via a reel lay vessel or via an S-lay vessel. However, the latter is likely to be uneconomic for Dolphyn as many S-lay vessels in the market are configured around large diameter pipelines that are not suitable for reel lay; it is generally suited to larger (18” and above) pipelines with longer lengths. A J-lay method is not suitable for Dolphyn as it is only applicable for shallower water depths. Reel lay method is suitable for pipelay for relatively short pipelines of 16” diameter or less. Hence, considering the pipeline diameter and length for Dolphyn prototype, as well as the water depth, pipeline laying is likely to use the reel lay method. With this method, the pipeline is fabricated onshore and then ‘spooled’ onto the pipelay vessel’s drums. The vessel then sails to location and lays the pipeline from its drum. The reel lay method would become uneconomic at longer pipelines due to the need for extra transits to and from the spool base for additional pipeline lengths; hence at full field development scale of Dolphyn the suitable pipelay method would need to be re-assessed. The laying of pipelines is a well-established and mature industry, the pipeline diameters expected for Dolphyn projects at all scales are within the boundaries of ‘standard’ pipelines commonly installed.

Following pipelay, the pipeline will be trenched and backfilled for long-term protection from fishing and other potential seabed interaction. There will be a short period during which it will be exposed to waves and current loads that can act to both lift and move or displace (by sliding) sections of the pipeline. A preliminary pipeline on-bottom stability assessment has been completed carried out based on preliminary met-ocean data and seabed surface soil conditions. It indicated that the pipeline is stable at the Dolphyn platform location for two installation windows of three month duration. At the next design stage, this shall be re-assessed based on detailed met-ocean data and seabed soil conditions obtained from marine surveys.

The flexible riser, connecting the Dolphyn substructure and the pipeline on the seabed, is detailed in order to avoid air diving inside the anchor pattern of Dolphyn. Diving inside the mooring patterns would create a significant health & safety and commercial risks (e.g. weather downtime for diving support vessel), hence it should be avoided. Furthermore, potential optimisation on riser installation methodology was identified during the design phase, which would provide significant financial benefit on future larger array installations. This potential optimisation shall be explored further in the next design stage.

## 2.9 Opportunities

Several opportunities were identified during the detailed design of the prototype unit, which can be further explored during the design of the larger scale unit (commercial scale demonstrator unit). These are presented below.

- There are likely to be further opportunities for integration and energy optimisation to be realised across the overall system.
- There is a potential for optimised hydrogen storage system. This is particularly of advantage for larger scale units where a larger hydrogen inventory would be required on board. A number of alternative solutions have been identified for consideration at larger scales of development.
- The design for energy generation and storage system are expected to be further optimised.
- Consideration of input from weather forecasting system into Dolphyn operating system. The WTG is expected to autonomously regulate its own operating mode, and thereby regulate power output in response to prevailing wind conditions.
- Considerations of possible use of oxygen (generated by the electrolyser system). A number of potential applications for the produced oxygen have been identified for consideration.
- Potential optimisation of riser installation, in particularly on future full field/ larger array installations where the offshore Dolphyn site is located further away from shore.
- Consideration to conduct stress/ strain measurements on global deck in order to identify actual performance. The test results can be used to further optimise the structural design, which would be advantageous for full field development.
- There is opportunity for local port/ fabrication yard in Scotland to build experiences on fabrication of the floating foundation if the first Dolphyn unit is to be constructed in a local port. This would support the local supply chain in its evolution towards the commercial scale field of Dolphyn. From an

economical viewpoint, however, there is a potential to reduce the platform fabrication cost by ~20% if the platform is fully fabricated at an experienced port site and transported to Scotland.

# 3. THE COMMERCIAL SCALE DEMONSTRATOR (10MW)

Development of the Detailed Design for the 2 MW prototype outlined in Section 2 has enabled engineering activities to focus on de-risking the project. The outputs of the detailed design activities have provided sufficient confidence for the project to implement an accelerated program to achieve commercial scale deployment sooner. Therefore, in addition to the completion of the development of the 2MW prototype, pre-FEED design activities were additionally carried out for the 10MW commercial scale demonstrator unit. This will accelerate the overall project timeline with the objective of installing the commercial scale demonstrator unit in 2024.

The outputs of the pre-FEED design activities have provided sufficient confidence that the scaled-up topsides would operate alongside the scaled up floating substructure. High level reviews of potential technologies for critical/ main systems were carried out, particularly those that would give significant benefits for the commercial scale unit and constructability. Potential challenges associated with the scale-up have been identified providing a risk based development plan for the FEED stage of the project with a high level of confidence in scope and schedule requirements.

The pre-FEED design activities for the 10MW demonstrator resulted in more than 20 set of engineering deliverables and studies, including key deliverables such as preliminary layout, Process Flow Diagrams (PFD) and Heat and Mass Balance (HMB), equipment list and electrical load list. Other key deliverables for preparation of FEED activities were also produced, including basis of design, review of technology selections, etc.

Key parameters and aspects of the pre-FEED design activities for the Dolphyn commercial scale demonstrator are highlighted in this section.

## 3.1 Overview of Pre-FEED Design Activities

The 10MW commercial scale demonstrator unit follows a similar overall concept to the prototype unit. Critically, it is designed for commercial use at wind farms at varying scale, ranging from 100 MW to multi-GW capacity. The Pre-FEED activities have demonstrated the feasibility of developing a commercial scale unit for first hydrogen production in 2024. Additionally the Pre-FEED activities have developed a prioritised development plan for a commercialised design with a focus on:

- Ease of Engineering, Procurement, Construction and Installation (EPCI) at scale
- Efficiency and reliability
- Optimised for ease of Operation and Maintenance
- Aligned with supporting Supply Chain Resilience, with a focus on promoting UK content
- Automation of Control

The commercial scale demonstrator unit is designed to export high purity dry hydrogen at a medium pressure to landfall. Production will be at ambient temperature, with a maximum production rate of ~150 kg/hr (~3,600 kg/day), suitable for injection into natural gas grid as well as for transport use at the point of delivery.

The pre-FEED design activities were focusing on identification of key challenges including potential interface challenges in the design that could prevent the development and deployment of the units, which shall be explored further in the next design stage. The pre-FEED includes the following activities:

- Preliminary sizing of process equipment
- Preliminary layout development, to check any major potential issue with relevant to physical footprint and weight budget that should be flagged in the next design stage
- Review of alternative technologies that would give significant benefit for bigger scale unit (a single commercial scale unit and full field development). This includes review of desalination technology, options for standby power supply, options for hydrogen storage and compression, as well as preliminary assessment of wind turbine generators (10 MW+).
- Assessment of alternative cases for hydrogen export pipeline
- Development of key deliverables for preparation of FEED activities
- Identification of issues requiring further consideration in specifying the onshore facilities for Dolphyn

The results of the pre-FEED design activities are presented in the following sections.

## 3.2 HSE in Design

The approach to HSE in design for the 10MW commercial scale demonstrator follows the same overarching philosophy as the 2MW concept, outlined in Section 2.5. The same legal framework applies, and given that the intention is to progress the design to construction and operation, the following are noted:

- Submission of a Design Notification (DN) to the UK HSE at least six (6) months prior to construction activities for the pipeline route, in accordance with Pipeline Safety Regulations (PSR) 1996.
- Voluntary development a Safety Case to demonstrate the application of a robust hazard management process.
- Expansion of Performance Standards scope to cover assurance and verification activities associated with procurement, fabrication, installation, commissioning and operations.

Whilst, the fundamental HSE design principles for the 10MW commercial scale demonstrator are the same as the 2MW concept, there may be some changes to the means of protection against major accident due to the changes in design and inventory. A review of the fire protection systems, in light of the changes in the inventory and pressure of hydrogen stored, will be performed during the FEED.

With the increase in capacity from 2MW to 10MW comes increased equipment footprints. Initial development of the layout for the 10MW was carried out by incorporating the main safety principles as highlighted in Section 2and will continue to be reviewed during design development to verify that the layout achieves an ALARP design.

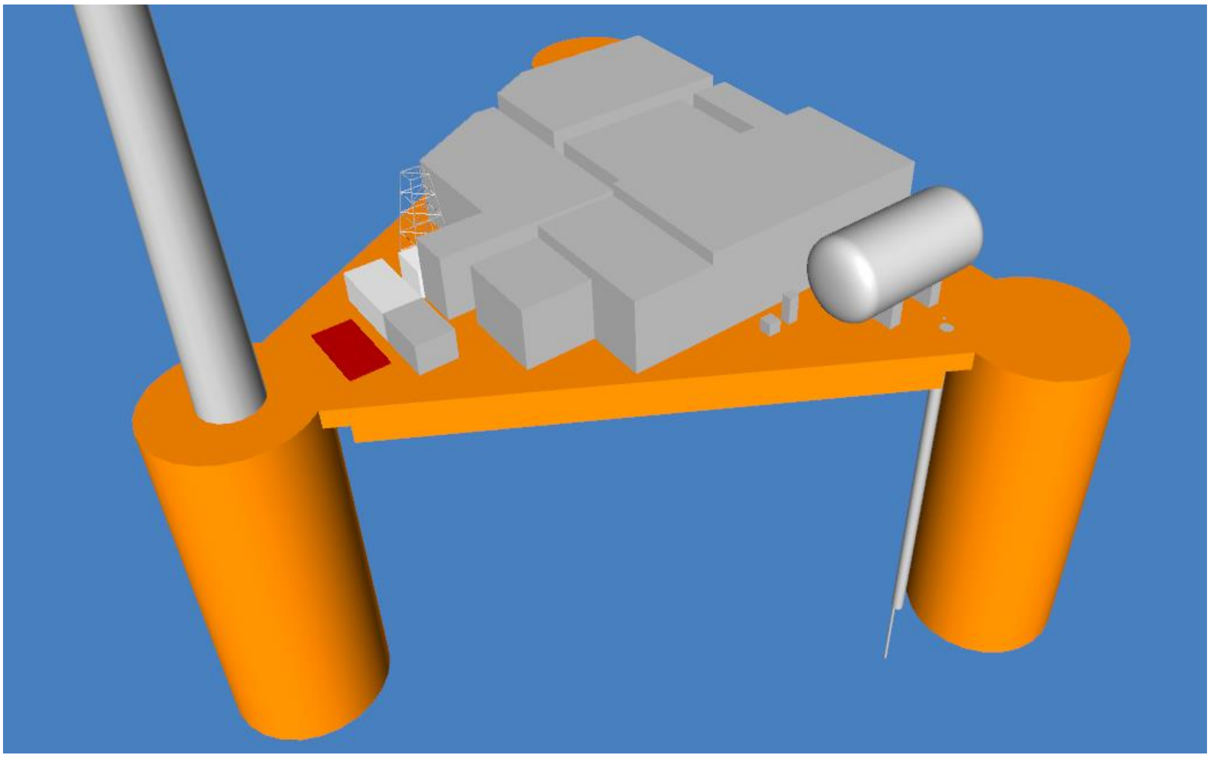
## 3.3 Verification

The verification of the Dolphyn 10MW commercial scale demonstrator will comprise detailed review of project documentation to check the assurance process followed by the project team and confirm the initial and ongoing suitability of the identified Safety and Environmentally Critical Equipment (SECEs). Verification activities will cover not only design, but also procurement, fabrication, installation, commissioning and operation phases. A verification road map has been developed in collaboration with the independent verification body (Lloyd's Register) and will form the basis for verification activities for the 10MW demonstrator.

## 3.4 Key Design Outputs

The pre-FEED design activities involved development of the preliminary layout to verify the main equipment would fit on the scaled up scheme. Preliminary sizing of main equipment items was carried out to provide input to the layout development. A 3D visualisation of the Dolphyn 10MW commercial scale unit is presented in Figure 3.1.

**Figure 3.1 3D Visualisation of Dolphyn 10MW Commercial Scale Demonstrator Unit**



### *3.4.1 Preliminary Equipment Sizing*

An area of potential optimisations identified during the design of the Dolphyn prototype unit is relevant to heat/ cooling integration. This aspect was explored during the pre-FEED design, in particular with relevant to the integration of the electrolyser system.

The commercial scale demonstrator unit uses thermal desalination technology, unlike the prototype unit (which uses reverse osmosis technology). The thermal desalination technology requires significant heat duty associated with the heating of seawater, providing the opportunity of using high-grade waste heat through a heat transfer system.

There is further cooling integration that can explored associated with cooling system integration, which will be examined further in the next design stage.

A preliminary electrical load list was developed during the pre-FEED design, which was used to determine the physical space and weight budget for the electrical system for layout development.

Key process deliverables such as Process Flow Diagrams and Heat Material Balance were produced.

### 3.4.2 Layout Development

A scale-up means an increase in some equipment sizing, however not all equipment items increase by the same amount. This efficiency in some equipment items helps to drive economic performance of the 10MW unit, but requires a review of layout, and weight. A preliminary layout was developed, based on the preliminary equipment sizing, weight and expected footprint. This exercise was conducted to consider the configuration of the decks and identify opportunities for layout optimisation.

This activity has provided sufficient confidence that scale-up topsides would fit into the floating platform. There are expected to be further optimisations on the layout explored at the next design stage.

### 3.4.3 Review of Alternative Technology Options

#### Desalination Technology

Review of suitable desalination technology was carried out during the pre-FEED stage. The review process considered the two leading viable desalination technologies, (reverse osmosis and thermal desalination). Both technologies are mature and proven for application on the Dolphyn project. The review considered similar technical, economical, safety and project risks aspects to those considered for the prototype. Thermal desalination technology was identified as the preferred desalination technology for the Dolphyn commercial scale demonstrator unit, partially driven due to its low maintenance requirement compared to the reverse osmosis technology. These maintenance requirements are a significant benefit when considering the long-term Dolphyn project objectives, such as unmanned operations far shore with minimum maintenance visits, particularly for a commercial scale field,.

#### Hydrogen Compression

Hydrogen is stored on board as part of the production and standby power systems. A larger quantity of hydrogen inventory is required to be stored on board the commercial scale unit than the prototype. Storing hydrogen at medium pressure (as for the prototype unit) would necessitate a much larger hydrogen storage system. Whilst it is feasible to store the volumes of hydrogen required it does raise a number of design challenges, including:

- The size and weight of the hydrogen tank (of the specified capacity required for the commercial scale unit) would require increased levels of quality assurance during the design, manufacture and testing of the hydrogen tank.

- The weight of the hydrogen tank would require additional supporting structure, which in turns resulting in additional weight budget to be allocated on this system. This indicates a further requirement to assess the weight impact of the tank on the platform structural stability.

These issues can be resolved by storing hydrogen on board at higher pressures; hence, a review of hydrogen compression system was undertaken.

Three types of compressor technology were reviewed, as follows:

- Centrifugal compressors. This type of compressor was found to be insufficient for hydrogen service due to the low molecular weight of hydrogen gas. However, further engagement with the vendor is required to check whether there is still potential to use this type of technology due to its high capacity application.
- Electrochemical hydrogen compressor. This type of compressor is showing promising results when used in small-scale hydrogen outlet pressure application, although more work is required to assess its performance in a wider range of pressure and temperature conditions. This technology is at low technological readiness level, hence may not be suitable for Dolphyn.
- Reciprocating compressor. This type of compressor is the recommended compressor technology as it can accommodate a wide range pressure (30 to 700 barg) and its efficiency is not limited by gas molecular weight.

An initial assessment of compressor power and cooling water requirements, based on reciprocating compressor technology, for the Dolphyn commercial scale unit was carried out. This assessment considered different hydrogen flowrates under different operating conditions.

A number of technically viable solutions exist, however a more detailed analysis around compressor selection is required at the next design stage, aiming to optimising the size of the compressor due to limited space on the platform. The viability for application of electrochemical hydrogen compression on the Dolphyn design will also be explored to understand potential alignment with the equipment development pathway.

### Energy Storage Options

A review of different energy storage options was carried out as part of the pre-FEED design, in order to evaluate the feasibility of each option for standby/ back-up power system on Dolphyn. The main results of the review are provided below.

**Batteries** - Different batteries technologies were reviewed, including: lithium-ion, lead acid, nickel cadmium, redox flow and zinc-hybrid cathode. Batteries are a robust and mature energy storage technology. They are used in UPS systems and provide instant “uninterruptible” power supply for long durations, with high efficiency of UPS systems at around 80-95%. In terms of maturity, all battery technologies reviewed are comparable, except for the redox flow, which is in early commercialisation stage. Lead acid batteries were found to have the cheapest cost per kWh; however its operational lifetime is lower, resulting in more regular replacements of batteries. In general, lithium and nickel cadmium batteries offer better longevity.

**Fuel Cells** - Fuel cells can be used to supply the required standby power, however the duration is dependent on the fuel (hydrogen) tank size. Its operational efficiency over short duration storage is around 50-55%, which is lower than that of batteries. Of the non-utilised energy, a large portion goes into the generation of waste heat which can be potentially used elsewhere on Dolphyn, improving the overall system efficiency.

**Hydrogen Internal Combustion Engine** - This technology was considered as alternative technology for standby power system. Similarly to fuel cells, the efficiency is lower for electricity production than batteries, with a high proportion of thermal production. However, this is a developing technology at is currently at a higher unitary cost than fuel cell technology. It is anticipated that hydrogen specific engines are under development to increase the efficiency. At the capacity required for the Dolphyn commercial demonstrator unit, the hydrogen genset is still being developed and is expected to be commercially available in the future. The viability for application of hydrogen internal combustion engines on the Dolphyn design is being explored to understand potential alignment with the equipment development pathway

**Supercapacitors/ Ultracapacitors** - Ultracapacitors were identified as having the highest power density and smallest footprint compared to alternative technologies. However, its relatively low energy density means they can only provide large power for short durations. This would be particularly useful in instances where large power is required in short periods – such as for frequency control. This technology is in early commercial stage. The current unitary cost is higher than alternate technologies.

