Milford Haven: Energy Kingdom

Feasibility HAZID

Prepared for:	Offshore Renewable Energy Catapult
Document No:	ARC-635-R003
Issue No:	2
Date:	June 2022

APPROVAL AND REVISION RECORD					
Issue No.	**Date**	**Prepared**	**Reviewed**	**Approved**	**Revision Notes**
1	May 2022	I Holmes	E Macfarlane	T Lambert	For participant comment
2	June 2022	I Holmes	E Macfarlane	T Lambert	Re-issue after client feedback.

Executive summary

Offshore Renewable Energy Catapult (OREC) have proposed three design options for a Hydrogen Chain, from the Celtic Sea to the Milford Haven port area, as part of the Milford Haven Energy Kingdom initiative.

Abbott Risk Consulting Ltd. (ARC) was commissioned by OREC to facilitate a Hazard Identification (HAZID) workshop to provide greater understanding of the safety considerations of integrating a Hydrogen Chain into the already existing energy infrastructure around Milford Haven.

The HAZID was conducted with a range of Milford Haven Energy Kingdom Project stakeholders, and used a structured brainstorming approach over three half-day sessions using a web based platform for remote participation. Whilst the workshops were focused on safety aspects, given the flexible nature of the study methodology other considerations raised by the participants (such as of operational or environmental impacts) were also captured.

During the workshop a total of thirty eight safety hazards were identified and twenty six specific recommendations were made as a result.

This report presents the findings from the workshop arranged into three broad categories covering: Observations, Forward Action Plans and Conclusions. These findings provide input into the further concept development.

Abbreviations

Abbreviation	Definition
ARC	Abbott Risk Consulting Ltd
CAA	Civil Aviation Authority
DDT	Deflagration to Detonation Transition
FAP	Forward Action Plan
FWT	Floating Wind Turbine
HAZID	Hazard Identification
MHPA	Milford Haven Port Authority
MCA	Marine & Coastguard agency
MoD	Ministry of Defence
NATS	National Air Traffic Services
OREC	Offshore Renewable Energy Catapult
OSS	Offshore Substation
RWE	Rheinisch-Westfälisches Elektrizitätswerk
SSSI	Site of Special Scientific Interest
UAV	Unmanned Air Vehicle
UKHO	United Kingdom Hydrographic Office

References

No.	Publication
1	Offshore Renewable Energy Catapult. (2022). Milford Haven: Energy Kingdom, Preparing Offshore Renewables for Long Term Trends
2	Offshore Renewable Energy Catapult. (2022). Milford Haven: Energy Kingdom, Energy Flow Model
3	Offshore Renewable Energy Catapult. (2022). Milford Haven: Energy Kingdom, Producing Low Carbon Steel

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1.0 Introduction

The Milford Haven: Energy Kingdom project is a two-year £4.5 million project, completing in 2022, exploring what a decarbonised smart local energy system could look like for Milford Haven, Pembroke and Pembroke Dock. The project sets out to explore the potential for zero carbon hydrogen alongside renewable electricity.

The Offshore Renewable Energy Catapult (OREC) is a leading technology innovation and research centre for offshore renewable energy. Their work covers research and innovation, testing and validation and analysis and strategy, as well as supply chain growth. The Milford Haven: Energy Kingdom project has been a key project for developing understanding around how hydrogen can fit into the energy system and for undertaking enabling actions to unlock multi-GW offshore wind projects in the Celtic Sea. This report is part of a suite of documents produced by OREC through the project. The others cover: Enabling activity for multi-GW offshore wind and hydrogen deployment in the Celtic Sea [reference 1]; modelling the flow of energy through integrated wind turbine – electrolyser systems [reference 2]; and using renewable energy and hydrogen to decarbonise steel in the context of Wales [reference 3].

OREC have proposed three design options to make a Hydrogen Chain, from the Celtic Sea to the Milford Haven port area, a reality. This Hydrogen Chain will consist of an offshore Floating Wind Turbine Generator (WTG) array providing the power to drive an electrolysis process to produce Hydrogen from water. This Hydrogen will then to be used as an energy vector to transport, store and then supply energy to end consumers.

Abbott Risk Consulting Ltd. (ARC) was commissioned by OREC to facilitate a Hazard Identification (HAZID) workshop to provide greater understanding of the safety considerations of integrating a Hydrogen Chain into the already existing energy infrastructure around Milford Haven.

The HAZID was conducted with a range of Milford Haven Energy Kingdom Project stakeholders, and used a structured brainstorming approach over three half-day sessions using a web based platform for remote participation. Whilst the workshops were focused on safety aspects, given the flexible nature of the study methodology other considerations raised by the participants (such of operational or environmental impacts) were also captured.

The outcomes of this HAZID will be used to inform further development of the three options developed by OREC, with the aim of developing a preferred option / architecture to be taken forward.

All information contained within this document has been provided by the workshop participants, either verbally or digitally.

2.0 Scope

The HAZID Study was focused on identifying the safety interactions and concerns both to and from the proposed Hydrogen Chain. It was also intended to identify and capture wider considerations to support the future concept development. The HAZID captured the following:

- Safety interactions / concerns that could credibly lead to significant loss of life, asset damage or environmental impact
- Potential causes of the safety concerns identified
- Wider considerations not directly related to safety but that which require further specific assessment

The HAZID assessed, at a high level, the following stages of the system development lifecycle:

- Installation and commissioning
- Operation and maintenance (planned & unplanned)
- Retirement and replacement

The HAZID did not assess or categorise the consequence severity or likelihood of the safety concerns raised.

This HAZID assessment was intended to be a high level, qualitative assessment of the following three options summarised in Table 1(these options are described in more detail in Appendix A). Whilst the primary focus was Option 1 given the time constraints, the other Options were considered by identifying and assessing their differences from Option1. The Options, and the variations between / within them, are summarised in Table 1.

Table 1 – Option Descriptions

Option	WTG Layout	Hydrogen Generation	Energy Consolidation	Offshore to Onshore Transmission	Energy Storage	End Consumer
1	Three potential configurations: - Daisy Chain - Fishbone - Star arrangement (Drawings presented in Section 1.1.6 of Appendix A)	On each individual Floating WTG	Gaseous Hydrogen from each string manifolded together	Pressurised gas in a single static pipeline to onshore	Large scale onshore pressurised gaseous storage	Power plant
2	Three potential configurations: - Daisy Chain - Fishbone - Star arrangement	Onshore single installation	Each string electrical cable combined within a single floating Offshore Substation (OSS)	One or more electrical cables to onshore	Large scale onshore pressurised gaseous storage	Power plant
3	Three potential configurations: - Daisy Chain - Fishbone - Star arrangement	Offshore single floating hydrogen production installation	Each string electrical cable combined within a single floating OSS to power electrolyser.	Gaseous hydrogen transfer to vessel that then offloads at terminal in the Milford Haven Sound	Large scale onshore pressurised gaseous storage	Power plant

3.0 Methodology

The workshop was conducted using the outline methodology presented in Appendix B. This was supplied to the proposed attendees, alongside the information presented in Appendix A, as a workshop study pack prior to the workshop.

The intent of the methodology was to:

- Ensure that there was a consistent understanding of the proposed options to be assessed, including any areas of uncertainty / variation
- Establish a consistent system boundary description so that credible interfaces to / from 3rd parties could be identified, and a consistent approach to consequence assessment could be made
- Provide sufficient structure for a coherent assessment, whilst maintaining flexibility for the workshop to re-focus effort and/or gather additional information as the workshop progressed to ensure that the potential options were explored as fully as possible within the time constraints of the workshop

The workshop was held as three separate half day sessions as this:

- Allowed the attendees to maintain focus during the remote sessions
- Ensured that a range of stakeholders could be involved in the workshop
- Provided time between sessions for additional information to be gathered from stakeholders
- Provided time to consider implications of any findings up to that point, and re-focus effort as required

The Study Team agreed that there was commonality across each of the three the options, specifically the FWT array and the onshore equipment downstream from the storage facility inlet. This supported the conclusion that many of the observations made for Option 1 could be extended to the other two Options. The final record for this HAZID workshop is presented in Section 2.0 in Appendix C.

Some discussions were seen as adding value, but were not directly applicable to the safety of personnel or the public. These discussions were placed into a "Parking Lot" for Option 1 and are presented in Section 5.0 in Appendix C.

Due to the significant ground to be covered in a limited time, it was decided to conduct a pure brainstorming session for Options 2 and 3, with all observations made placed in a single list, or "Parking Lot" (see Section 6.0 in Appendix C). The scope detailed in section 3.1.1 was followed for both options but discussions focused on those risks specific to the High Voltage cables from the FWT to shore (Option 2) and to the shipping of Hydrogen from the Hydrogen Substation to shore (Option 3). The final record for this HAZID workshop is presented in Section 4.0 Appendix C.

The notes gathered during the workshop are presented in the following Appendix C sections, and additional information provided after the workshop is provided in Appendix D:

- Workshop attendees - Section 1.0
- Boundary description - Section 2.0
- HAZID Notes Option 1 - Section 3.0
- HAZID Notes Option 2 & 3 - Section 4.0
- Parking Lot Option 1 – Section 5.0
- Parking Lot Options 2 & 3 – Section 6.0
- Post-workshop Information - Appendix D

The workshop notes were reviewed during the production of this report, and the findings arranged into the following sections:

- Observations:
    - System boundary description – high level description of the system and the interfaces across that boundary
    - Arising common themes – consistent themes or issues identified across the workshops
    - Specific hazard scenarios – principal hazards scenarios to be considered during future development of the concept
- Forward Action Plan (FAP):
    - Specific recommendations – these are those from HAZID workshop directly identified by the attendees
    - Further recommendations – these are based on the arising common themes of specific hazard scenarios
- Conclusions – broad conclusions that can be drawn from the workshop observations and FAP

4.0 Observations

4.1 System Boundary Description

The system boundary presented diagrammatically in Figure 1 is based on the notes presented in Appendix C Section 2.0. It is intended to present a consistent boundary that encompasses all of the options presented to the workshop attendees, and is the limit of the control that the project has influence over. In addition, the description provides interfaces with 3rd parties that the system must or, or may, interact with.