For the Dolphyn commercial scale demonstrator unit, the suggested technology for standby power system is fuel cells with accompanying Li-ion battery to provide the power surge needed for WTG start-up.

Hydrogen internal combustion engine, as the alternative option, has the disadvantage of lower efficiency and higher cost per kW, compared to the fuel cell technology. The development of this technology for commercial scale would be the critical factor for its consideration on Dolphyn application.

#### Wind Turbine Generators

A preliminary assessment of wind turbine generators (at 10+ MW capacity) was carried out during the pre-FEED stage. Different offshore wind turbine technology available at ta variety of scales were compared. The 10MW capacity is already available on the market, with units already in operation in an offshore floating wind scenario. Wind turbines at larger scales are being developed, with 14 - 15 MW capacity expected to be commercially available from the mid-2020s. Use of these larger turbines in the future would further enhance the economic performance of the Dolphyn system.

### *3.4.4 Assessment of Preliminary Hydrogen Export Pipeline Sizing*

An assessment of different capacities for hydrogen export pipeline was carried out. In particular, the sizing of pipeline for a single Dolphyn commercial demonstrator unit (10 MW) and a number of cases of multiple units up to 300 MW was assessed, in order to review how the pipeline size increases as the number of commercial scale units increases. The approximate pipeline size for different pipeline capacities, based on the expected pipeline pressure drop and velocity (to prevent erosion), are provided below.

**Table 3.1 Summary of Approximate Pipeline Capacity Assessment**

| Case | Distance to Shore (km) | Approximate Pipeline Diameter (mm) |
|---|---|---|
| 10 MW | 15 | 75 (3”) |
| 20 MW | 25 | 75 (3”) |
| 50 MW | 25 | 150 (6”) |
| 100 MW | 50 | 150 (6”) |
| 300 MW | 50 | 250 (10”) |

The outcome of this assessment shows that deployment of larger scale fields at increasing distances from shore can be facilitated with pipeline diameters that are well within the normal limits of offshore pipeline operation.

A preliminary assessment of the wall thickness with regards to the pressure containment and (temporary) pipeline on-bottom stability when subject to wave and current loads has been undertaken for 6” and 10” pipeline sizes.

A further assessment is required to confirm the optimum sizing pipeline diameter, incorporating the pipeline insulation, heat transfer, stability and strength, constructability and pipeline laying implications.

### *3.4.5 Onshore Facility Considerations*

Design activities for the Dolphyn onshore facility (reception terminal) will start during the next phase and are not included in the scope of work for this phase. By way of preparation and project de-risking, a review of different aspects, which require consideration in specifying the onshore facilities, was carried out.

The onshore facilities are required to enable hydrogen to be supplied from the Dolphyn site in a safe and reliable manner through the following principles:

- Maintain control of the pipeline. The site should be located close to landfall with emergency control valves anticipated.
- Support distribution to customers. Site should be well located to supply customers and have suitable means of metering, quality control and supply to customer site.
- Support reliable hydrogen supply potential buffer storage sized for periods of low production, depending on the customer’s requirements.
- Be zero carbon during operation.
- Minimise environmental impact.
- Be secure and safe – suitable location safety and security arrangements.
- Be considerate to local stakeholders.
- Accessible via pipeline and compatible with pipeline construction methods envisaged (e.g. horizontal directional drilling).

Should hydrogen storage be required, its control and management will voluntarily be conducted in line with the COMAH Regulations (2015), i.e. considered a higher tier site where storage exceeds 5 tonnes (although actual storage is likely to be less than this). Good industrial practice and management systems will be used to guide the management of dangerous substances stored onsite. This good practice means that the design will refer to codes and standards or industry or learned society guidance notes. .

The overall context of the onshore facilities was assessed, to aid early scoping and feasibility of the plot size and location, discussed in Section 4.3. Typical end-user cases were considered, to assess the differing requirements, which may need to be accommodated by the Dolphyn project facilities, both onshore and offshore. Typical design solutions for the onshore facilities were identified, which require further development in the next project phase. The work completed provides confidence that a suitable onshore reception facility can be developed in line with the project objectives.

## 3.5 Opportunities

Several opportunities were identified during the pre-FEED design of the commercial demonstrator unit.

- A review of technology selection for energy storage system indicates that an Internal Combustion Engine using hydrogen is a viable option. This technology is suitable for applications where hydrogen is available at lower specifications (compared to that required for fuel cell application). However, as this is a developing technology the unitary cost is higher than for existing technologies. The development of this technology for commercial scale applications would be the critical factor for its consideration on Dolphyn application.
- Supercapacitors were found to be viable energy storage option for Dolphyn application, in particular for emergency power. However, this technology is in early commercial stage and the unitary cost is higher than for existing technologies.

# 4. SITE SELECTION

## 4.1 Overview

Site selection exercises were completed for both the offshore and onshore components of the Project to identify sites that meet Project requirements. These need to be consentable, and least constrained by technical, environmental and commercial considerations. The site selection process was focussed on the development of a 2MW prototype initially, with potential future expansion to a 10MW commercial scale demonstrator unit. As the project looked to accelerate its development to a commercial scale demonstrator unit, the foresight of the site selection process helped facilitate a low risk pathway to deployment. The findings from the site selection process were unchanged from the decision to move to an accelerated deployment timetable.

Site selection was driven by a GIS-based overlay of a wide variety of factors and summaries of the selection methodologies and results of both exercises are presented in this section.

## 4.2 Offshore site selection

### *4.2.1 Approach*

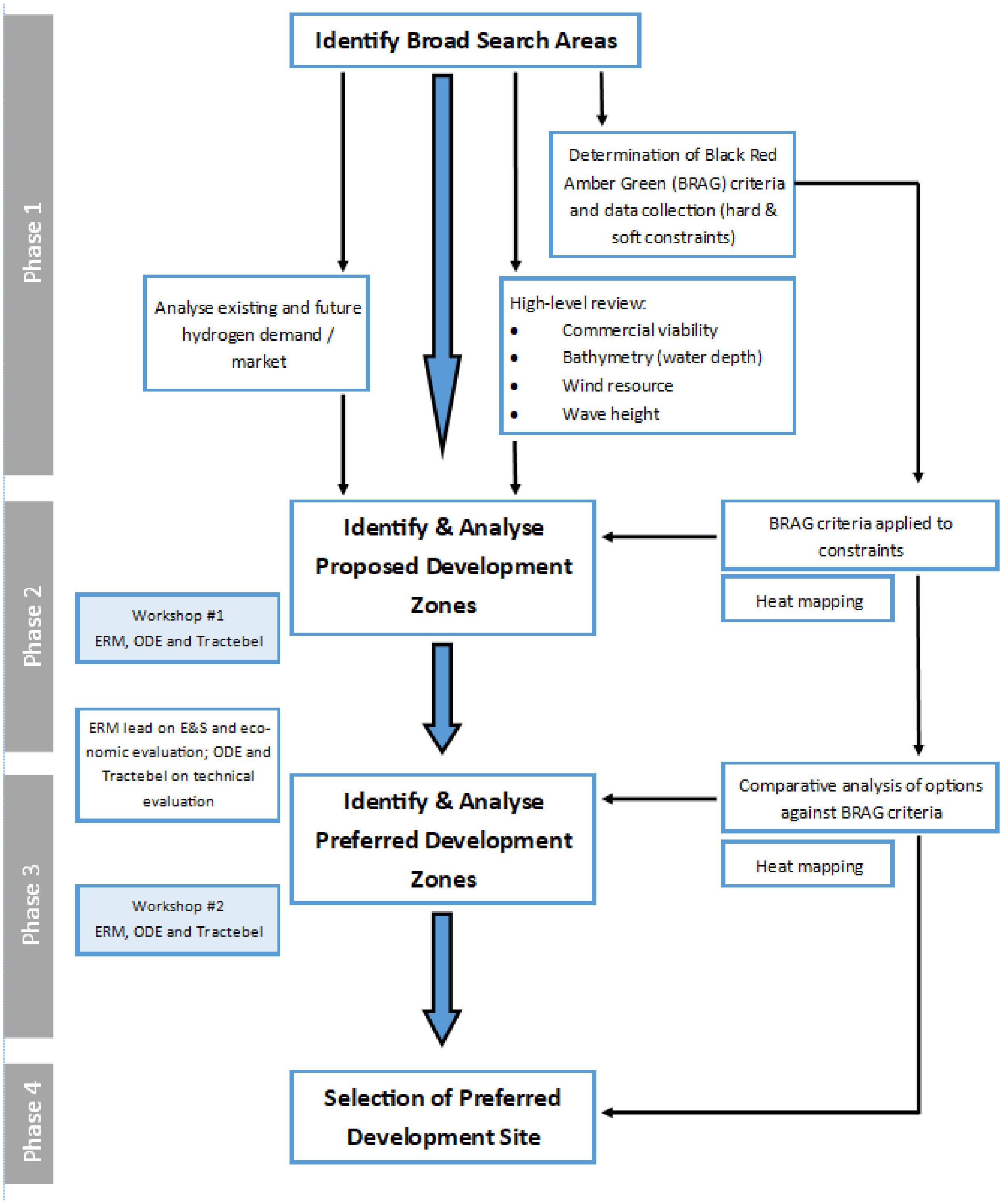
The process consisted of three iterative stages, which incorporated the identification and analysis of:

- broad search areas
- proposed development zones
- preferred development zones

The process gradually refined the areas/zones being considered for the Project by identifying developable sites with the least constraints, using a Black Red Amber Green (BRAG) approach. A summary of the site selection process is illustrated in Figure 4.1

.

**Figure 4.1 Site Selection Process**



*ERM, 2020*

Technical, environmental and commercial risks, constraints and considerations were taken into account to develop the Black Red Amber Green (BRAG) criteria used for the GIS-based site selection process. BRAG criteria were devised for each of the constraints being considered, including both “soft” and “hard” constraints:

> A “hard” constraint is a constraint that must be avoided through the site selection process (i.e. the Project will not be feasible if sited in a location effected by a hard constraint).
>
> A “soft” constraint can be accommodated, but to site the Project might require a compromise in terms of technical, environmental or commercial considerations or performance.

Two workshops were held at key stages of the site selection process. Representatives from the technical, environmental and commercial disciplines were present at these workshops to enable the BRAG criteria (especially the qualitative criteria) to be considered in a balanced manner throughout the site selection process.

### *4.2.2 Selection Criteria*

The following key technical constraints were considered in developing the BRAG criteria:

- Existing offshore infrastructure
- Consented developments
- Active pipelines, cables and subsurface structures
- Suspended oil and gas wells
- Shipping and navigation routes
- Military munition disposal sites
- Bathymetric contours
- Met-ocean conditions
- Seabed morphology and sediment

The following key environmental constraints were considered in developing the BRAG criteria:

- Marine archaeology
- Commercial fishing activity
- Aquaculture activity
- Benthic habitats (including those listed in Annex I of the Habitats Directive)
- Conservation designations
- Ornithology
- Fish ecology

In order to inform the site selection process and to enable the development of commercial considerations for the BRAG assessment, drivers of site commercial viability were also considered at a high-level. This enabled the relative commercial attractiveness of different sites to be compared, which was of particular use where the technical and environmental constraints did not allow differentiation.

The site selection process also looked to identify any alternative scenarios (outside of developing in a "green-field" offshore location) with commercial attractiveness, such as being co-located within an existing, licenced offshore wind field.

Co-locating the Project within an existing licenced field provides the potential to increase the efficiency of the development and to share resources during the operational phases of the Project. Only one appropriate, existing field exists within the areas considered, the Kincardine Offshore Wind Project.

### *4.2.3 Identification of Broad Search Areas*

Broad search areas were initially identified in the North Sea using a few key constraints from the BRAG criteria:

- commercial viability - access to an onshore market for hydrogen off-takers
- bathymetry - locate the floating semi-submersible structure in water deeper than 40m to enable sufficient anchorage
- wind resource – average annual wind spends between 10 and 25 meters/second (m/s) to enable generation of adequate electricity for production of hydrogen
- wave height – maximum wave height of 14 m (100 year return) to reduce risk of compromising offshore structures

The consideration of these constraints steered the site selection process to three focal points on the east coast of Scotland:

- Grimness, South Ronaldsay, Orkney Isles
- St Fergus, Aberdeenshire
- Aberdeen City, Aberdeenshire

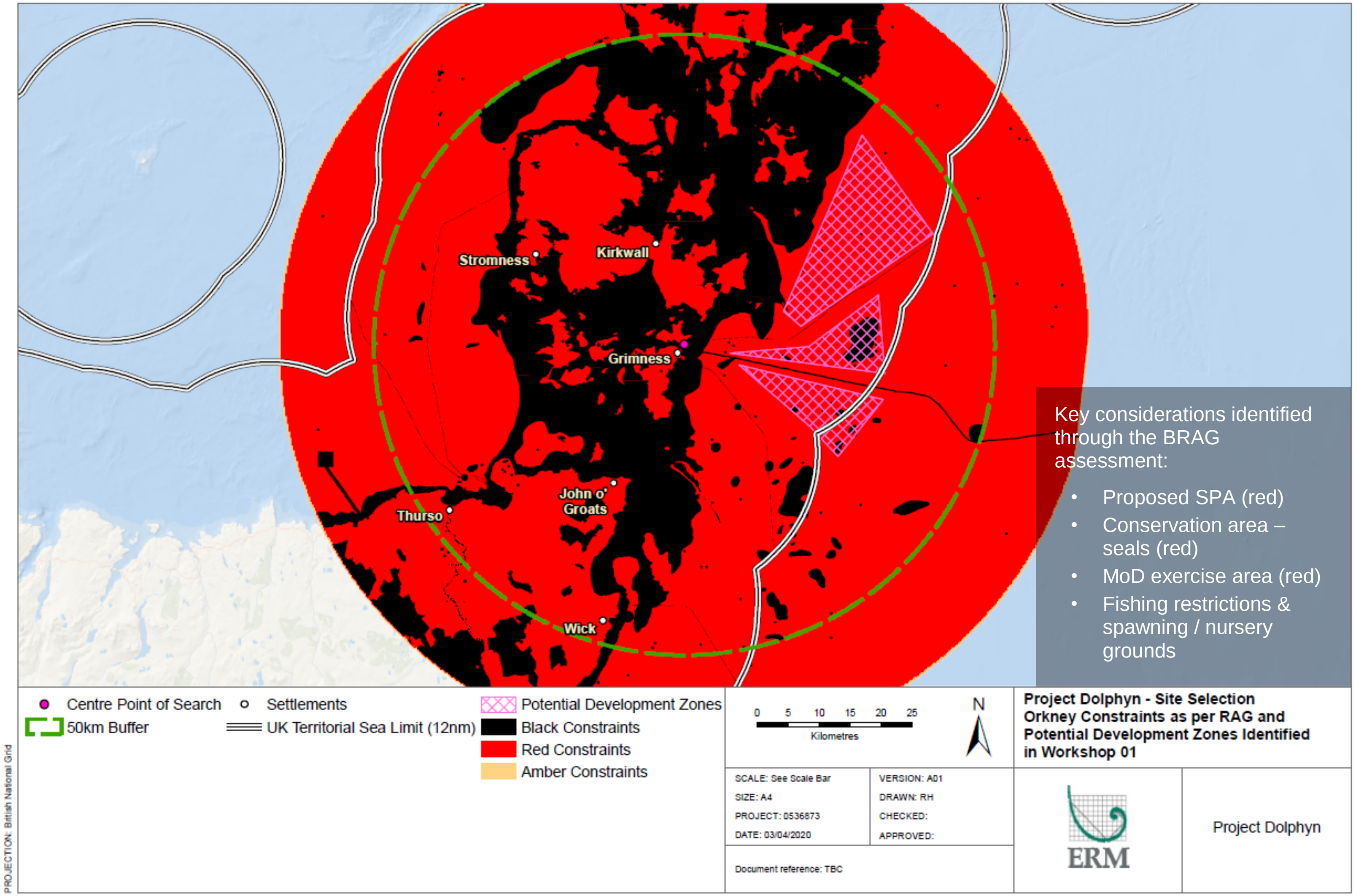
### *4.2.4 Identification & Analysis of Proposed Development Zones*

At this stage, hard and soft engineering and environmental constraints, both offshore and at the landfall, were assessed within the GIS using the full BRAG criteria. The most developable areas (i.e. those with the lowest potential environmental sensitivity and least number of potential engineering issues) were then identified, and a comparative analysis carried out through a workshop with representatives from the technical, environmental and commercial disciplines.

A key commercial consideration that took precedence at this stage of the site selection process was to consider only proposed development zones within UK territorial waters (12 nautical miles). The reason for this was to minimise capital expenditure (CAPEX) associated with the installation of pipeline bringing hydrogen to shore for the prototype development.

The three broad search areas, including key considerations identified through the BRAG assessment are presented in Figure 4.2, Figure 4.3 and Figure 4.4.

## Figure 4.2 Wide Area Search – East Orkney Region



Key considerations identified through the BRAG assessment:

- Proposed SPA (red)
- Conservation area – seals (red)
- MoD exercise area (red)
- Fishing restrictions & spawning / nursery grounds

**Project Dolphyn - Site Selection**
**Orkney Constraints as per RAG and Potential Development Zones Identified in Workshop 01**

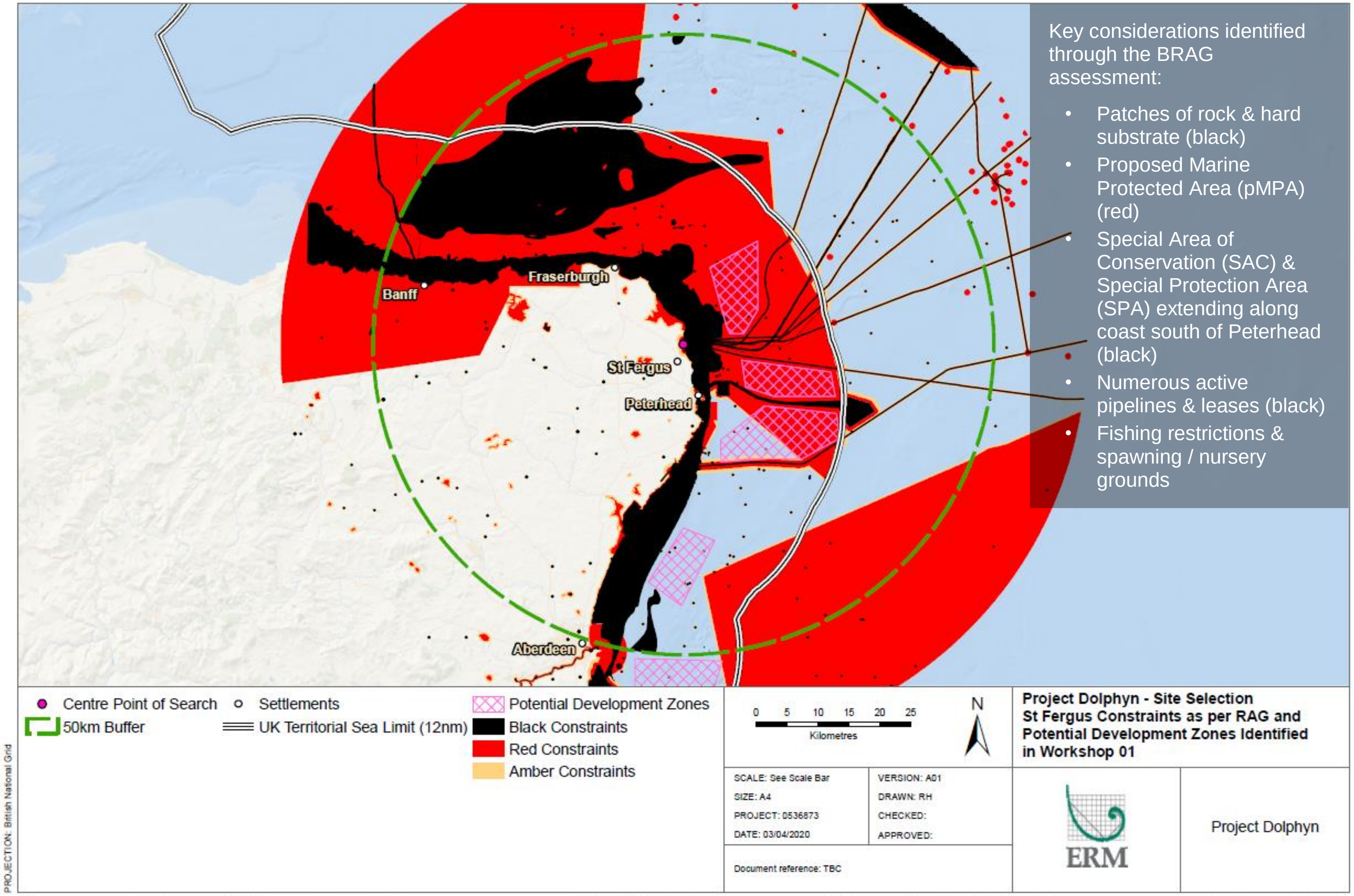
SCALE: See Scale Bar
SIZE: A4
PROJECT: 0536873
DATE: 03/04/2020
VERSION: A01
DRAWN: RH
CHECKED:
APPROVED:
Document reference: TBC

Project Dolphyn

SOURCE: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors;
(Copyright Scottish Natural Heritage/Historic Environment Scotland) Contains Ordnance Survey data © Crown copyright and database right (2020); © British Geological Survey (2020); © Crown Estate Scotland 2020

Path: \\UKLONSV04\Data\Manchester\Confidential Projects\0536873 Dolphyn Project Phase 2.DC\9. WP4 - Consenting\GIS\MAPS\Site Selection Report\Orkney_Constraints_A01.mxd

**Figure 4.3 Wide Area Search – St Fergus Region**



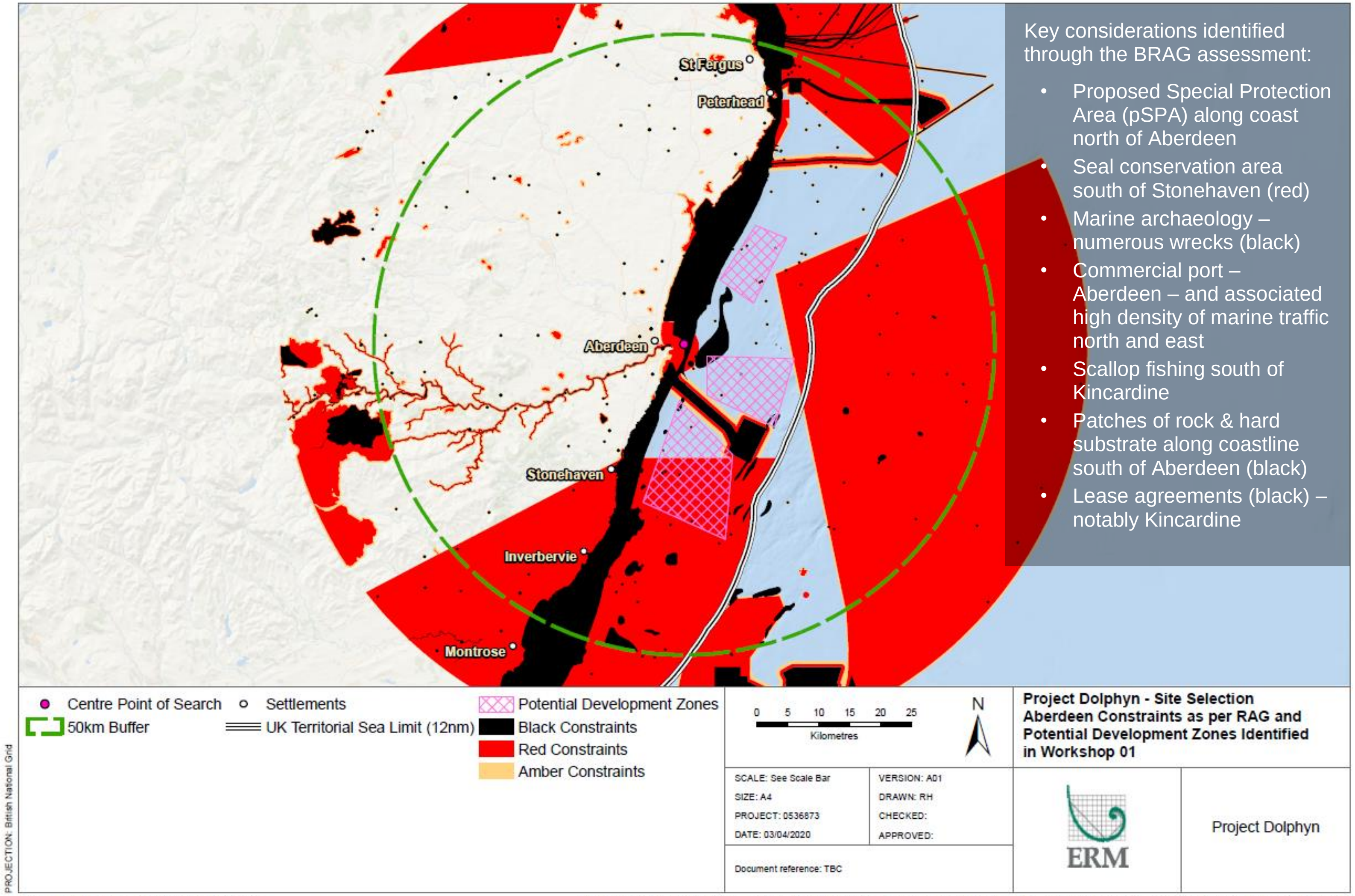
Key considerations identified through the BRAG assessment:

- Patches of rock & hard substrate (black)
- Proposed Marine Protected Area (pMPA) (red)
- Special Area of Conservation (SAC) & Special Protection Area (SPA) extending along coast south of Peterhead (black)
- Numerous active pipelines & leases (black)
- Fishing restrictions & spawning / nursery grounds

SOURCE: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors;
(Copyright Scottish Natural Heritage/Historic Environment Scotland) Contains Ordnance Survey data © Crown copyright and database right (2020); © British Geological Survey (2020); © Crown Estate Scotland 2020

Path: \\UKLONSV04\Data\Manchester\Confidential Projects\0536873 Dolphyn Project Phase 2.DC\9. WP4 - Consenting\GIS\MAPS\Site Selection Report\St_Fergus_Constraints_A01.mxd

### Figure 4.4 Wide Area Search – Aberdeen City Region



Key considerations identified through the BRAG assessment:

- Proposed Special Protection Area (pSPA) along coast north of Aberdeen
- Seal conservation area south of Stonehaven (red)
- Marine archaeology – numerous wrecks (black)
- Commercial port – Aberdeen – and associated high density of marine traffic north and east
- Scallop fishing south of Kincardine
- Patches of rock & hard substrate along coastline south of Aberdeen (black)
- Lease agreements (black) – notably Kincardine

**Project Dolphyn - Site Selection Aberdeen Constraints as per RAG and Potential Development Zones Identified in Workshop 01**

SCALE: See Scale Bar
SIZE: A4
PROJECT: 0536873
DATE: 03/04/2020
VERSION: A01
DRAWN: RH
CHECKED:
APPROVED:
Document reference: TBC

Project Dolphyn

SOURCE: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors; (Copyright Scottish Natural Heritage/Historic Environment Scotland) Contains Ordnance Survey data © Crown copyright and database right (2020); © British Geological Survey (2020); © Crown Estate Scotland 2020

Path: \\UKLONSV04\Data\Manchester\Confidential Projects\0536873 Dolphyn Project Phase 2.DC\9. WP4 - Consenting\GIS\MAPS\Site Selection Report\Aberdeen_Constraints_A01.mxd

### 4.2.5 *Identification & Analysis of Preferred Development Zones*

Based on the comparative analysis of the proposed development zones the Aberdeen site was identified as being the least constrained and most advantageous. The three development zones at the Aberdeen location (A, B and C – see Figure 4.5) became the "preferred" development zones in the site selection process.

These development zones were then further scrutinised through the BRAG assessment process. Additional data on marine vessel traffic was also received at this point which showed high volumes of traffic moving north to/from Aberdeen harbour. Bearing this data in mind, it was decided that the northern-most development zone should not be further considered in the site selection process. The reasons included the challenges of siting the Project offshore structures in an area with high volumes of marine traffic.

At this point, another preferred development zone was identified within the Aberdeen broad search area. Within the zones under consideration, an existing offshore floating wind development was identified, the Kincardine offshore wind farm (located southeast of Aberdeen – see Figure 4.5).

The Kincardine field offers a number of project similarities to Dolphyn; it is a floating wind farm, with 10 MW units, and utilises a similar substructure and mooring design. The development of the Project requires licencing and consenting to be in place, which in turn requires information on the local site including environmental and bathymetric survey data. Locating the Project within the Kincardine field would likely increase the complexity of stakeholder interfaces but would offer a number of potential efficiencies.

These three preferred development zones (A, B and C) were then further refined (i.e. removing any constrained parts of the zones). Due to the proximity to/within the Kincardine license area these preferred development zones cumulatively are referred to as the "Greater Kincardine" area.

Now that the three preferred development zones for the floating semi-submersible structure and offshore turbine had been identified within the Greater Kincardine area, the site selection team was able to focus on the routing and landfall options for the small-diameter pipeline bringing the produced hydrogen to shore.

#### *4.2.5.1 Offshore Pipeline*

At this stage, only broad routing corridors have been identified for the offshore pipeline from each of the preferred development zones to the stretch of coastline south of Aberdeen harbour with potential options for the landfall. The detailed routing of the pipeline within the corridor requires an interface with the onshore site development, which in turn is influenced by the offtake agreements in place. Analysis of the potential pipeline corridors provide confidence that a technical, economic, and consentable route is feasible. Figure 4.5 shows the broad routing corridors for each option.

The preliminary pipeline routing study did conclude that it would be logical to follow the existing offshore cable routes from the Kincardine windfarm, with the small-diameter hydrogen pipeline being installed at a suitable safe distance to avoid electrical interference, anchor spreads, and plough deviations during installation. The review of the environmental conditions from development of the Kincardine field

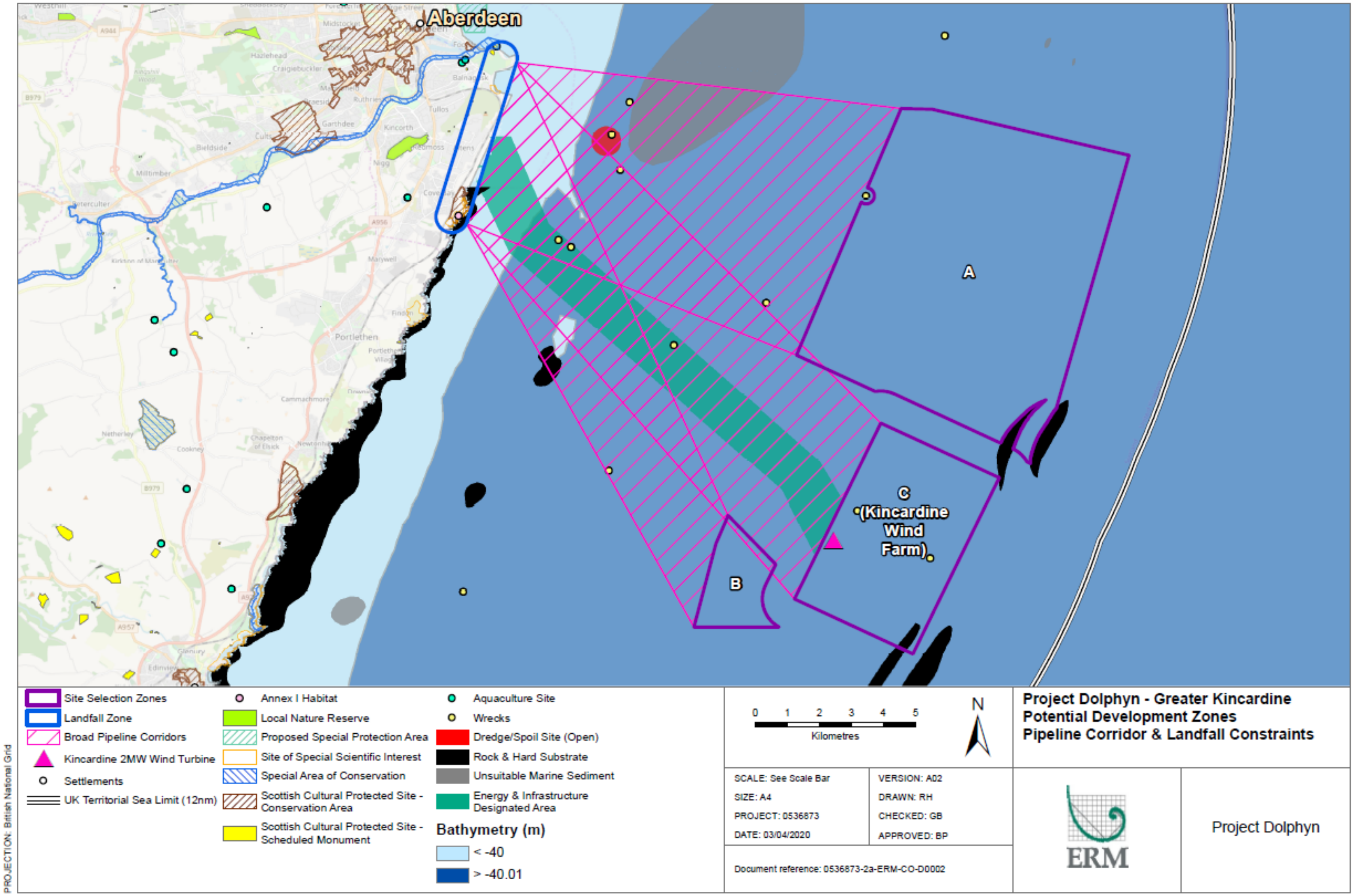
[11] also indicates that the development route is clear, with no other pipelines in the vicinity of these routes when the study was undertaken.

### *4.2.6 Selection of Preferred Development Site*

All three preferred development zones within the Greater Kincardine area (A, B and C) are viable for the Dolphyn Project. However, the option to co-locate the Project within the Kincardine Offshore Windfarm field was selected as the preferred development site for the following reasons:

- Initial assessment of the Kincardine field indicates a high-level of similarity between the Dolphyn and Kincardine projects, therefore proving that it is possible to avoid, mitigate and/or manage any potential impacts to the receiving environment during construct and operation of floating turbines at this location.
- The Kincardine site indicates technical feasibility of locating the Dolphyn floating unit, bringing a hydrogen pipeline back to shore, and connecting to appropriate onshore infrastructure.
- There is the opportunity to utilise existing project information from the Kincardine field and applying project learnings to Dolphyn.
- There is the opportunity to realise synergistic efficiencies with the Kincardine project during construction and operation of Dolphyn.

**Figure 4.5 BRAG Assessment & Preferred Development Zones – Greater Kincardine Area**



SOURCE: © OpenStreetMap (and) contributors, CC-BY-SA;
(Copyright Scottish Natural Heritage/Historic Environment Scotland) Contains Ordnance Survey data © Crown copyright and database right (2020); © British Geological Survey (2020); © Crown Estate Scotland 2020

Path: \\UKLONSV04\Data\Manchester\Confidential Projects\0536873 Dolphyn Project Phase 2.DC\9. WP4 - Consenting\GIS\MAPS\Site Selection Report\Greater_Kincardine_Areas_Constraints_A02.mxd

## 4.3 Onshore site selection

### *4.3.1 Approach*

### *4.3.1.1 Pipeline Landfall*

To support the identification of a suitable landfall for the hydrogen pipeline, the project team have completed a review of the most suitable landfall options. This included a review of the landfall options the Kincardine windfarm had investigated for their HV electrical cable which comes ashore south of Aberdeen and avoids busy shipping channels north of Aberdeen harbour.