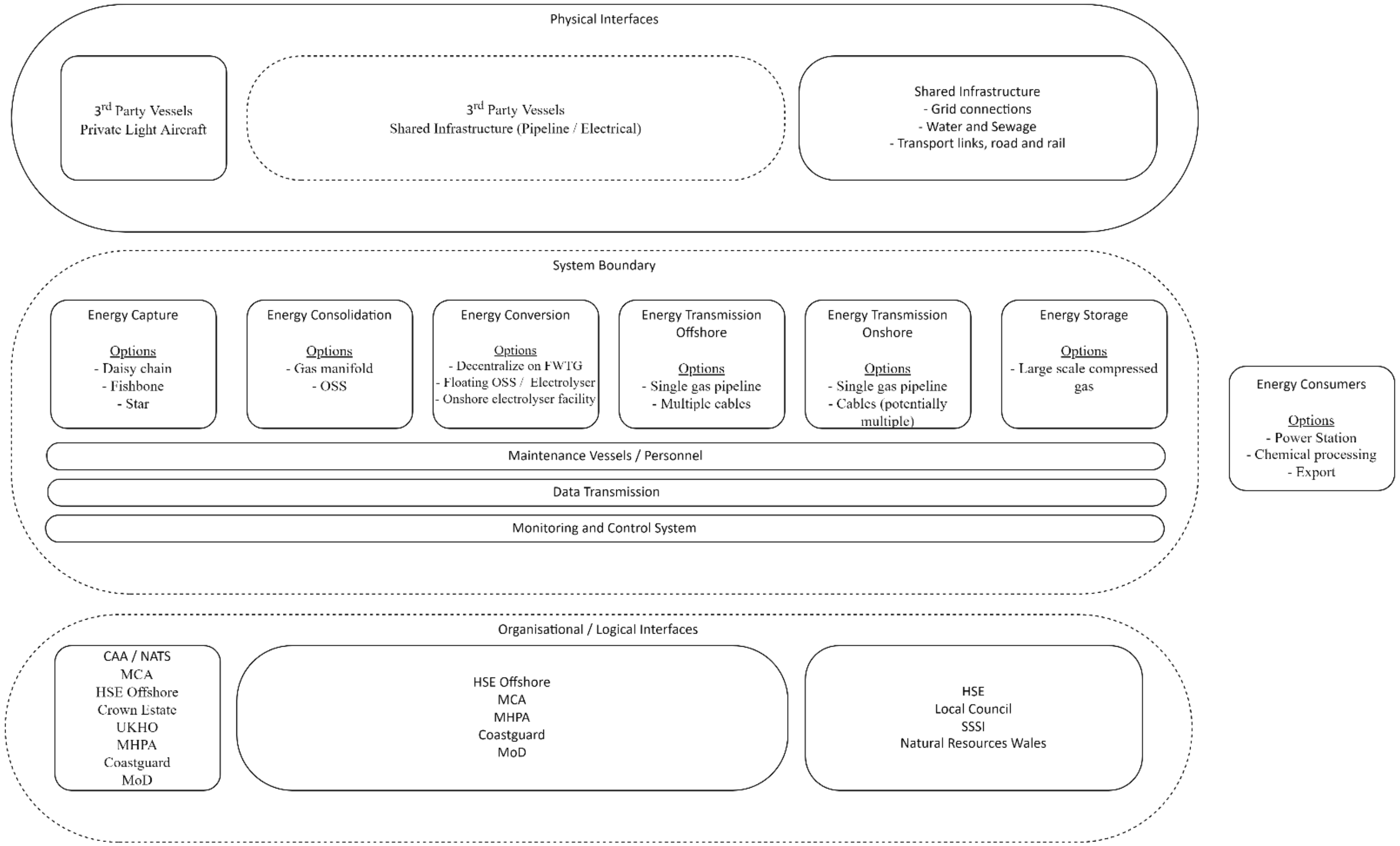


Figure 1: Boundary Description

The system boundary description will need to be reviewed and updated as part of the following activities to further develop the system concept.

The system boundary description has been broken down into the following principal elements, so that the internal interfaces between the main system elements are clearly presented:

- Energy capture
- Energy consolidation
- Energy conversion
- Energy transmission
- Energy storage
- Energy Consumers
- Parallel system elements:
    - Maintenance vessels / activities
    - Data transmission
    - Control and management system

The diagram is intended to show different types of interfaces as they align broadly with the above:

- Physical – this may be other users of the environment or parties that may be impacted by accident scenarios
- Organisational / Logical – this may be interfaces with organisations, such as regulators, or potential information sources / transfers that are required for operation of the system

The types of interfaces are described in Table 2.

Table 2 – System Interfaces

Interface	Description
3rd Party Vessels	This is intended to cover a wide range of other civilian users of the marine environment including the following parties / interactions: - Fishing vessels operating in or around the wind array - Private pleasure craft They may impact anchor systems, pipelines or cables either from drifting vessels, vessels dragging anchors or whilst undertaking operations e.g. fishing trawling. In addition, in the event of failure of an anchoring systems there is the potential for them to be impacted by a drifting FWT There may be indirect impacts e.g. where options for anchoring are limited due to the presence of the system, or due to restrictions on routes they can use.
Private Light Aircraft	This is intended to cover flights at lower altitudes, potentially in uncontrolled airspace, who may interact with the system (e.g. using the wind array/OSS as known waypoint to navigate by). There is the potential for a direct impact, however it is considered more credible for impacts on navigation systems, such as radar. Consideration should be made for UAV (Unmanned Air Vehicles)
Shared Infrastructure Offshore (Pipelines / Electrical)	For the offshore environment, it is common for shared infrastructure to be present. This will require coordination between the various stakeholders, and an appreciation of the potential for impacts to/from others using the shared infrastructure. Consideration for other infrastructure in the locality should be considered.
Shared Infrastructure Onshore (Grid Connections / Water & Sewage)	Similar to the offshore environment, it is common for there to be shared infrastructure onshore. This could include infrastructures such as electrical substations / grid connections, mains water supplies with multiple offtakes in an area, communication cables, sewage and transport links (road rail) Consideration should also be given to non-physical infrastructure such as local first responders that need to be coordinated with through development of emergency plans. Again this will require coordination between the various stakeholders, and a appreciation of the potential for impacts to/from others using the shared infrastructure.
CAA / NATS	This is primarily around ensuring that the CAA/NATS are aware of the presence of the wind array, and that it has been appropriately incorporated into maps for air space users. In addition, there may be interactions directly if helicopter operations are undertaken.
MCA	Broadly the Marine & Coastguard agency will be one of the main organisations to coordinate with.
HSE Offshore	Depending on the final architecture of system configuration chosen, the relationship with the HSE Offshore may be quite different. The HSE currently takes a different regulatory approach for offshore wind in comparison with the offshore oil & gas sector. The presence of large volumes of hydrogen gas may mean that something more akin to the O&G regime would be expected.