Two key technical constraints were considered during the identification of suitable landfall options:

- Coastal geomorphology – avoiding hard rock and steeper cliffs and where possible avoiding gravel, heavily vegetated or dynamic (e.g. shifting sands) shores, to reduce pipeline installation costs.
- Distance of landfall to hydrogen off-taker - limiting the extent of onshore pipeline required, and hence the number of landowners (and potentially local authority jurisdictions) which are crossed, will also limit the number of difficult on-shore features such as road or river crossings.

The project team identified a number of technically feasible options for landfall within an approx. 5 km stretch of coastline south of Aberdeen harbour, from Nigg Bay to south of Cove Bay. The potential landfall zones are presented in Figure 4.7.

### *4.3.1.2 Onshore Pipeline*

A formal commercial arrangement with an offtake had not been finalised at this stage of the project, although a short list of high potential offtake options has been identified, with commercial discussions underway. A suitable representative location was identified by the project team to enable development of the project without prejudicing ongoing commercial discussions. The Aberdeen Hydrogen Centre re-fuelling station on Langdykes Road, in Cove (south Aberdeen), was taken as a suitable representative location for preliminary development purposes.

A preliminary study of routes for the onshore pipeline was undertaken looking at the likely stretch of potential coastline landfall to the Aberdeen Hydrogen Centre. The knowledge and experience of the Kincardine development are highly useful in understanding the potential feasibility of different pipeline routing options. A number of technically feasible pipeline routes have been identified providing confidence that a feasible pipeline route is available following announcement of the offtake locations.

All the route options identified avoid known Sites of Special Scientific Interest (SSSIs), although there is an SSSI (Cove Bay) approximately 500m south of route, designated for geological and biodiversity interest. The pipeline route options considered maintain their distance from residential and industrial premises, with deviations following the edge of the railway line through agricultural land. The pipeline route will be finalised considering a variety of factors including, location of offtake site, environmentally sensitive receptors, stakeholder input and consideration, land ownership and access.

### *4.3.1.3 Onshore facility*

In February 2020, Aberdeen City Council (ACC), Invest Aberdeen and Opportunity North East, commissioned the Aberdeen Energy Transition Zone (ETZ) Feasibility Report to review the potential to accommodate a major international energy transition zone within an area centred on the Bay of Nigg and land around Aberdeen South Harbour (i.e. the landfall and onshore area being considered for the Project). The ultimate aim of this study was to inform and influence Aberdeen's emerging Local Development Plan 2022, to ensure suitable land is identified for future energy transition developments. [12]

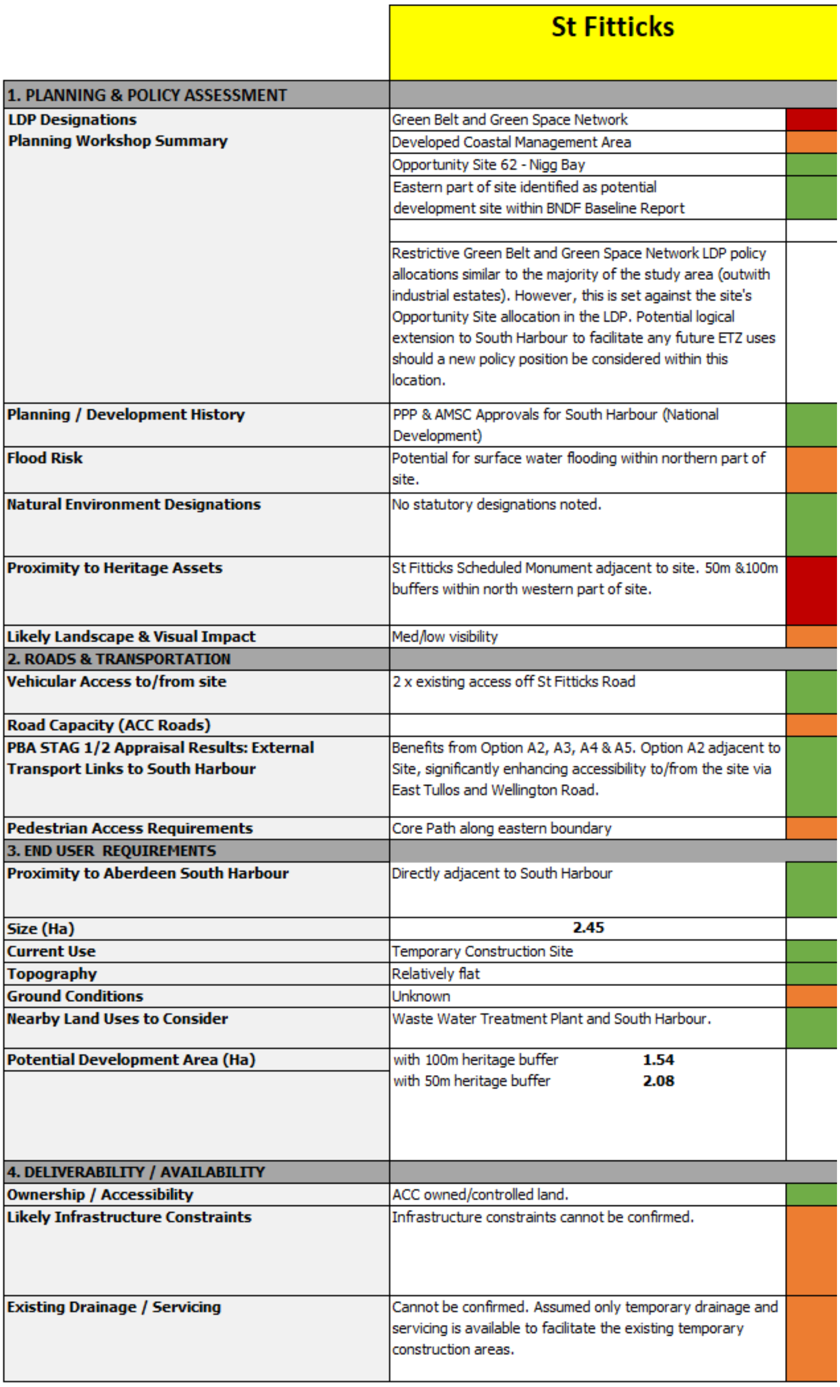
A comprehensive assessment of the suitability, accessibility and deliverability of sites identified by ACC was undertaken based on the following criteria:

- *Planning & Policy* – to consider planning policy implications and environmental constraints;
- *Roads, Transport and Other Infrastructure* – review of existing road infrastructure and potential new road provision/investment that could include site selection;
- *End User Requirement* – to consider operational requirement for land and proximity to the harbour etc.; and
- *Deliverability and Availability* – to consider ownership, infrastructure constraints and servicing amongst other issues.

Critically, site assessments were also influenced by commentary received during technical workshops with key stakeholders as this provided an extra level of insight not available when undertaking desktop reviews. [12]

An example of the criteria and data collected for the assessment is presented in Figure 4.6.

## Figure 4.6 Example of ETZ Feasibility Study Assessment Criteria & Data



| | **St Fitticks** | |
|---|---|---|
| **1. PLANNING & POLICY ASSESSMENT** | | |
| **LDP Designations**<br>**Planning Workshop Summary** | Green Belt and Green Space Network | 🟥 |
| | Developed Coastal Management Area | 🟧 |
| | Opportunity Site 62 - Nigg Bay | 🟩 |
| | Eastern part of site identified as potential development site within BNDF Baseline Report | 🟩 |
| | | |
| | Restrictive Green Belt and Green Space Network LDP policy allocations similar to the majority of the study area (outwith industrial estates). However, this is set against the site's Opportunity Site allocation in the LDP. Potential logical extension to South Harbour to facilitate any future ETZ uses should a new policy position be considered within this location. | |
| **Planning / Development History** | PPP & AMSC Approvals for South Harbour (National Development) | 🟩 |
| **Flood Risk** | Potential for surface water flooding within northern part of site. | 🟧 |
| **Natural Environment Designations** | No statutory designations noted. | 🟩 |
| **Proximity to Heritage Assets** | St Fitticks Scheduled Monument adjacent to site. 50m &100m buffers within north western part of site. | 🟥 |
| **Likely Landscape & Visual Impact** | Med/low visibility | 🟧 |
| **2. ROADS & TRANSPORTATION** | | |
| **Vehicular Access to/from site** | 2 x existing access off St Fitticks Road | 🟩 |
| **Road Capacity (ACC Roads)** | | 🟧 |
| **PBA STAG 1/2 Appraisal Results: External Transport Links to South Harbour** | Benefits from Option A2, A3, A4 & A5. Option A2 adjacent to Site, significantly enhancing accessibility to/from the site via East Tullos and Wellington Road. | 🟩 |
| **Pedestrian Access Requirements** | Core Path along eastern boundary | 🟧 |
| **3. END USER REQUIREMENTS** | | |
| **Proximity to Aberdeen South Harbour** | Directly adjacent to South Harbour | 🟩 |
| **Size (Ha)** | **2.45** | |
| **Current Use** | Temporary Construction Site | 🟩 |
| **Topography** | Relatively flat | 🟩 |
| **Ground Conditions** | Unknown | 🟧 |
| **Nearby Land Uses to Consider** | Waste Water Treatment Plant and South Harbour. | 🟩 |
| **Potential Development Area (Ha)** | with 100m heritage buffer **1.54**<br>with 50m heritage buffer **2.08** | |
| **4. DELIVERABILITY / AVAILABILITY** | | |
| **Ownership / Accessibility** | ACC owned/controlled land. | 🟩 |
| **Likely Infrastructure Constraints** | Infrastructure constraints cannot be confirmed. | 🟧 |
| **Existing Drainage / Servicing** | Cannot be confirmed. Assumed only temporary drainage and servicing is available to facilitate the existing temporary construction areas. | 🟧 |

*Reference: Aberdeen Energy Transition Zone (ETZ) Feasibility Report* [12]

The onshore site selection team for the Dolphyn Project used the sites considered by ACC within the ETZ Feasibility Report as the starting point to guide the selection of potential onshore facility sites for the Project. The Project requirements considered as part of this process included:

- Distance from residential areas;
- Prominence or visual exposure;
- Accessibility; and

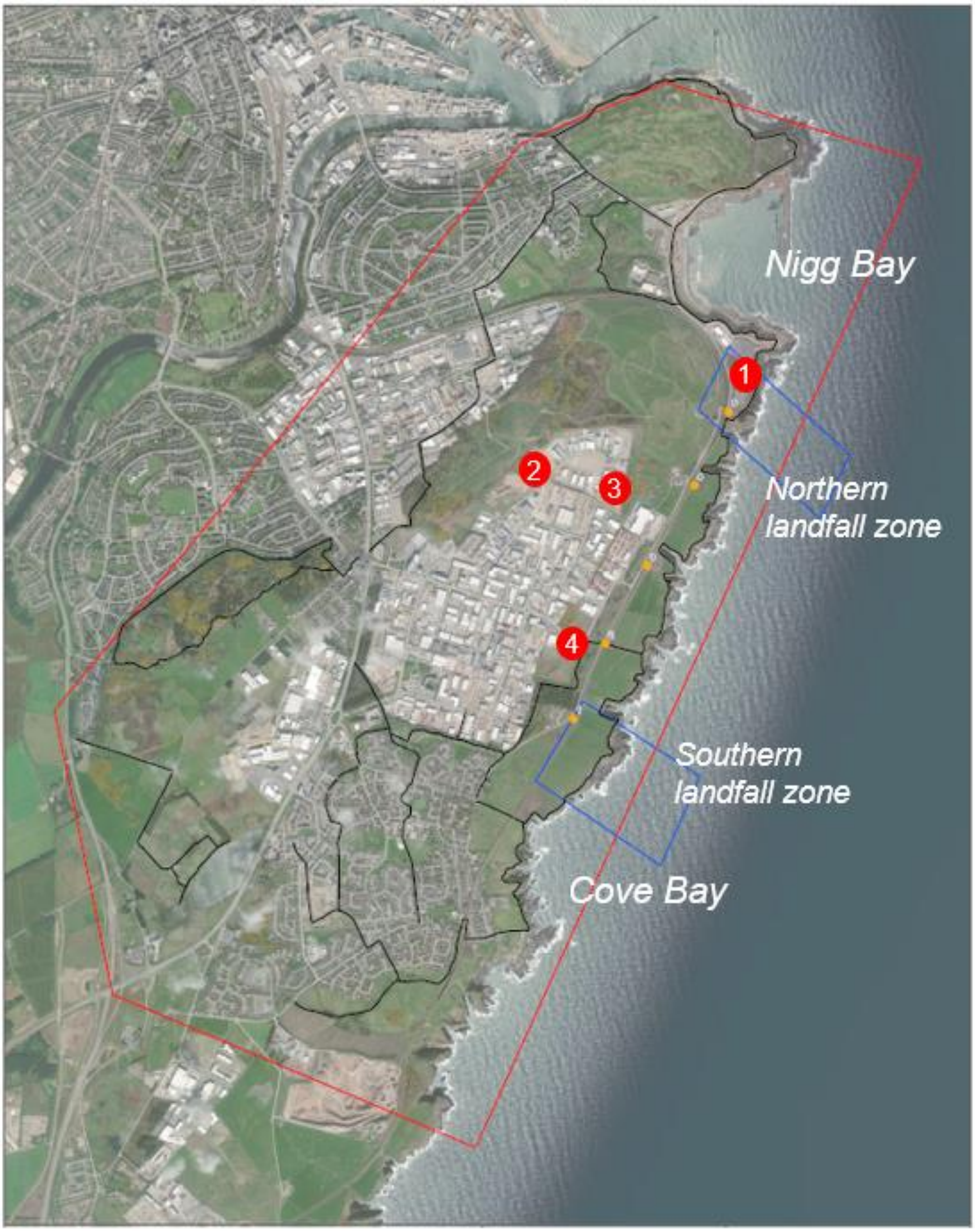
- Onshore pipeline corridor.

Based on these Project requirements, the following four sites were identified from the ETZ study with potential to accommodate the Project onshore facilities:

- Site 1 - Gregness (ETZ ref: Site 1c)
- Site 2 - Altens North / Peterseat Industrial Estate (ETZ ref: Site 2a)
- Site 3 - Altens North / Peterseat Industrial Estate (ETZ ref: Site 2a)
- Site 4 - West of Coast Road at Hareness Road (ETZ ref: Site 2d)

These sites are presented in Figure 4.7.

**Figure 4.7 Preliminary Feasibility Landfall Zones & Onshore Facility Sites**



*Source: ERM 2021*

### *4.3.2 Onshore Surveys Completed*

A number of preliminary surveys have been completed to gather additional information to inform the landfall and onshore facility site selection process. These onshore site surveys were impacted by COVID restrictions on travel and also social distancing. All surveys were conducted using visual inspection from publically accessible areas only, with a focus on minimising the risk of infection. All surveys have been successfully completed without safety incident.

The onshore definition of the project is at early feasibility stage, following announcement of the offtake agreement the onshore site and pipeline layout can be confirmed and taken forward for detailed analysis. These preliminary surveys focused on the following areas:

- 2.5 km stretch of coastline between Cove Bay and Nigg Bay
- Pre-identified northern and southern landfall survey zones
- Three potential onshore facility sites [12]

The landfall and onshore facility preliminary surveys included:

- A site visit in February 2021 completed by ERM to determine accessibility of the area for survey work and to gather photographs and high-level observations of the sites being considered.
- A site walkover in March 2021 completed by ERM/Arcus to review all current onshore site locations, and the two landfall zones, from a landscape and visual perspective.
- Landfall assessment survey completed in May 2021 to assess potential sites to bring the submarine pipeline from the proposed offshore development to onshore and continue onward routing inland to the selected location for the onshore hydrogen facility or connection point to a terrestrial system.

A selection of photographs from the preliminary surveys are presented in Figure 4.8.

**Figure 4.8 Photographs from the Preliminary Landfall & Onshore Facility Surveys**

*Source: ERM 2021*

### *4.3.3 Results*

The landfall zone selection and preliminary survey work conducted to date has confirmed the potential of the 2.5 km stretch of coastline south of Nigg Bay as being suitable for bringing the Project pipeline onshore.  However, detailed feasibility and engineering assessments will be required at the next stage of the Project to determine a technically feasible landfall site and pipeline route (near shore and onshore).

At this stage of the development process, the onshore site selection and preliminary survey work conducted to date has confirmed that three of the sites identified have potential to site the gas receiving facility and associated infrastructure.  This provides sufficient confidence that a technically feasible pipeline routing and onshore site exist.  The likely development risks and cost implications to the project are understood and have been taken forward into the development plan.  Following detailed feasibility and engineering assessments at the next stage of the Project a technically feasible site for the onshore facilities will be selected.

# 5. CONSENTING AND PERMITTING

## 5.1 Overview

ERM Dolphyn is a novel green hydrogen project and the consenting route is uncharted. A variety of consents will be required for the different components of the project. ERM has therefore sought the views of the Oil and Gas Authority (OGA), Crown Estate Scotland (CES) and Marine Scotland (MS) amongst others to confirm the consents required and establish who will be the lead consenting authority. The discussions with these authorities has informed the consenting approach developed. ERM are keen to work with regulatory bodies to understand and align ourselves fully with the innovations and evolutions ongoing within the low carbon regulatory landscape.

The consenting strategy for the Project has also been informed by discussions with legal firm Cameron McKenna Nabarro Olswang LLP, which has extensive experience of consenting offshore wind farm projects in Scottish Waters, including Kincardine Offshore Windfarm.