Crown Estate	The Crown Estate is one of the principle stakeholder involved in offshore activity.
UKHO	Marine maps incorporating the systems elements offshore will have to be provided through the United Kingdom Hydrographic Office.
Milford Haven Port Authority (MHPA)	Milford Haven Port Authority will be one of the most significant stakeholders.
Coastguard	The coastguard will be one of the principle stakeholders for Emergency Planning coordination.
MoD	The MoD is involved in a range of activities in and around the areas being considered. There is the potential for them to be a source of potential accident scenarios, and will need to be one of the parties coordinated with for Emergency Planning.
HSE	The HSE will be the principle stakeholder, either directly or through one of their nominated representatives with regards safety assurance activities for the onshore environment. This will be especially important when considering large scale hydrogen storage onshore.
Local Council	One of the principal stakeholders for the onshore elements of the system.
SSSI	One of the principal stakeholders for the onshore elements of the system.
Natural Resources Wales	One of the principal stakeholders for the onshore elements of the system.

In addition, the following assumptions have been made when developing this systems boundary description. These assumptions should be reviewed, and challenged if necessary, as one of the follow up actions to this workshop. The assumptions are as follows:

- Energy will be consolidated prior to the transmission to shore
- A power plant being the initial end consumer drives towards compressed hydrogen as the closest fit with its current fuel

4.2 Arising Common Themes

The following common themes were identified as part of the production of this report. They are linked to specific HAZID line entries, Specific Recommendations or entries in the Parking Lot where possible.

Table 3 – Arising Common Themes

No.	Theme Description	Source(s) / Reference(s)
1	System Architecture Choice – The different options considered during the workshop represent only 3 potential options. There are multiple other credible configurations that could have been selected to be assessed. The principal variations between the options are focused on the following aspects: - The degree of centralisation versus distribution of equipment - The point in the hydrogen chain at which the conversion from electricity to hydrogen is undertaken - The balance between conversion capacity versus storage capacity - The specific energy vector (energy storage and transmission system) used at each stage in the Hydrogen Chain The balance struck between the aspects identified above directly influences the following considerations for safety, environmental, maintenance, availability, and the resilience of the overall system: - The number of individual systems elements, each of which will be subject to independent failure - The need for operator transfer / access to undertake necessary inspection and maintenance tasks - The overarching isolation / venting philosophy for the system which will require an appreciation of scale of consequences linked to each isolation section, and how failures may propagate through the system - The risk of exposure to external factors, including cybersecurity - The scale of consequence from accident scenarios - The ability to recover from off-nominal scenarios (e.g. need to be able to achieve black start) - Potential for escalation between the system elements, degradation of safety systems (e.g. impact on control systems) - Concentrations of waste products (oxygen and saline) from energy conversion processes, and their associated risk. Whilst these are not currently being considered as products, oxygen especially may be a credible product in its own right	HAZID Notes Option 1 – 4, 5, 6, 7, 17, 18, 19, 20, 21, 24 to 28, 29, 30, 34 HAZID Option Notes 2 & 3 Parking Lot for Option 1 – 4, 5, 6 Parking Lot for Options 2 and 3 – 1, 2, 3, 4, 7, 8, 9, 10, 11, 12

No.	Theme Description	Source(s) / Reference(s)
2	System Routing – The system layout will need to consider several current stakeholders that already use the offshore environment. This needs to cover both commercial and private users of the environment. The pipeline or cables from the offshore wind array will need a route that accounts for the following: - Current locations used as safe anchorages for vessels during adverse weather and/or as a safe hold point prior to entry to Milford Haven - Locations where vessels may need to deploy anchors in an emergency to limit their movement if they lose power. This will primarily be in the Milford Haven sound where there is limited room to manoeuvre - Potential shared, or alternative, infrastructure that may be used alongside other stakeholders in the area. This means there may need for a negotiated route that is acceptable to more than one stakeholder - Clear definition and protection of the pipeline / cable as it comes ashore and transfers to onshore route - Coordination of Emergency Planning with other stakeholders The concern here is that introduction of the system either degrades current safe practice (e.g. stopping vessels from using a safe haven) or introduces significant new risks (e.g. anchor dragging into a high pressure gas line)	Boundaries for Option 1 – No. 3, 4, 9, 10, 13, 20, 27, 28 HAZID Notes Option 1 – 4, 14, 15, 16 Parking Lot for Option 1 – 1, 2, 13, 15 Parking Lot for Options 2 and 3 – 14, 15
3	System Onshore Integration – The system will need to integrate with several physical and organisational elements in the onshore environment: - Conversion of current system (e.g. natural gas pipelines and turbines) to support hydrogen, and specific requirements of the installed system - Specific risks associated with new infrastructure (typical risks associated with standard transmission lines, should AC transmission be used, i.e. circuit breakers. Additional challenges in the case of DC cables / overhead lines due to the increased difficulty / cost in integrating protection systems.) - Impacts on local staff availability in competition with current business and activities, and implications for local infrastructure e.g. roads/schools etc.	Boundaries for Option 1 – 18, 21, 23, 25, 26, 28, 30 Parking Lot for Option 1 – 14, 16 Parking Lot for Options 2 and 3 – 6, 7

No.	Theme Description	Source(s) / Reference(s)
4	Hydrogen Energy Vector Selection – the trade-off between different energy vectors is linked with the both the overall system architecture, and the expected end consumer. The current assumption of a power plant being the initial end consumer drives towards compressed hydrogen as the closest fit with its current fuel. This underlying assumption should be challenged together with the following additional considerations: - Ammonia is a widely traded commodity, and there is already an existing infrastructure to handle large volumes of ammonia worldwide. Ammonia may represent a better long distance/long duration energy vector - Consideration should be given for multiple energy vectors to shore, to meet different end consumer needs onshore	Parking Lot for Option 1 – 12, 17 Parking Lot for Options 2 and 3 – 16
5	High pressure gas systems – high pressure gas hazards present for most options. There are specific hazards associated with the initial failure or rupture. In addition, there are secondary hazards associated with high pressure gas interactions in the surrounding environment (e.g. direct high pressure gas jet impingement/generated debris/pipe whip impacts on other equipment and reduced buoyancy locally above rupture point in the marine environment) NB these are distinct from the flammable / explosive risks associated with hydrogen.	Boundaries for Option 1 – 3, 9, 22 HAZID Notes Option 1 – 4, 14, 16,17, 29, 30, 32, 33 Parking Lot for Option 1 – 1, 2, 3, 6, 7 Parking Lot for Options 2 and 3 – 1, 3, 5

4.3 Specific Hazard Scenarios

Based on the notes presented in Appendix C the following principal hazardous scenarios have been identified. These are a consolidated set of hazardous scenarios that will need to be considered for all future systems configurations /. The implications of the scenario are discussed for both the offshore and onshore environments, as well as the trade-off considerations when looking at the different system configurations / all future systems configurations / options.

Table 4 – Hazardous Scenarios

No.	Hazardous Scenario	Offshore Context	Onshore Context	Discussion
1	High pressure gas release	For the offshore scenario, the primary sources of this hazard are: - The point at which hydrogen is generated (either on individual FWTs or an OSS) - Where the hydrogen supply is consolidated and transmitted to shore (manifold and pipeline) Any large offshore storage of high- pressure gas will expose the immediate environment to both potential overpressure from the initial release, resulting fragments and the physical impact of the high-pressure gas plume, or movement of equipment as a result of the release (e.g. pipe whip). Release of the pressure can occur due to internal failures of the pressure envelope, or due to external impacts on pipeline / storage vessels such vessels collision or anchor dragging on the pipeline	Similar to the offshore scenario, the primary source of this hazard are: - The point at which hydrogen is generated - Where the hydrogen supply is consolidated and transmitted - Where hydrogen is stored in bulk Any large onshore storage of high- pressure gas will expose the immediate environment to both potential overpressure from the initial release, resulting fragments and the physical impact of the high pressure gas plume, or movement of equipment as a result of the release (e.g. pipe whip). Scenarios for impact on onshore systems are less likely because the scenario of drifting vessels / dragged anchor can't occur. However, vehicle impact or civil works resulting in penetration of pipeline are still credible	The principal design considerations are: - Where hydrogen will be initially generated, and in what quantities will it be stored - What is the minimum viable pressure that the system can be operated at There is a trade-off between having fewer items of equipment, with reduction in potential leak points / items to be maintained at lower pressure, versus larger single inventories and higher pressures to minimise installation footprint
2	Flammable gas release leading to jet fire	All high-pressure gas release scenarios could potentially lead to an immediately ignited release, and a jet fire. In the offshore environment there is greater constraint on space and equipment layout, meaning that potential jet fire impingement and escalation may be more difficult to design out.	All high-pressure gas release scenarios could potentially lead to an immediately ignited release, and a jet fire. The onshore environment will allow greater margin to design out the potential for jet fire impingement, although it will still be a consideration.	The principle trade off here is between: - Reducing jet fire risk through layout and spacing - Passive fire protection to reduce likelihood of escalation in the event of a jet fire - Active fire protection systems to limit duration and severity of any jet fires
3	Flammable gas release with delayed ignition leading to explosion	All high-pressure gas release scenarios could potentially lead to a delayed ignited release, and a conflagration / detonation. The offshore environment will tend to be more congested and confined due to space limitations and the need to protect equipment from the local environment. These are both factors that increase the likelihood of Deflagration to Detonation Transition (DDT) if a flammable gas volume has formed. However, any gas cloud that is formed and migrates outside of the facility is not likely to impact 3rd parties.	All high-pressure gas release scenarios could potentially lead to a delayed ignited release, and a conflagration / detonation. The onshore environment will provide greater opportunity to reduce congestion and confinement to reduce likelihood of DDT. However, there is more likely to be 3rd parties that release scenarios may impact.	The principle trade off here is between: - Reducing inventories that can be released - Decreasing the potential volumes where gas cloud can accumulate / maximising ventilation - Elimination of ignition sources - Considering whether blast attenuation technologies are viable and beneficial - Blast protection for critical items - Segregation from 3rd parties