## 5.2 Consenting Strategy

### *5.2.1 Objectives*

The key objectives of the consenting strategy are:

- To gain required planning consent to develop, construct and operate the Project for both the offshore and onshore components;
- To leverage the proposed siting of the offshore wind turbine, electrolysis and desalination facility and hydrogen production unit (HPU) within the consented Kincardine offshore windfarm development (e.g. being able to utilise the existing Marine Licence); and
- To ultimately enable the commercial demonstrator unit to achieve first hydrogen by 2024.

In addition, it is intended the consenting strategy will meet the following objectives:

- To engage with regulatory and public stakeholders to obtain a “social licence to operate” for the novel, green hydrogen technology; and
- To develop a robust strategy that will provide a consenting pathway for future offshore, green hydrogen projects in Scotland within the current regulatory regime.

### *5.2.2 Project Components*

The Project has been split into three distinct components for consenting purposes:

- Offshore wind turbine, electrolysis and desalination facility and HPU;
- Offshore pipeline works; and
- Onshore components, including onshore pipeline.

The following sections describe the projects understanding of regulations and the proposed approach to consenting for each of the Project components.

### 5.2.3 Offshore Wind Turbine, Electrolysis & Desalination Facility and HPU

#### 5.2.3.1 Section 36 Consent

Consent under section 36 of the Electricity Act 1989 is required to construct or operate a generating station. The HPU will include an offshore wind turbine of rated capacity 10MW. It is the view of the project team that the wind turbine component of the HPU's should be considered a generating station and will require Section 36 Consent.

#### 5.2.3.2 Marine Licence

A Marine Licence is required for licensable marine activities, including depositing any substance on the seabed from a vessel and construction works.

A new Marine Licence, or a variation to the existing Marine Licence held by KOWL for the Kincardine offshore windfarm, will be required under the Marine (Scotland) Act 2010.

### 5.2.4 Offshore Pipeline Works

#### 5.2.4.1 Marine licence

A Marine Licence is required for licensable marine activities, including depositing any substance on the seabed from a vessel and construction works. A marine licence is required for construction of the pipeline under the Marine (Scotland) Act 2010.

Exemptions from a marine licence by virtue of Section D2 (oil and gas) in Part II of Schedule 5 to the Scotland Act 1998 [13] (c.46) have been considered and are found not to apply. This is because the gas to be transported is hydrogen and the works will be partially within controlled waters [14].

#### 5.2.4.2 Pipeline Works Authorisation (PWA)

Under Part 3 of the Petroleum Act 1998, a PWA is required for the construction and/or use of a “pipeline” in “controlled waters”. For these purposes, controlled waters means the territorial sea adjacent to the UK and the sea in any area designated under section 1(7) of the Continental Shelf Act 1964 [15].

The Energy Act 2008 defines pipelines as a “pipe or system of pipes (excluding a drain or sewer) for the conveyance of anything, together with all apparatus, works and services associated with the operation of such a pipe or system”. This includes pipelines used for the conveyance of hydrocarbons, water, chemicals, apparatus for the supply of energy for operations, hydraulic control lines or umbilicals, as well as services (for example, the provision of fuel or power).

Based on the wording of the Petroleum Act 1998 and the Energy Act 2008, it is the view of ERM that the subsea pipeline component of the Project is subject to the requirement for a PWA. The PWA would only apply as far as the mean low-water mark. Any development beyond that point would be subject to the onshore/terrestrial planning regime.

A PWA application will be made to the OGA in addition to a Marine Licence.

### *5.2.5 Onshore Components including Onshore Pipeline*

For laying of the pipeline onshore above the mean watermark, and for any other onshore components that may be required, planning permission will be sought from the relevant Local Planning Authority (Aberdeen City).

## 5.3 Process for Consenting

The Project has been screened against the requirements for an EIA under the Marine Works (Environmental Impact Assessment) (Scotland) Regulations 2017 (EIA Regulations).

Schedule 1 of the EIA Regulations identifies development types which require EIA in all cases. Schedule 2 identifies development types where, if the relevant threshold criteria are exceeded, further consideration is required (with reference to Schedule 3) in order to determine whether EIA is required.

An assessment of the Project against Schedule 1 does not indicate that the Project falls into any of the Schedule 1 categories. Therefore, the project does not fall under Schedule 1 of the EIA Regulations.

Schedule 2, Class 3, of the Regulations includes the following project type, where hub height of any turbine or height of any other structure exceeds 15 metres. The Dolphyn Project is considered to fall into this category. If development within this category is considered likely to cause ‘significant’ environmental effects, an EIA will be required in support of a future Marine Licence and/or Section 36 consent.

The requirement for an EIA to be undertaken for the Project is currently being formally considered in liaison with the relevant regulatory authorities.

The Offshore EIA Scoping Report has been drafted, ready for submission to the regulatory authorities when a formal EIA Screening Decision is received from MS.

## 5.4 Engagement Activities

The following engagement activities have been completed to date for the consenting and permitting work stream:

- Written submission of Project consenting strategy to OGA to coordinate with other relevant regulatory stakeholders.
- Project presentation of proposed consenting strategy for regulatory consideration to CES, OGA and HSE.
- Call with Marine Scotland (MS) to provide update on the project, discuss the proposed consenting roadmap and present our initial thoughts on site selection.
- MS identified as lead authority for the offshore component
- Formal EIA Screening Request issued to Marine Scotland for comment.

The regulatory authorities have provide positive feedback on the Project to date and have indicated a positive approach to enable the production of green hydrogen in Scotland, taking a pragmatic approach to consenting within the existing regulatory regime.

The Project team will continue engagement with the regulators over the coming months, as the Project moves to the next phase, to keep them updated on relevant Project activities and to maintain the relationships we have established.

## 5.5 Overview of Survey Works Completed

A programme of onshore ecology surveys have safely been conducted over the past 6 months with the implementation of stringent Covid-19 management and mitigation measures. The safety of personnel is critical to the successful delivery of the Dolphyn project. ERM's corporate HSE team implement a series of enhanced safety procurements for all site activities during COVID, in addition to the national rules and guidance.

The project team implemented measures to safely manage travel/logistics, overnight stays, onsite welfare and potential interaction with members of the public. All surveys were completed in line with national, local, and corporate requirements and good practice. All surveys have been completed safely with no injuries, near misses, or transmissions of COVID reported.

The following surveys have been undertaken to gather data for the future assessment of the onshore facilities and to take advantage of the 2021 survey season window:

- Extended Phase 1 Habitat surveys completed for potential landfall and onshore Project locations from public rights of way and review of publically available information.
- Wintering bird surveys from public rights of way undertaken across 3 visits between February and March 2021
- Breeding bird surveys undertaken from public rights of way across 4 visits between April – June 2021

Surveys undertaken so far have been to identify any constraints at the proposed onshore Project locations related to protected habitats or species, and to identify any areas used by species, which may be linked to a nearby Natura 2000 sites or other, designated sites.

More detailed habitat, flora and protected species surveys may be required to confirm ecological constraints associated with the final selected onshore site, depending on the level of survey for that area that has been possible from public rights of way.

A selection of photographs from the ecology surveys are presented in Figure 5.1.

**Figure 5.1 Example Photographs from Bird Surveys**

*Source: ERM 2021*

## 5.6 Overview of Expected Future Survey Works

The Offshore EIA Scoping Report has been prepared for submission and discussed with the regulatory authorities. The focus of this discussion will be to agree on the baseline data required to complete the assessment of the construction and operation of the offshore wind turbine, electrolysis and desalination facility and HPU, and offshore pipeline works.

In order to prepare for the next phase of the project and to minimise lead-in times for the commissioning of likely marine survey work required, the Project team has already developed a marine survey plan and scopes of work for the environmental, geophysical, and geotechnical surveys. The Project team will agree the data requirements and therefore survey extents and scopes with Marine Scotland prior to mobilisation.

The baseline data required for assessment of the onshore project components will be agreed with the Aberdeen City Council and their statutory consultees as early as possible in the next phase of the project. Although as previously noted, data collection has already commenced for birds and habitats to make use of the 2021 survey season.

## 5.7 Consenting Challenges & Uncertainties

The ERM Dolphyn concept is a novel green hydrogen project that will require a variety of consents for the different components. The consenting route is uncharted and the existing regulatory regime is not entirely fit-for-purpose for this kind of technology.

Although a consenting strategy has been devised within the existing regulatory regime, the Project team is still seeking formal agreement on the requirements for the project.

Project engagement with the regulators (OGA, CES and MS) has been proactive and positive to date, and the Project team will continue to work collaboratively to navigate the regulatory system in the most pragmatic way possible. The pragmatic approach from all parties provides confidence in the successful consenting of the commercial scale unit.

This process will likely set the precedent for the consenting of offshore green hydrogen projects in Scotland within the existing regulatory regime.

# 6. SUPPLY CHAIN ENGAGEMENT

The development of the Dolphyn project requires a complex and proactive approach to engagement with the supply chain. In addition to developing novel technology for its first of a kind offshore hydrogen production system, the project team are keen to work with potential suppliers to understand future development pathways and oportunities, explore constraints to rapid scale up, proactively identify options for optimising future operations, as well as working with offtakers to promote alignment across the hydrogen value chain. A roadmap of the key philosophies for project engagement is shown in Figure 6.1.

**Figure 6.1 Roadmap of Drivers to Supply Chain Engagement**

## 6.1 Supply Chain Readiness

To inform the development of Dolphyn and minimise the risk to the project, it has been important that potential suppliers are brought on the development journey for Dolphyn. Key objectives for working with the supply chain are to:

- provide best value to ERM in development of the Commercial demonstrator project;
- inform future developments of Dolphyn including 100-300MW fields and GW scale fields;
- be structured and provide clarity of the approach taken to engage and establish a supply chain;
- act with business integrity by operating an open and fair approach to developing a supply chain;
- support development of cost estimates in the financial models; and

- deliver compliance with the Industry Code of Practice whereby any tenders issued are to suitable contractors for the major execution and supply elements of the scope.

In line with the procurement strategy for Phase 2, the project has taken an honest and open approach to engaging the supply chain to keep them informed about project developments and to be clear around expectations on programme and opportunities. The key objective to date has been to identify suppliers with interest and capability to provide support for Dolphyn's long lead items. This engagement was initially focussed on the development of the 2MW prototype unit, before being expanded to additionally consider the development of the 10MW commercial scale unit in line with the accelerated development timeline.

### 6.2 Supply chain engagement

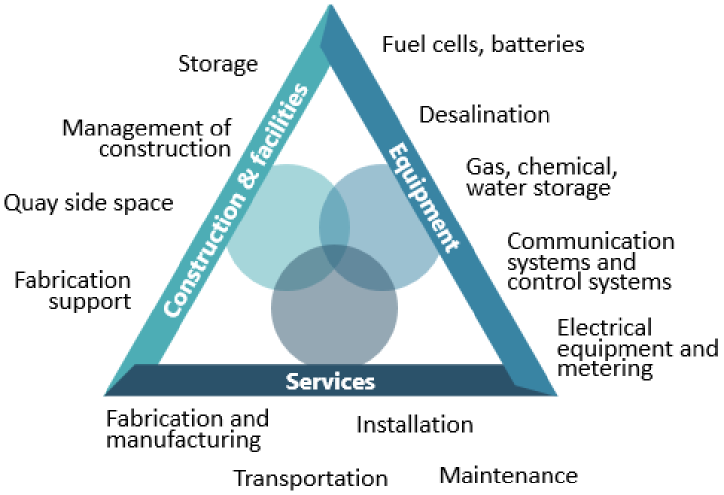
The project to date has encouraged interest in Dolphyn by engaging directly with potential suppliers as well as taking opportunities to share information about the project within existing networks within the energy sector.

To date, engagement has:

- established direct lines of communication and key contacts with suppliers;
- provided identification of suppliers with existing capabilities to manufacture required equipment and supply required services;
- increased confidence and validity of cost estimates for the ERM financial modelling for both 2MW and 10MW scale project;
- provided insight into technical specialist knowledge of scalability for the commercial scale development;
- insight into opportunities for improvement around fabrication and standardisation potential for commercial scale development; and
- identified the details technical information that will be needed in Phase 2b to update financial modelling and arrange procurement.

The project has been encouraged by the willingness and reciprocated transparency when engaging with a wide range of suppliers from the UK, Europe and globally. Key areas of focus are outlined in Figure 6.2. Discussions have been open and honest and the project has made significant effort to remove the feeling of conversations being transactional, with initial engagement aimed at relationship building and finding areas of common innovation ambition.

**Figure 6.2 High Level Areas for Supply Chain Contribution**



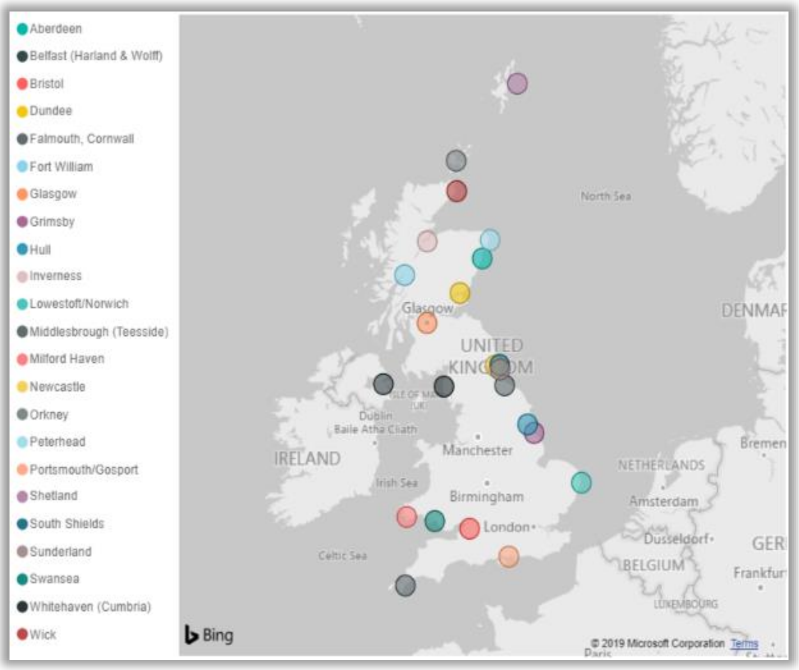
## 6.3 Statement of Intent

ERM Dolphyn is an innovation project and encourages the project and supply chain alike to consider alternative technology and proposals that deliver the required service scope and meet the needs of the project. The Dolphyn contracting strategy will seek to identify where possible opportunity for alternative or new products, process and contracting methodologies to be proposed.

As the project continues to develop, the Dolphyn project team will continue to develop relationships with contractors and suppliers who follow procurement best practices and are aligned to appropriate business codes of conducts through their own activities and the management of their own suppliers and subcontractors. Through the development of these relationships the project is aligning its development plan with individual technology provider’s innovation and development pathways.

The project understands that as a developer, it has a role to play in being transparent about its procurement needs and where possible, supporting the supply chain to understand aspirations for future development. Where possible, the project is seeking to emphasis UK content in its supply chain acknowledging the large opportunity the UK has to grow a world-class manufacturing and supply chain base to meet the challenges and demands of the rapidly growing offshore wind sector, Figure 6.3 shows the potential UK Ports benefitting from the development of an offshore hydrogen sector.

**Figure 6.3 UK Ports Potentially Benefitting from Onshore Floating Wind for Hydrogen**



The project is particularly keen to engage with those suppliers who are actively seeking to contribute to the UK carbon targets as well as being able to demonstrate a contribution to sustainable development and are economically, environmentally and socially responsible.

ERM acknowledges the importance of contributing to UK government targets and assisting to align with existing values and visions of stakeholders in the renewable energy sector, working collaboratively. These areas of focus are driven by ERM's core strategy to promote low carbon technologies, as well as its existing robust procurement management systems and have featured specifically in the development of the ERM Dolphyn procurement pre-screening criteria.

## 6.4 Completed Activities

### *6.4.1 Supplier Management Register*

To date, the project has recorded more than 150 equipment providers, 200 Service providers and more than 30 manufacturing facilities with capacity to support the project.

The project has developed an extensive Supplier Management Register that has been essential to understanding the supply chain readiness for Dolphyn. This register forms the project database of supply chain contacts as well as keeping a record of engagement and screening activity progress. The database also forms the basis for monitoring the evolving supply chain and identifying potential project risks.

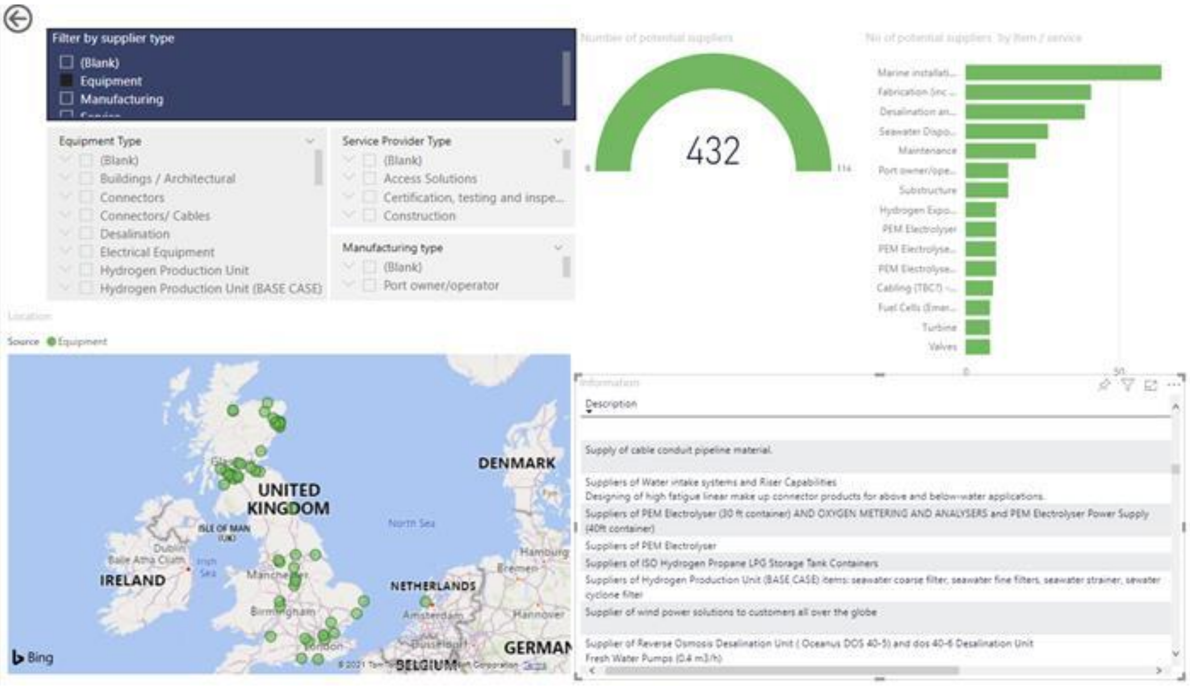
The register will continue to be used for future project phases and to date has provided:

- a database of supply chain contacts and relevant experiences;

- shared visibility of all engagement activities and actions taken when engaging supply chain stakeholders;
- an audit trail and internal control of information shared and obtained from the supply chain;
- a mechanism to record and track progress of suppliers through the procurement phases (including record of pre-qualification checklist completion); and
- a mechanism to identify and record any evolving risks.