No.	Hazardous Scenario	Offshore Context	Onshore Context	Discussion
4	3rd party physical impact or collision with system	In the offshore environment there are multiple parties that may want to operate in / near the system. In addition, the systems may be routed near locations where 3rd parties already operate, such as sheltered anchorages. This is a scenario where the system is dependent on providing the relevant information and then 3rd parties operating in an appropriate manner. Emergency Plans will need to account for the scenarios where 3rd parties have lost control of their assets.	This scenario is more easily controlled, as 3rd parties can be excluded more easily form the areas where the system is operated.	The principal trade off here is between: - Control / exclusion of 3rd parties from access to the system, including such things as barriers -Emergency Planning and system response to this scenario
5	Collision or impact by system on 3rd party	This scenario primary relates to failure of the FWT anchor systems and a FWT being uncontrolled and breaking free in open water. Potential collision with third parties.	This scenario does not really exist for the onshore environment, apart from the potential use of tube trailers or other road vehicles that may be used to transfer generated hydrogen.	The principle trade off here is between: - The design and maintenance of the anchor systems - The system response to this scenario (i.e. isolation of gas/electrical connections) - Emergency response to this scenario
6	High Voltage electrical system exposure leading to injury / damage	This scenario primarily relates to: the flexible cabling between the FWT and any OSS, as that will be the most stressed element of the offshore electrical cabling, or during maintenance activities where the electrical isolation will be one of the main protections for maintenance personnel.	This scenario primarily relates to: the transition from offshore cabling to onshore where a clear understanding of responsibility is needed, or during maintenance activities where the electrical isolation will be one of the main protections for maintenance personnel.	HV electrical systems are well established in both the offshore and onshore environment. Standard accepted best practice should be applied. The principal design trade-off is between: - Where should the transition from electrical energy to hydrogen occur - Where should there be transitions between DC and AC electrical systems

No.	Hazardous Scenario	Offshore Context	Onshore Context	Discussion
7	Crew / equipment transfer or movement leading to physical Injury to maintenance staff	The offshore environment is more challenging for undertaking personnel and equipment transfers. This is both in terms of the inherent more onerous environment (salt water environment, wave movement of facilities etc.) and also the need to transfer between a support vessel and the infrastructure. There is a direct linkage between the number of transfers required and the overall risk exposure, both for the whole system and on an individual basis.	Whilst there are very similar risks associated with personnel movements and equipment transfer, the onshore environment is a more benign environment, with a greater range of more controllable methodologies for undertaking these kind of activities.	The principal design trade-off is between the following considerations: - The degree of centralisation of the system, so that equipment is in fewer locations versus system resilience against single point failures - The required throughput of energy from a location requiring conversion to hydrogen - The number and type of credible crew transfer, and equipment transfers that will be required to achieve the desired availability of the system

5.0 Forward Action Plan (FAP)

The following section presents either:

- Specific Recommendations identified in the workshop by the attendees
- Further Recommendations, for attendees' consideration during review of this document, arising from the development of this workshop report

5.1 Specific Recommendations

There were a number of Safety Hazards of consequence where insufficient safeguards could be expected and where a recommended action was made by the workshop. These recommendations are presented in Table 5 and Table 6 below.

Table 5: List of Recommendations made by the Workshop for Risks Specific to Option 1 and common to all

No.	System Element	Operation Phase	Prompt	Cause	Consequence	Safeguards	Recommendations	
							Recommendation Description	Responsibility
4	Offshore	Safety	High pressure gas	Pipeline rupture, hydrogen embrittlement of line.	Localised gas release, leading to a reduction of buoyancy of vessels passing through. Change of atmosphere could impact on combustion engines in the locality of the wind farm.		Modelling for high pressure gas release.	Project Developer
6			Flammable / explosive gas – jet fire / explosions	Hydrogen/air mix in the electrolyser enclosure (buffer store).	Fire explosion in enclosure housing.	Electrolysers to be outside the turbine housing. Hydrogen detection philosophy within the enclosure. Hydrogen venting philosophy and vent location.	Find a safe solution for venting, considering both individual turbine and wind array.	Project Developer
7				Oxygen venting.			Assess credible oxygen concentrations around single turbine and array as a whole. Strategy for venting of oxygen. Expect only a very small zone (approx. 6 metres). Consider an option to disperse into the water.	Project Developer
8				Large leak with immediate ignition.	Jet fire impinging on other equipment causing escalation of damage.		Assess credibility of underwater jet fire.	Project Developer
9					Potential for water ingress to the pipeline.		Modelling of impact of water ingress on flexible and fixed lines. Consider remediation replacement philosophy. Assess requirement for pigging capability. Isolation philosophy should not permit water ingress throughout the system - impact on ability to return to operation. Each turbine is expected to be isolatable.	Project Developer
11			High voltage electricity	Shorting of Circuit Breaker in the presence of a local hydrogen cloud.	Potential ignition of flammable gas.		Consider electrical isolation philosophy for such a scenario. (switchgear and power control circuitry) Consider the physical segregation philosophy.	Project Developer
12				Shorting as a result of turbine movement in the presence of a local hydrogen cloud.	Potential ignition of flammable gas.		Ensure earthing philosophy and methodology is consistent with specifics of the wind array architecture and technologies used.	Project Developer
13							Firefighting philosophy; fire suppression systems on board to be thought through.	Project Developer
14			Impact / collisions - pipeline	Impact with merchant shipping in the area. Note that there is a high volume of traffic through the Irish sea.	Potential for line rupture where the pipeline is in shallow waters as it is coming inshore. (12" bore pipeline).	Potential of a Vessel Traffic Services system to help identify wind farms that are being developed. Merchant shipping likely to stay in the main channel.	Ensure minimal shallow run of the piping. Potential for trenching and physical protection where coming ashore to mitigate the risk.	Project Developer

No.	System Element	Operation Phase	Prompt	Cause	Consequence	Safeguards	Recommendations	
							Recommendation Description	Responsibility
16				Impact of Anchor dragging / trawling.	Potential for line rupture. Potential for vessel loss. Vessel can be stuck in position.	Pipeline inventory segregation by isolation valves. Fibre optic system to identify pipeline rupture with appropriate system response. Fibre Optics can be part of the communications with array.	Mark off areas where vessels are not to go. Consider routing away from area that large vessels (over 24 metre load line length or more than 150 gross tonnes) would want to anchor. Consider inventory isolation and depressurisation philosophy. Ensure it covers daisy chained pipelines as well. Emergency planning regarding stuck vessel. How to identify this happens. Gas line escape needs to be modelled to identify the potential impact to the vessel.	Project Developer
18			Impact / collisions - wind array	Impact with merchant shipping in the area. High volume of traffic through the Irish sea.	Damage to anchor systems so the turbines are no longer anchored correctly. Damage to the wind turbines. Damage to the turbine ladder for onboarding; staff could be marooned. Damage to daisy chained pipelines.		Consider movement control during infield operation.	Project Developer
19				Impact with private shipping.				
20				Impact with infield vessels.				
21				Impact with fishing vessels / trawling impact	Damage to anchor systems so the turbines are no longer anchored correctly. Damage to the wind turbines. Damage to the turbine ladder for onboarding; staff could be marooned. Damage to daisy chained pipelines.		Consider the issue of discarded nets and options to remove them.	Project Developer
22				Turbine breaking free.	Partial loss of anchorage could mean they are only lightly tethered. Potential for loss or overturned turbine to release to the local environment.		Look at the different floating configurations to understand turbine behaviour on loss of moorings. Consider scenarios where turbines sweep out an area and potential impact on neighbouring turbines in the array.	Project Developer

No.	System Element	Operation Phase	Prompt	Cause	Consequence	Safeguards	Recommendations	
							Recommendation Description	Responsibility
27		Operational	Inspection / Repair/ Maintenance	Five yearly - Electrolyser stack changeover, consumables change over, recertification, Hull inspection, riser, other structural inspections 3 monthly - consumables, changeover, walkdown inspection, access confirmation 6 monthly - alkali swap over (for alkaline electrolysers), strainers/filters, Calibration. Any SIF assurance tasks (e.g. sequential shutdown)	Increased downtime. Greater lifts required (each stack 1 tonne). Swung loads. Potential diving / ROV operations. Remove turbine from the array. Potential for ROV entanglements. Co-ordination with clients, big service disruptions. Greater maintenance personnel crews required. More co-ordination with third party services. Potential for dry dock service. SOLAS or DNV marine certification requirements.	Redundancy of design to improve availability of critical systems and allow duty/standby without disruption of process. Ensuring safe accommodation for turbine crews (consider greater number of crew members, currently 2). Plan to minimise maintenance crew and crew exposure to minimal practical.	Overall array architecture to support rolling maintenance. Compare expected scheduled downtime depending on array architecture. Is the concept of hydrogen generation per turbine going to meet business objectives? RAM modelling. Digital twins.	Project Developer
29	Onshore	Safety	High pressure gas	Overpressure in the storage system.	Potential for explosion with debris acting as shrapnel. Potential for pipe whip and escalation damage at a significant distance (100s of metres).	Flaring to atmosphere rather than venting (probably not allowed to vent large quantities of Hydrogen).	Siting of control room, explosion proof or outside of the over-pressure contour. Is the flare system design for O&G suitable for Hydrogen? Would need a flare area, a large space underneath, and maybe an exclusion, no-fly zone. Speed of flaring system must be suitable for Hydrogen over pressure. Consider potential scenarios for venting rather than flaring. Blast protection design is based on hydrocarbons, is it suitable for Hydrogen too?	Project Developer
30				Human error when working with High Pressure Hydrogen Systems.	Potential for serious injuries or death during construction and operation.		Ensure personnel are suitable trained to work with High Pressure Hydrogen Systems.	
31			Flammable / explosive gas – jet fire / explosions	Fire/explosion crossing boundary line.	Potential for Fire / explosion to travel further downstream via pipelines.		Consider methods of deflagration isolation. Blast protection design is for Hydrocarbons. However hydrogen burns differently; this needs to be reassessed. Offsite emergency plan – if co-locate with an LNG facility, would need to think about escalation between sites. Co-ordinate with local first responders, ensure they are prepared for Hydrogen fires. Plan for common fire drills, integrated fire alarm and fire response. Request for Port of Milford Haven Authority, request for emergency response plans.	Project Developer
32		Operational	Loss of transmission / function / service	Hydrogen gas saturation. By compressing and then cooling there may be significant water drop out in the line.	Potential for line rupture.	Potential for drying capability within the electrolyser itself.	Some drying / water trap approach required. Would get a good few years out of desiccant material	Project Developer
33				Hydrogen embrittlement in the pipeline.	Potential for line rupture.		Material selection to combat the mechanism of embrittlement.	Project Developer

No.	System Element	Operation Phase	Prompt	Cause	Consequence	Safeguards	Recommendations	
							Recommendation Description	Responsibility
34			Disruption to other users / operators.	Incident or accident with LNG ship that is collecting Hydrogen from the Port.	Potential for fire and explosion.		Emergency plan for something going wrong in the haven, and for facilities along the haven to be discussed with MHPA and other sites, do other sites need to halt operations while another site experiences problems? Permit to work process required. Co-ordinate with other facilities on scheduled and unscheduled shutdowns.	Project Developer

Table 6: List of Recommendations made by the Workshop for Risks specific to Options 2 and 3