The register will continue to be maintained by the supply chain manager and engineering teams. Shared visibility of the register across the project team has provided an opportunity to record key questions and information to build a picture of information required to support both understanding of Dolphyn requirements and the interests of the supply chain.

**Figure 6.4 ERM Dolphyn Supply Chain Dashboard Overview (anonymised)**



| Description |
|---|
| Supply of cable conduit pipeline material. |
| Suppliers of Water intake systems and Riser Capabilities<br>Designing of high fatigue linear make up connector products for above and below-water applications. |
| Suppliers of PEM Electrolyser (30 ft container) AND OXYGEN METERING AND ANALYSERS and PEM Electrolyser Power Supply (40ft container) |
| Suppliers of PEM Electrolyser |
| Suppliers of ISO Hydrogen Propane LPG Storage Tank Containers |
| Suppliers of Hydrogen Production Unit (BASE CASE) items: seawater coarse filter, seawater fine filters, seawater strainer, sewater cyclone filter |
| Supplier of wind power solutions to customers all over the globe |
| Supplier of Reverse Osmosis Desalination Unit ( Oceanus DOS 40-5) and dos 40-6 Desalination Unit<br>Fresh Water Pumps (0.4 m3/h) |

### 6.4.2 *Maintaining Contact through COVID*

In March 2021 as part of planned activities, the project undertook a supply chain dedicated webinar with open invitation to a range of stakeholders. The event was advertised directly by project Dolphyn to the existing supply chain database as well as shared with members by key supply chain organisations, such as the DeepWind Supply Chain Cluster.

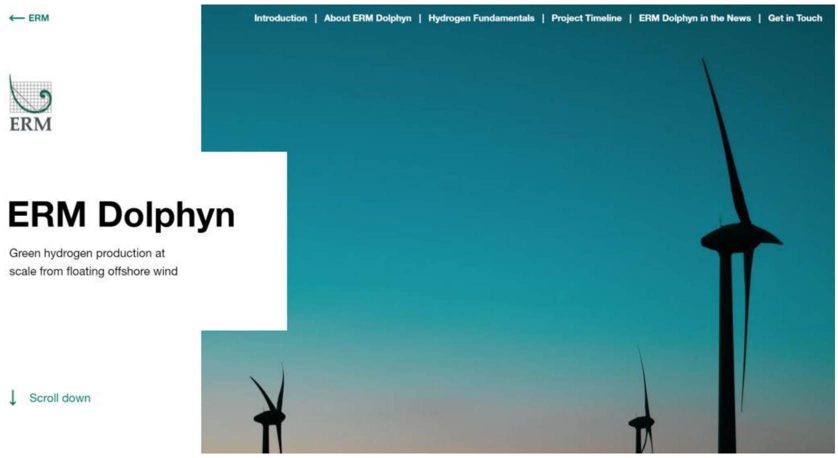
The webinar was successful with over +120 attendees and good feedback from these attendees. Approximately 50 conversations following this with suppliers took place between March and May with a further number of email exchanges and register of interest to continue receiving project information.

The webinar took attendees through the ERM Dolphyn concept, an overview of the design, the proposed project development timeline and procurement needs and how suppliers can get in contact with the project.

### *6.4.3 ERM Dolphyn project sub-site*

A website for the Dolphyn project was launched in 2020 (www.ermdolphyn.erm.com) and provides key information relating to the concept and development timeline. The site has also been cited in news articles and other media and has facilitated a clear line of communication for stakeholders including suppliers to contact the project; directing visitors to reach out to the connect_ermdolphyn@erm.com inbox. The project will continue to utilise this platform to share information about developments and opportunities to support and connect with the project.

**Figure 6.5 ERM Dolphyn Engagement Site**



ERM Dolphyn

Green hydrogen production at scale from floating offshore wind

Over a 3 month period between March 2021 and May 2021, the webpage saw over 2,000 page views with an average of 25 page views per day and visitors spending on average 2 minutes and 10 seconds looking at the website content.

## 6.5 Key findings

Engagement with suppliers of equipment and services to date has proven extremely useful to the project. Based on these discussions and coupled with the work undertaken by the engineering teams, at this stage there has not presented any critical risk of supply for the major components and services (Tier 1) to support development of the ERM Dolphyn 10WM unit.

Where potential modifications to existing technology or scaling of components has been considered, these have been found to be within the capability of known suppliers.

The project has also considered future scale development of Dolphyn in the late 2020 and early 2030’s and the risks to the project of pressures on the supply chain from what is considered to be a very busy period of development for offshore wind.

A well-understood limitation in the current UK supply chain is the current limitation in availability of quayside space with required water depths for installation (Tier 2 supply). ERM is keen to work to explore solutions for optimising constructability at scale in the UK.

## 6.6 Maintaining Communication

A large number of potential suppliers have been identified and engaged during Phases 1 and 2. A key objective for the project is to promote ongoing engagement and communication with these suppliers. There are a variety of benefits to both project Dolphyn and potential suppliers by maintaining regular lines of communication, including:

- keep potential suppliers up to date with tender timeline to facilitate preparedness for the tendering process;
- align technology development pathways;
- optimise opportunities for accelerated development, testing, and deployment;
- provide suppliers with early insight of critical requirements;
- align preparation for rapid scale up of deployment;
- identify potential risks and support their mitigation (e.g. constructability); and
- stimulate innovation in the design and project delivery.

## 7. FINANCIAL MODELLING

Detailed bottom up financial modelling was undertaken in order to develop a detailed understanding of lifetime costs associated with the project, the potential for these costs to reduce over time, and the revenue support that may be required for accelerated development to large scale.

This section summarises the financial modelling aims and process, key assumptions and sources, and describes the key results and implications for the project and the hydrogen sector more widely.

The Commercial Development Plan for ERM Dolphyn targets a rapid move to at-scale deployment, while incorporating learnings from the project and from the sector more widely. Reflecting this, the project team has produced four financial models in order to further investigate and understand the lifetime cost reduction pathway for the technology:

- “10MW Model” – Detailed financial model of a single 10MW commercial demonstrator, including detailed cost modelling and Monte Carlo analysis. The model assumes commercial operation in summer 2024, a single 10MW WTG, and 20 year lifespan.
- “100MW Model” – High level financial modelling of an array of 10 WTGs, each of 10MW installed capacity, assuming commercial operation in summer 2028 and a 20-year lifespan. This model demonstrates the impact of cost savings, learnings and design improvements expected towards the end of this decade on ERM Dolphyn’s development pipeline of 100-300MW scale projects.
- “GW Model with 10MW WTGs” – A full-scale commercial stage project, involving an offshore hydrogen wind farm comprised of an array of 10MW WTGs. Commercial operation is assumed in 2032 and a 30-year lifetime was assumed. This model demonstrates the potential for significant cost savings by the early 2030s, with the bulk rollout of hydrogen production enabling large-scale decarbonisation of industry and transport applications in particular.
- “GW Model with 15MW WTGs” – A full-scale commercial stage project, involving an offshore hydrogen wind farm comprised of 15MW WTGs. Commercial operation is assumed in 2040 and a 30-year lifetime was assumed. This project demonstrates the potential for significant cost savings as economies of scale and industry learnings impact project cost and performance.

The models were built with sufficient flexibility to investigate how lifetime costs might change under a number of development scenarios. The financial model is a live tool used to accurately reflect the latest data in a rapidly evolving sector. As the design work and supplier engagement for the project is ongoing, a cut-off date of 25 June 2021 was used when developing the costs presented in this report.

The financial modelling incorporates detailed bottom-up cost estimates produced by key equipment manufacturers and suppliers, including ODE, Tractebel, Vestas, PPI, Doosan and NEL. ERM has sense checked and supplemented these detailed cost estimates based on its own analysis and database of hydrogen production costs, as well as benchmarking with wider industry sources.

As significant cost and performance improvements to the concept are expected moving forward, ERM has produced a “Targeted LCOH Model” based on industry benchmarks, supplemented by specific site and project data for the 10MW commercial demonstrator. This analysis will be used in the next phase of the project to inform and manage specific cost reduction and performance improvement objectives for each element of the project, with the aim of ensuring the hydrogen produced by the project is within the range indicated to potential offtakers and commensurate with industry benchmarks.

## 7.1 ERM Dolphyn Commercial Scale Demonstrator (“10MW Model”)

ERM has undertaken detailed bottom-up financial modelling of the first 10MW commercial demonstrator project to be built. The model includes detailed cost estimates for key equipment items, as well as fabrication, installation, O&M, and decommissioning. These estimates were produced by the design teams working on the project, supplemented with quotes from key suppliers. In particular ODE, Tractebel, PPI, Doosan and NEL all made important contributions to the cost estimates. ERM sense checked and supplemented these detailed cost estimates using its proprietary database of hydrogen production costs, as well as benchmarking with wider industry sources.

The model was produced assuming commercial operation in summer 2024 and a 20-year lifespan. In reality there may be potential to extend the lifespan making this is a conservative rather than optimistic assumption.

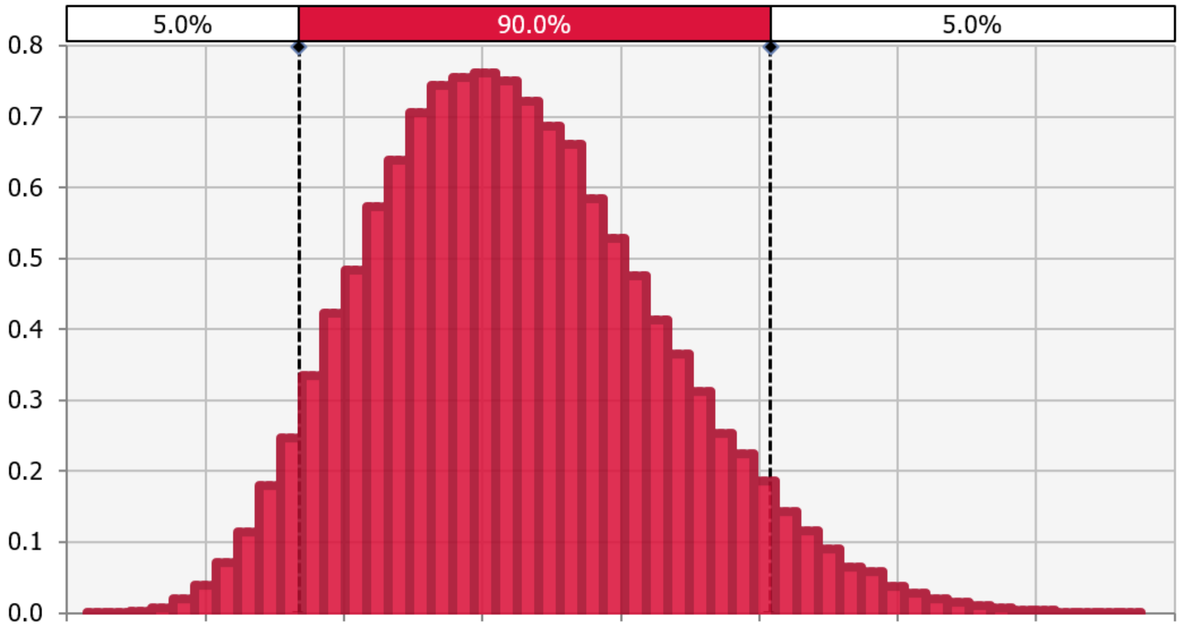
Based on areas of potential cost savings identified, targets for Capex and Opex reductions have been set and included within a project Balanced Score Card (BSC) which the project, including its suppliers, will work to in the next phase. The achievement of these target cost savings and targeted performance improvements, would result in a target LCOH (before any revenue support) and including costs associated with onshore reception facilities, at a level of interest to potential offtakers. This cost relates specifically to the first unit to be built and will reduce significantly when producing multiple units for a commercial field development.

As the mechanism and level of government support for early stage hydrogen production projects like ERM Dolphyn is not yet known, ERM undertook analysis of the impact of different levels of revenue support on both the current and targeted LCOH for the 10MW commercial demonstrator. The net impact on the target LCOH, after revenue support is applied, indicates that the net cost of hydrogen produced by the project would be in a range of interest to potential offtakers. This observation is supported by the positive discussions ERM has had with potential offtakers as well as by publically available information on hydrogen procurement prices, e.g. a hydrogen target price of £6.15 for the Aberdeen Hydrogen Hub [16].

As would be expected for this stage of the project, many of the financial modelling inputs have uncertainty associated with them. In order to analyse and understand the key drivers of the project lifetime costs and implied cost of hydrogen, Monte Carlo analysis was undertaken in addition to the basecase financial modelling. Probability distributions were applied to the modelling inputs and then thousands of simulations were run in order to understand the potential range of the key outcomes of the financial model, and the likelihood that these might occur.

The results of the Monte Carlo simulation are summarised in Figure 7.1 below, which demonstrates the potential variation of the target LCOH as the inputs vary.

**Figure 7.1 Target LCOH (10MW Model)**



As can be seen from Figure 7.1, the current estimate for the target LCOH is slightly higher than industry benchmarks, which reflects a number of factors:

- This is a single WTG project, so does not benefit from economies of scale. As ERM Dolphyn proceeds through the Commercial Development plan and larger scale projects become operational in the second half of this decade, significant economies of scale are expected to arise, reducing both Capex and Opex.
- The project includes bespoke solutions, produced specifically for this project, and so with relatively high production and development costs. As the key equipment manufacturers move to serialised manufacture at scale, significant cost savings are expected to develop. This is particularly relevant for the floating platform.
- The 10MW project size reflects feedback from potential investors and other stakeholders, indicating the importance of rapid scale-up of the solution; however components at scale are not yet available for some emerging system technologies. As the hydrogen supply chain develops and components scale up in size, significant cost reductions are expected.
- The project site has been chosen from a variety of technical and commercial factors including proximity to shore and ease of development, rather than optimisation of cost of production and available wind resource profile. The larger commercial projects will be located on sites that have been selected focussed on commercial viability.
- The project is currently over-engineered with significant contingency included in many systems. At least 24 areas with potential for significant cost savings

and performance improvement have been identified, and these will be focussed on in the next phase of design work, in order to optimise the lifecycle cost. In particular the following areas are expected to yield significant cost savings:

  - Optimisation of the design to remove duplication, reduce costs and optimise performance, as explained in Section 2.9.
  - Optimisation of the Opex, in particular through use of labour resource and vessels for maintenance of multiple systems, through remote monitoring and control systems, and through a design approach focussed on reliability and availability.
  - Optimisation of the construction, installation and commissioning process, through engagement with local resources and a coordinated approach across all equipment items.
  - Improvements in hydrogen production, for example through reduction in parasitic load through design development.
- The opportunities to optimise the project are discussed further in Sections 2.9 and 3.5.

During the next phase, the ERM Dolphyn team will focus on the areas of potential cost savings identified in order to optimise the design and realise the associated benefits.

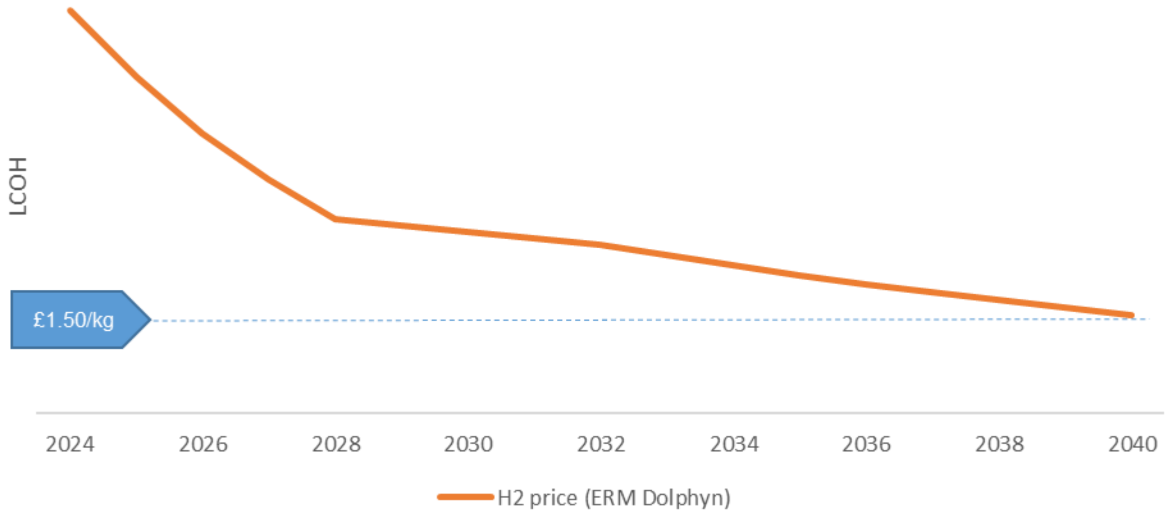
## 7.2 ERM Dolphyn Cost Reductions with Scale

The Commercial Development Plan for ERM Dolphyn targets a rapid move to at-scale deployment, while incorporating learnings from the project and from the sector more widely. Reflecting this, ERM produced four financial models in order to further investigate and understand the lifetime cost reduction pathway for the technology.

In order to derive the future costs associated with each project, the detailed bottom-up cost estimates for the 10MW model have been adjusted to take account of economies of scale and learning rates from comparable industries, with the resulting cost estimates then sense checked with suppliers and other industry experts. Generic offshore wind site information has been used in order to derive benchmark site-specific assumptions such as capacity factor and distance from shore.

The targeted cost reduction over time can be seen in Figure 7.2 below.

**Figure 7.2 Targeted Hydrogen Long Term Cost Trend**



As can be seen from Figure 7.2, reducing Capex and Opex, improving equipment performance, and economies of scale, all act to reduce costs significantly over time for ERM Dolphyn projects. This analysis has been sense checked against industry studies [17].

By 2040, hydrogen at a price of around £1.50/kg would be available for bulk scale production from ERM Dolphyn projects, enabling a significant contribution to large-scale decarbonisation of transport, industry and heating, both domestically and internationally.

# 8. DEVELOPMENT PLAN

## 8.1 Overview

The Commercial Development Plan for ERM Dolphyn targets a rapid and efficient move to at-scale deployment. The plan has been developed incorporating feedback from potential investors and offtakers, which been extremely positive. A phased approach to build-out will enable learnings from the project and from the sector more widely to be incorporated to reduce costs and optimise performance.

The Commercial Development Plan's assumptions align with the UK Government's objectives on decarbonisation and the development of a hydrogen economy, enabling ERM Dolphyn to be a key enabler of these national objectives.

Key features of the Commercial Development Plan are summarised below:

**Timeline to market** – A phased approach to commercial deployment has been developed, with each step adding to learnings and reducing risk. Initially, a 10MW commercial scale demonstrator will be developed, targeting commercial operation from 2024. FEED work for this project will be undertaken concurrently with development work on multiple fields at 100-300MW scale, for which deployment is targeted in the late 2020s onwards. Deployment of GW scale commercial projects will follow from the early 2030s. Moving quickly to at-scale production, while incorporating learnings from earlier phases, will assist in reducing costs to levels commensurate with fossil fuel counterfactuals, once externalities are priced in, as discussed in Section 6.1. The timeline to market is discussed further in Section 8.2.

**Routes to market** - The ERM Dolphyn system will produce high purity hydrogen suitable for direct use in a variety of applications including transport (i.e. fuel cells). This means there are a number of offtake options, and ERM is in advanced discussions with a range of potential offtakers with very encouraging results. A number of offtake options are being progressed at this stage for the 10MW Commercial Demonstrator including, for deployment directly into the gas network and supply to a major multinational energy company. Under the network supply option, hydrogen would be blended into the low pressure gas network at the Aberdeen South Pressure Reduction Station situated close to the point at which the hydrogen lands. Hydrogen could also be provided for a variety of purposes, including transport for a major multinational energy company. As ERM Dolphyn moves to larger projects, at-scale offtake options include injection or blending into the National Gas Transmission system or injection into lower pressure 100% hydrogen pipelines linking to industrial clusters for a wide variety of decarbonisation applications. Such a route to market would enable ERM Dolphyn to be a key facilitator of decarbonisation of multiple sectors and applications. The route to market for the 10MW Commercial Demonstrator, as well as larger scale projects is discussed further in Section 8.3.

**Supply chain engagement** – ERM will continue to engage with the supply chain actively, in order to line up long-lead items, protect availability and commercial competition, and incorporate learnings and insights into the design and the cost estimates. For a full description of activities undertaken so far and the supply chain engagement strategy, please see Section 6.

**Remaining technical, commercial and financial challenges and opportunities** – During the next phase of the project, work will be undertaken to overcome the remaining technical, commercial and financing challenges. Public funding will be critical to achieve this, as discussed in 6.1. The areas of focus are discussed further in Section 8.4, 2.9 and 3.5.

Further detail is provided in the following sections.

## 8.2 Timeline to Market

Moving quickly to at-scale production, while incorporating learnings from earlier phases, and from the wider industry, will be critical to achieve cost reductions. As a result, ERM has developed an accelerated timeline to market, in conjunction with our partners and suppliers, bringing decarbonisation benefits more quickly to offtakers and to the UK as a whole.

The ERM Dolphyn project accelerated route to scale is summarised in Figure 8.1 below.

**Figure 8.1 ERM Dolphyn Route to Scale**

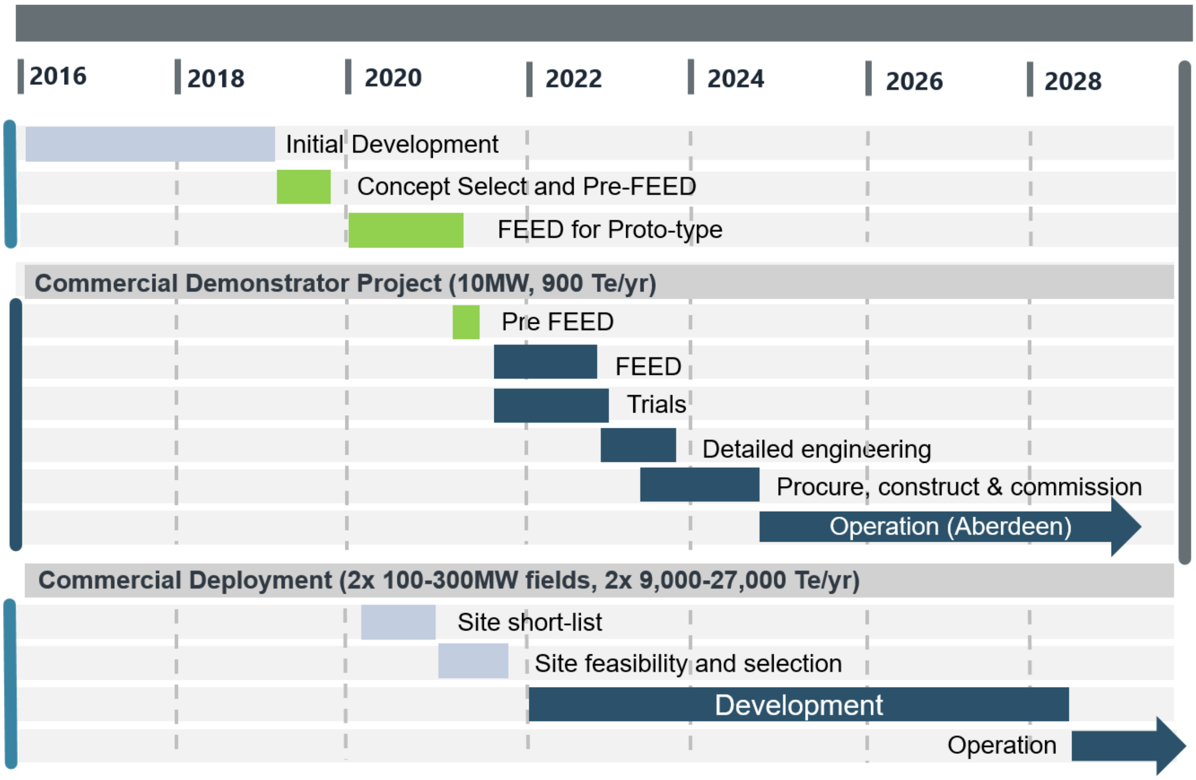
| | Operational from | Location | Hydrogen production rate (tonnes/yr) | Development status |
|---|---|---|---|---|
| **Small scale hydrogen performance demonstration trials** | 2022 | UK (near shore) | n/a – short duration performance trials | Project defined |
| **Commercial scale demonstrator unit (10MW)** | 2024 | Aberdeen | 900 | Project defined |
| **Deployment of multiple commercial fields 100-300 MW** | Late 2020s onwards | UK (North Sea and Celtic Sea) and global locations | 9,000 – 27,000 | Pipeline of sites, 2 at advance stage of development |
| **GW scale large commercial projects** | Early 2030s onwards | UK (North Sea and Celtic Sea), other sites globally | ~360,000 | Site identification underway |

As can be seen from Figure 8.1, a phased approach to commercial development is envisaged, with each step adding to learnings, and reducing risk and cost:

- **10MW Commercial scale demonstrator**, operational from 2024. A preferred site has been identified and pre-FEED activities undertaken.
- **Deployment of multiple commercial scale fields at 100-300MW scale** in the late 2020s onwards, focussing on the North Sea and Celtic Sea locations, in addition to options globally. ERM is currently in advanced discussion with potential partners and undergoing pre-feasibility stage analysis of potential sites, with two high priority sites identified so far.
- **Deployment of GW scale commercial projects** from the early 2030s onwards, with potential locations including the North Sea and Celtic Sea as well as globally. Site identification is currently underway.

Figure 8.2 below shows the timeline for development and deployment of the 10MW Commercial Demonstrator project and larger commercial scale (100-300MW) projects.

**Figure 8.2 Gantt for Commercial Demonstrator and Early 'At Scale' Projects**



The projected timescales for ERM Dolphyn are based on availability of a bulk scale market for hydrogen emerging in the UK, aligned with the UK Government's energy strategy. To reach the levels of production envisaged we have assumed that the hydrogen produced can be blended (up to 20% by 2024) or injected directly (at 100% by the early 2030s) into local distribution or national transmission networks. Options to export hydrogen at scale to Europe, either as ammonia, methanol, liquid hydrogen or LOHC are also being explored.

## 8.3 Routes to Market

### *8.3.1 Routes to Market for Commercial Demonstrator*

The UK Government is currently reviewing a number of business models for hydrogen and has been receiving feedback from industry on these. The Government is understood to be keen to put in place the right model that will provide the necessary incentives for investment in hydrogen production, and one of the favoured approaches seems to be a contract for difference (CfD) arrangement that has proved so successful for developing the offshore wind industry in the UK. A BEIS expert group is continuing to assess potential models and ERM has input to the process via the Decarbonised Gas Alliance Group. A decision on the business model to be deployed is to be announced early in 2022. In the meantime, ERM has been developing routes to market with offtakers pending confirmation of the form and level of hydrogen production support.

The location of the 10MW commercial demonstrator project in the Aberdeen region offers significant benefits in terms of hydrogen offtake options. The region has been an early mover in the development of the nascent hydrogen economy [18], recognising the economic benefits of leveraging skills and infrastructure associated with the oil and gas sector and offshore wind. Hydrogen is already used for transportation applications in the city of Aberdeen and there are longer term plans to develop other opportunities, including linking the city with the Grangemouth industrial cluster and exporting hydrogen at bulk scale to both domestic and international markets.

The ERM Dolphyn system will produce essentially pure hydrogen suitable for direct use for transport (fuel cell) applications. This will be piped directly to shore and will not be co-mingled with natural gas to avoid any contamination. This means there are a high number of offtake options.

In order to optimise value and reduce risk associated with the offtake, ERM has engaged with a range of potential offtakers with a number of strong options available:

- **Blend the produced hydrogen into the Local Gas Distribution Network** (up to 15%, similar to HyDeploy, is expected to be allowable from 2024). We have had several discussions with SGN (the gas network operator) which is evaluating a future hydrogen network for Aberdeen (including a 100% hydrogen pipeline linking to St Fergus) as part of the Aberdeen Vision project. There is a connection point to the network close to the landing point for the ERM Dolphyn hydrogen pipeline at which up to 15% blend can be introduced. There is also the potential to inject directly into the Aberdeen-St Fergus 100% hydrogen pipeline at the same location. There would be a direct line to a blending station at the Aberdeen City Gate Pressure Reduction Station and an offtake to the Aberdeen Hydrogen Hub (and possibly Aberdeen Harbour South /Energy Transition Zone).

  For the future commercial expansion of Dolphyn there is the potential to blend hydrogen directly into the NTS. National Grid are currently undertaking research to examine the suitability of the NTS for different concentrations of hydrogen (HyNTS project) and it is expected that decisions on allowable levels could be made as early as 2028.

- **Hydrogen for transport applications** – ERM has engaged with a major multinational energy company considering purchasing hydrogen for transport applications. A mutually beneficial contract structure suitable for this type of project has been developed, and the potential offtake arrangements are at an advanced stage of discussion. Certainty over the level of government support will be key to concluding these discussions and formalising any future offtake pricing structure.

- **Aberdeen Energy Transition Zone** - Opportunity North East (ONE) is working with potential partners and funders in industry, the public sector and government to develop a world leading Aberdeen Energy Transition Zone (ETZ). The ETZ would be a physical place in Aberdeen for research and development, testing, demonstration and manufacturing activities in an exemplar net zero environment, acting as a focal point for the development of an energy transition industry cluster in the region. ERM and ONE have been liaising for over a year regarding the potential for ERM Dolphyn to supply hydrogen into the ETZ, and have an NDA in place. The ETZ will include potential links with industrial users (at Altens industrial estate), marine (at Aberdeen Harbour South) and buildings applications.

- **Aberdeen transport** – Aberdeen City Council has invited expressions of interest to explore potential delivery options to achieve Aberdeen Council's ambitions to deliver a hydrogen hub in Aberdeen, for which ERM has registered interest. ERM has an established relationship with Aberdeen City Council through our annual hydrogen conference in Aberdeen and we have engaged with members of Aberdeen City Council regarding the project.
- **Small-scale industrial users** – A further offtake option is to supply small scale industrial users. For example, hydrogen could be used to decarbonise heating in water treatment plants, and there is also a potential demand for the oxygen produced by ERM Dolphyn, which could be used to accelerate bacterial digestion of waste. Oxygen supply is not currently part of the project but could be added if the volumes required make it economical to add an extra pipeline. ERM has engaged with small-scale industrial users in the region with decarbonisation targets that could be enabled through hydrogen supply, and the results of the discussions have been very positive.

### *8.3.2 'At Scale' Route to Market*

The ERM Dolphyn project could have a significant role to play in the development of the UK's hydrogen supply chain, the development of hydrogen technology and end use applications/ markets. The development of the hydrogen market is subject to a chicken-and-egg situation with development of supply and demand required concurrently. As the 10MW Commercial Demonstrator project continues to FEED, ERM will continue to engage with potential offtakers, suppliers and other stakeholders with a view to rapid development of at-scale solutions.

Potential routes to market for bulk production of hydrogen from ERM Dolphyn include:

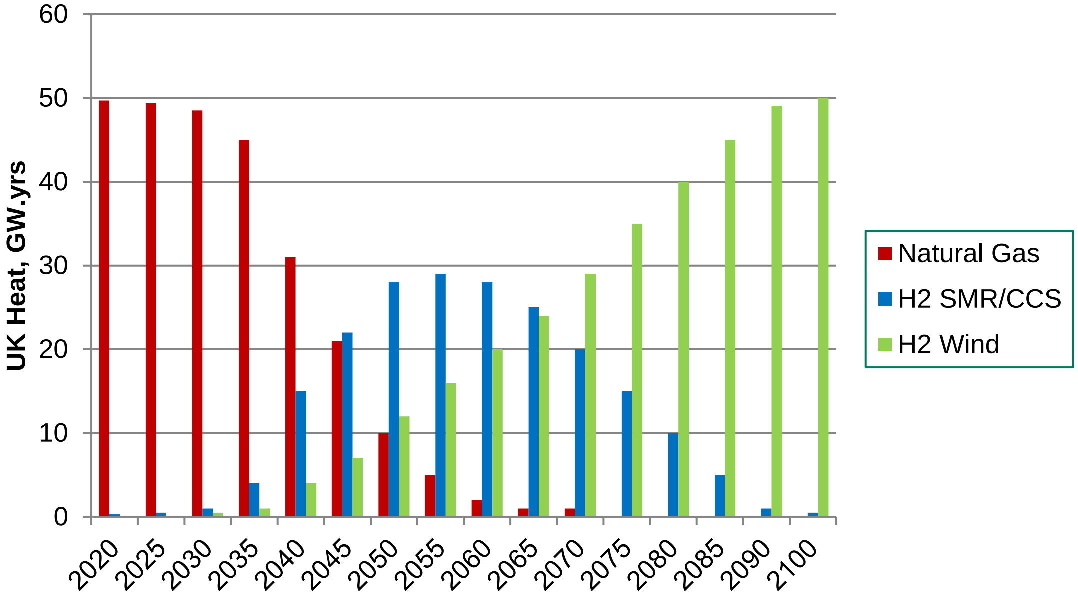
- **Transport applications** – in particular heavy-duty vehicles and potentially trains, marine and aviation. In the short term hydrogen supply for captive fleets which operate from a single point (for example buses and other municipal vehicles) are likely to provide small enabling markets, while other applications such as trains and aviation are likely to develop later once technical and EHS considerations have been fully explored. The hydrogen produced by ERM Dolphyn is high purity so ideally suited for transport applications, and this market may also be less price sensitive than other options. ERM has engaged with transport fuel providers in order to gauge interest in hydrogen offshore from ERM Dolphyn and the results are very encouraging.
- **Industrial applications** - in particular supply to UK industry clusters to assist with decarbonisation of UK heavy industry fuels and feedstocks. Given the timelines associated with developing an industrial switching project at scale, it is likely that this offtake solution would be most relevant for ERM Dolphyn projects becoming operational towards the end of this decade rather than the 10MW commercial demonstrator. ERM is in discussion with the UK industry

clusters regarding the potential decarbonisation opportunities that large scale ERM Dolphyn project(s) would provide and is actively undertaking feasibility work associated with bulk hydrogen production for industry clusters.

- **Blending into the gas network** - A significant amount of work has been done to research the percentage of hydrogen allowable in gas networks. This has been predominantly conducted in Europe and the US with projects such as HyDeploy (low-pressure network) and H21/HyNTS (high-pressure network). The findings so far indicate that up to 20% hydrogen blend can be used in low-pressure networks without affecting gas appliance performance. At present France, Germany and the Netherlands allow 6%, 10% and 12% respectively. This is likely to increase to 20% within the next 5 years, including in the UK and other European countries. The intention is for both low-pressure distribution and high-pressure transmission networks to move to 100% hydrogen across Europe during the 2030's. Countries such as Japan, South Korea, the US, and China are also looking at hydrogen gas networks seriously and are expected to follow Europe's lead.

ERM undertook a study in 2019 for the Offshore Wind Innovation Hub, with Offshore Renewable Energy Catapult as a key delivery partner [19], to consider the role that hydrogen from offshore wind could play in the UK gas network. This considered a gradual transition away from fossil fuels over several decades, with SMR/ATR+CCS being used as a transition technology and green hydrogen complementing and increasingly replacing blue hydrogen as early SMR units reach the end of their operational lifetime. This shows the potential to replace natural gas with green hydrogen in the UK by the end of the century. The relative energy projections for burning natural gas (red), using hydrogen from natural gas in SMR/ATR with CCS (blue), and use of hydrogen from offshore wind through ERM Dolphyn (green) are shown in Figure 8.3 below.

**Figure 8.3 Hydrogen Supply for 100% UK Gas Network Conversion**



The UK is uniquely placed to be a leader in the development of hydrogen production from offshore wind using ERM Dolphyn facilities. The UK is home to an excellent offshore wind resource, a unique geographical advantage. Its potential for more than 600GW [20] of installed capacity, is well above the 75-100GW likely to be required for UK electricity generation by 2050, and could be the backbone of the economy's future energy needs. Hydrogen from floating wind offers particular opportunities; providing access to excellent wind resources in deeper waters and opening up areas for development where long-distance underwater electricity transmission infrastructure would be prohibitively expensive.

In addition to its outstanding levels of offshore wind resources, the UK has a leading offshore wind industry and established oil and gas industry. Our gas distribution network, which is on track to be almost be 100% polyethylene by 2030, is another major advantage. The UK is therefore well placed to extract maximum benefit from the technology.

In order for the rapid deployment of ERM Dolphyn to be successful, and the UK to achieve the economic and decarbonisation benefits of hydrogen, UK Government support is required. In particular, revenue and/or grant funding support for early stage projects like ERM Dolphyn, the removal of regulatory barriers, and the stimulation of market demand for hydrogen, will be key to success.

## 8.4 Remaining Technical, Commercial and Financing Challenges and Opportunities

During the next phase of the project, work will be undertaken to overcome the remaining technical, commercial and financing challenges, and realise opportunities to optimise the project that have been identified during the work so far. Public funding will be critical to achieve this.

No technical or commercial showstoppers have been identified. The project philosophy is to use high technology readiness level equipment in a novel system configuration. The key technical and commercial risks can be managed as follows:

- **Obtaining consent at location** – The project is progressing a preferred option to co-locate with an existing licenced floating offshore wind farm. The project team has reviewed the consenting and planning policy and implications, and engaged with the appropriate consenting and regulatory bodies who have shown a positive and pro-active approach to consenting and permitting. Offshore hydrogen production units do not fall under existing regulations or consenting pathways, although there are lessons to be learned from the renewables and oil and gas sectors. This is discussed further in Section 5.

- **Regulatory compliance** – The design will need to comply with all relevant regulations, including the Health and Safety at Work Act 1974 and subordinate legislation such as Construction Design and Management Regs 2015 and Management of Health and Safety at Work Regulations 1999. Furthermore, hydrogen (operating above 7 barg) is defined as a dangerous fluid according to Reg 18(2) and Schedule 2 of The Pipelines Safety Regulations 1996 (PSR) and so PSR and the additional requirements of PSR for Major Accident Hazard (MAH) pipelines will apply to the pipeline and riser. These requirements are being addressed through the activities of the project, further discussed in Section 2.5.

- **Securing finance** – The UK government has funded the ERM Dolphyn project so far under the Hydrogen Supply Competition. The next funding cycle will begin later this year, to which ERM will apply. We will require external investment to procure, construct and commission the commercial demonstrator project and additional finance will be required to fully commercialise the technology (first 100MW hydrogen wind farm) beyond that. ERM is in discussion with a number of potential investors and are therefore confident that the level of investment required will be forthcoming from the market.

- **Offtake arrangements for produced hydrogen** – We are progressing with discussions with several potential offtakers in order to mitigate the risk of any one offtake option not coming to fruition. This is discussed further in Section 8.3.1. In order to finalise offtake arrangements for the 10MW commercial demonstrator, confirmation of the level of UK Government support is required.

- **Cost reductions** – The current estimate for levelised cost of hydrogen (LCOH) is slightly higher than industry benchmarks, reflecting the small size, first-of-kind nature and location of the project. Significant areas of material cost savings have been identified, and targets for Capex and Opex reductions have been set and included within a project Balanced Score Card (BSC) which ERM, and its suppliers, will work to in the next phase. This is discussed further in Section 6.1.

## 8.5 Final Comment on Commercial Development Plan

In summary, the Commercial Development Plan represents a rapid and efficient means of quickly moving to at-scale deployment, while incorporating learnings and aligning with the UK Government’s objectives on decarbonisation and the development of a hydrogen economy.

# 9. REFERENCES

1. ERM, 2019. Dolphyn Public Report. 0500255-01-ERM-PM-R01.
2. ABP Marine Environment Research, 2017. UK Renewables Atlas. Available online: https://www.renewables-atlas.info/explore-the-atlas/
3. British Oceanographic data centre, Global Wind Atlas
4. EMODnet Bathymetry Consortium (2020): EMODnet Digital Bathymetry (DTM). https://doi.org/10.12770/bb6a87dd-e579-4036- abe1-e649cea9881a
5. Contains information provided by the OGA. Data provided under the terms and conditions of the Oil and Gas Authority Licence (OGA Licence: https://www.ogauthority.co.uk/media/5850/ogaopen- user-licence_210619v2.pdf)
6. Contains information from the Scottish Government (Marine Scotland) licensed under the Open Government Licence v3.0. http://www.nationalarchives.gov.uk/doc/opengovernment- licence/version/3/
7. Flanders Marine Institute (2019). Maritime Boundaries Geodatabase: Maritime Boundaries and Exclusive Economic Zones (200NM), version 11. Available online at https://www.marineregions.org/. https://doi.org/10.14284/386
8. Office for National Statistics licensed under the Open Government Licence v.3.0 Contains OS data © Crown copyright and database right 2021
9. Guidelines for Offshore Oil and Gas Installations that are not Permanently Attended, Energy Institute.
10. The Offshore Installation (Offshore Safety Directive) (Safety Case etc.) Regulations (SCR) 2015
11. Kincardine Offshore Wind Farm, Environmental Statement and Appendices
12. Aberdeen Energy Transition Zone (ETZ) Feasibility Report (February 2020).
13. Schedule 5 of the Scotland Act 1998
14. within the meaning of section 30A(1) of the Control of Pollution Act (COPA) 1974 (c.40)
15. Section 1(7) of the Continental Shelf Act 1964
16. Aberdeen City Council update to Committee on the proposed investment and delivery model for the Aberdeen Hydrogen Hub, available online at: https://committees.aberdeencity.gov.uk/documents/s117515/Hydrogen%20Hub%20-%20Final%20Report.pdf
17. See for example Hydrogen Council, 2020, Path to Hydrogen Competitiveness, https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf
18. Aberdeen City Council, hydrogen section of website: https://www.aberdeencity.gov.uk/services/environment/h2-aberdeen

19. ERM, 2019, Feasibility Study of Large Scale Hydrogen Production from Offshore Wind in the UK, Final Report
20. ORE Catapult, 2020, Solving the Integration Challenge https://ore.catapult.org.uk/wp-content/uploads/2020/09/Solving-the-Integration-Challenge-ORE-Catapultr.pdf
21. See for example Project Dolphyn Consultation Report, 10 November 2020

# APPENDIX A EXAMPLE KEY REPORTS DEVELOPED

| Area | Title |
|---|---|
| **Anchoring and Mooring** | Mooring Configuration Drawings |
| | Mooring System Design Report |
| **Civil/Structural Engineering** | Pipeline Overall Route |
| | Pipeline Technology Selection |
| | Piping Specification/Datasheets (x12) |
| | Pipeline Pre-commissioning Strategy |
| | Pipeline On-Bottom Stability |
| | Pipeline Wall Thickness Sizing |
| | Pipeline Allowable Freespans |
| | Pipeline Cathodic Protection |
| | Pipeline Upheaval Buckling & Protection Design |
| | Pipeline End Expansion and Spool Design |
| | Pipeline Construction Philosophy |
| | Pipeline Construction Report |
| | Pipeline Material Take Off |
| | Riser Checks for Flexibility and Mooring |
| | Structural Design Drawings Deck Structures |
| **Consenting** | Greater Kincardine Potential Development Zones |
| | Greater Kincardine Pipeline Corridor and Landfall Constraints |
| | Onshore Facility: Indicative Search Area |
| | Offshore EIA Screening Letter |
| | Consenting Strategy and Environmental Impact Assessment Screening Opinion Request |
| | Site Selection Approach |
| | Data Management Standards for Overall Field Layout Development |
| | Onshore L&V Survey Note |
| | Onshore – Extended Phase 1 Habitat Survey |
| | Marine Surveys – Plan |
| | Marine Surveys - Scope of Works |
| | Consenting Roadmap and Site Selection Approach for Consultations |
| | Onshore Site Selection Report |
| | Site Selection Report |
| | Offshore EIA Scoping Report |

| Area | Title |
|---|---|
| | Met-ocean Criteria |
| | Onshore Preliminary Ecology Survey Report |
| | Onshore – Wintering Bird Survey |
| | Landfall Assessment Report |
| | Marine Data Review Report |
| **Cost Estimate CAPEX & OPEX** | Financial Modelling Workshop Notes |
| | Installation Cost estimate |
| | Financial Modelling Memo |
| | Development Plan |
| | Financial model for 2MW prototype |
| | Financial model for 10MW pre-commercial project |
| | Financial model for full scale commercial project |
| | Basis for Cost Estimate |
| | Operating Personnel Requirement (Maintenance Assessment) for OPEX |
| | MTO Development Report |
| | Cost Estimate Report |
| | Topside OPEX Estimation |
| | Topsides QA/QC Report - Quality Plan |
| | Cost estimation report - 2MW |
| | Cost comparison report - 2MW vs 10MW |
| **Electrical Engineering** | Assumptions for Battery sizing study |
| | Overall Single Line Diagram |
| | UPS Distribution Board Diagram |
| | Interconnection Diagrams (x5) |
| | Overall Single Line Diagram 10MW |
| | Power Installation Standard Drawings (x8) |
| | Earthing Installation Standard Drawings (x7) |
| | Lighting Installation Standard Drawings (x14) |
| | Specifications (x8) |
| | Datasheets (x8) |
| | Electrical design criteria |
| | Cable sizing philosophy |
| | Start-up philosophy |
| | Sizing calculations |

| Area | Title |
|---|---|
| | Power System Study |
| | Electrical load list |
| | Electrical Equipment list |
| | Electrical Cable schedule |
| | Electrical Cable MTO |
| | Power Management System Load Shedding Philosophy for LV Loads |
| | LER Specification |
| | Standby Power Supply Option Review |
| | Electrical Load List 10MW |
| | Load-Flow and Short-circuit Studies |
| | Battery Sizing Final Report |
| | Technical memo on capabilities of Supercapacitors |
| **Instrumentation / Control** | Instrument Cable Block Diagrams (x11) |
| | System Architecture Drawing |
| | Instrument Termination Diagrams (x37) |
| | Specifications and Datasheets (x18) |
| | Instrument Index and I/O Schedule |
| | Control System Philosophy |
| | Instrument schedules (x5) |
| | Manual Valve List |
| | Functional specification of Fire Alarm System |
| **Mechanical Engineering** | Mechanical Datasheet and Specifications (x8) |
| | Mechanical Handling Report |
| **Process Engineering** | Hydrogen Generation Process Flow Diagram |
| | Offshore Electrolyser Preliminary Layout Plot Plan |
| | Offshore Electrolyser Process Specification |
| | Electrolyser: Basis of Design 2MW |
| | Electrolyser Marinisation Feasibility Study Report |
| | Offshore Electrolyser Pre-FEED Basis of Design |
| | Offshore Electrolyser Equipment List |
| | Offshore Electrolyser Preliminary Heat & Mass Balance |
| | Offshore Electrolyser Risk Register (Pre-FEED 10MW) |
| | Desalination technology Selection 2MW |

| Area | Title |
|---|---|
| | Wastewater Discharge |
| | Desalination Technology Selection 10MW |
| | Basis of Design (2MW) |
| | Commercial Demonstrator Basis of Design |
| | Register of Codes and Standards |
| | Process Flow Diagram 2MW Pilot Prototype |
| | Piping and Instrumental Diagrams (x15) |
| | Process Flow Diagram - 10MW Commercial Scale Demonstrator Unit |
| | Equipment Data Sheets (x16) |
| | Onshore Facilities Design Technical Note |
| | Topsides Layout Guidance Technical Note |
| | Technical Notes |
| | Process Control Philosophy |
| | Material selection report (H2 system) |
| | Process Calculations |
| | Cause & Effect Diagrams |
| | Codification Procedure |
| | Heat and Material Balance |
| | Equipment List (2MW Prototype) |
| | Line List |
| | Special Piping Items List |
| | Heat and Material Balance 10MW |
| | Equipment List (10 MW Pre-FEED) |
| | HVAC design |
| **Project Management** | Fortnightly Progress Meeting Checklist |
| | Quarterly Progress Meeting Checklist |
| | Project Summary Description for Phase 2 and 3 |
| | Scope of Work for 10MW Pre-FEED |
| | Project Management Plan |
| | Dolphyn Quarterly Progress Updates |
| | Phase 2 Final Report |
| | Master Document Register |
| | Risk Register |
| | Dolphyn Action Tracking Register Phase 2a |

| Area | Title |
|---|---|
| | IP Log |
| | Minutes of Meeting Log |
| | Engineering Interface Register |
| | Project Interface Register |
| | Document Numbering and Control Procedures |
| | List of Codes and Standards (Topsides and Export Pipeline) |
| | Phase 2 2MW Demonstrator Final Report |
| | 10MW Commercial Scale Demonstration Unit Pre-FEED Execution Plan |
| | Project Delivery Organisation Chart |
| | Project Engineering Execution Plan |
| | Competence Assessment and Management |
| | Project Quality Management Plan |
| | Non Conformity Report & Log |
| | Project Interface Execution Sequence |
| | Master Document Control Index |
| | Engineering Project Schedule |
| **Regulatory Compliance** | Bowtie Diagrams |
| | Performance Standards (X27) |
| | Design Hazard Management Plan (10MW) |
| | HSE Philosophy 2MW |
| | Fire and Explosion Hazards Assessment |
| | Fire Explosion and Other Hazards Assessment |
| | Escape Evacuation and Rescue Analysis |
| | Essential Systems Survivability Analysis |
| | ALARP Demonstration |
| | IVB Plan |
| | HAZOP Terms of Reference |
| | HAZOP Report |
| | Project Data and Assumptions |
| | Identification of Major Accident Hazards |
| | HSE Philosophy 10MW |
| | Preliminary selection of Safety & Environment Critical Elements |
| | HAZOP Actions Closeout Strategy |

| Area | Title |
|---|---|
| **Sub-structure** | Standard for Referencing Systems |
| | Equipment Layout Plot Plan |
| | 3D model/ general 3D views |
| | Topside General Arrangements |
| | Floater General Arrangements |
| | General Layouts |
| | Overview structural drawings |
| | Basis of Design: Topside |
| | Weight Control Report |
| | Global Performance and Loading Report |
| | Equipment Analysis Reports (x4) |
| | Design Methodology Report - Hull Design |
| | Hull and Mooring Design Basis |
| | Design Methodology Report - Mooring System |
| | Design Methodology Report - Construction and Installation Plan |
| | Analysis of Floater Interface |
| | Hull and Mooring Design Basis 10MW |
| | Scope of work for 10MW Floating Foundation pre-FEED |
| | Floater design - Summary report |
| | Topside Equipment Weight and Inertia Estimation |
| **Supply Chain Readiness** | 2MW Procurement Strategy |
| | 10 MW Procurement Strategy |
| | Supplier Management Tracker |
| | Cost Outline for Design Options |
| **Wind Turbine Generator** | WTG Conceptual Selection and Start-up/Idling Power Requirements |
| | Wind Turbine Generators Comparison – 10MW |
| | Offshore Installation Plan |
| | Turbine Integration Plan |

## ERM has over 160 offices across the following countries and territories worldwide

Argentina
Australia
Belgium
Brazil
Canada
Chile
China
Colombia
France
Germany
Guyana
Hong Kong
India
Indonesia
Ireland
Italy
Japan
Kazakhstan
Kenya
Malaysia
Mexico
Mozambique
Myanmar

The Netherlands
New Zealand
Norway
Panama
Peru
Poland
Portugal
Puerto Rico
Romania
Russia
Singapore
South Africa
South Korea
Spain
Sweden
Switzerland
Taiwan
Tanzania
Thailand
UK
US
Vietnam

**ERM Manchester**
11th Floor
5 Exchange Quay
Manchester
M5 3EF
United Kingdom

connect_ermdolphyn@erm.com

T: +44 (0)161 958 8800
F: +44 (0)161 958 8888

www.erm.com
ermdolphyn.erm.com

*The business of sustainability*

ERM