No.	System Element	Operation Phase	Prompt	Cause	Consequence	Safeguards	Recommendations	
							Recommendation Description	Responsibility
1	Offshore	Safety	Flammable / explosive gas – jet fire / explosions.	of oxygen leading to oxygen cloud.	Potential for explosion.		Handling of large volumes of Oxygen has significant safety hazards associated. These must be identified and acted upon.	Project Developer
2				Bleed over between hydrogen and oxygen streams. Potential about getting in each other's tanks.	Potential for explosion.		Look for suitable active isolation system.	Project Developer
3			High voltage electricity.	Anchors dragging the main power cable.	Potential for shorting and power outage.		Impact of Anchor dragging to be further risk assessed.	Project Developer
4	Onshore	Operational	Loss of transmission / function / service.				Risks associated with diesel day tanks for the black start diesel generator.	Project Developer

5.2 Further Recommendations

The following Recommendations are linked to the Arising Common Themes presented in Table 3.

No.	Recommendation Description
1	Common Theme 1 - The consortium should research and establish the 'transition' points where the various option aspects move between different design responses. This would cover: - The degree of centralisation versus distribution and this impacts the availability requirement (primarily the ability to undertake maintenance), and also the underlying risk to personnel during construction and maintenance activities - The location for electricity to hydrogen conversion and how this interacts with: required energy throughput, concentration of 'waste' products at the conversion location including environmental and safety implications - Understand the balance of conversion capacity versus storage capacity and its interaction with availability for end consumers and safety implications. Should storage capacity be reached, consideration should be made for capability to direct electrical supply to end consumers. - The specific energy vector to be used and the trade-offs between risk exposure, e.g. flammable / explosive risk of compressed gaseous hydrogen versus toxic and environmental impacts of ammonia, and the intended end consumer
2	Common Theme 2 – To support decisions on credible offshore pipeline /cabling routes the consortium should: - Determine what common infrastructure currently / will exist - Determine potential routes that could be used for either pipeline or cable routes for intended throughput, and assess the potential safety scenarios along those routes
3	Common Theme 3 – To support decisions on credible onshore locations and pipeline / cabling routes the consortium should: - Determine what infrastructure services will be required for their proposed installation - Determine what locations could potentially support those service requirements - Assess the potential safety scenarios for those locations
4	Common Theme 4 – The consortium should re-evaluate their current assumed main end consumer to ensure that they are considered the best placed end user and how that may influence the choice of hydrogen energy vector
5	Common Theme 5 – The consortium should ensure that high pressure gas release / rupture scenarios are considered in more detail and appropriate mitigations applied, such as burying pipelines where practicable.

6.0 Conclusions

The following are broad conclusions form the workshop, based on common emerging themes or issues that must be accounted for in the future development of the concept:

- The overall concept of the Hydrogen Chain to transfer captured energy from the Celtic Sea to Milford Haven is considered feasible, with no fundamental safety concerns that would preclude further development of the concept
- The concept does not introduce any unique safety hazards, however there will be significant safety assurance work to be undertaken to integrate the system in the current established offshore and onshore environments
- There are significant trade-offs between the different system architectures, and the consortium needs to properly understand the 'transition' points where one architecture option would become preferrable to another
- The completely de-centralised hydrogen production architecture introduces a maintenance burden, with the associated impact on availability and safety to personnel, in comparison with the other options considered in the workshop
- The onshore system elements will likely fall under the Control of Major Accidents and Hazards (COMAH) regulations. This will provide a structured safety assurance process for future concept development, and should be used as a reference point for future safety reviews/activities for the system development

Appendix A Options Supporting Information

1.0 Proposed Site Location and Options for the Hydrogen Chain

1.1 The proposed site location and the interface with existing infrastructure.

The existing sites in Milford Haven can be seen in Figure A1 (reference https://www.google.co.uk/maps/@51.7145394,-4.9814636,9476m/data=!3m1!1e3). These include Valero’s Pembroke Refinery, one of Europe’s largest and most complex refineries with a total capacity of 270,000 barrels per day; RWE’s 2.2 GW Pembroke Power Station which hosts combined cycle gas turbines; South Hook LNG terminal, which regasifies LNG and is the largest such site in Europe; Dragon LNG, another LNG terminal which, together with South Hook LNG terminal, can handle up to 25% of the UK’s gas requirement; and other facilities. Note that much of the information here was referenced from Port of Milford Haven, Wales | The UK's Largest Energy Port (mhpa.co.uk)

1.1.1 Traffic through the Milford Haven Sound

The Port of Milford Haven handles over 30 million tonnes of cargo annually, predominantly hydrocarbons. Their team works in marine operations, cargo handling, shipping layover, marine renewables, freight and passenger ferry services, fisheries, commercial property management, leisure and retail.

The Port’s southernly operation, Pembroke Port, accommodates bulk, break bulk, dry bulk and heavy lift cargoes. This has included a 380 tonne heat exchanger and project transportation to a refinery. It also has extensive onsite storage, fabrication and laydown options and acts as a supply port for industries working offshore. It provides emergency and planned layover and supplies services, as well as bunkering (afloat and on-quay) and has an explosives licence.

The Port of Milford Haven’s Pembroke Dock has a ferry terminal which accommodates a year round twice-daily ferry service to Ireland. It has a two-tier linkspan and handles freight and passenger traffic. The site has the capacity to provide additional ro-ro and ferry services and can accommodate vessels of up to 185 metres in length and drafts of up to 6.5 metres. This is supported by a 60T tugmaster fleet.

Another facility is the Milford Fish Docks, Wales’s largest fishing port. This has landing berths and platforms and is supported by a fleet of cargo handling/lifting vehicles, an ice plant and chill store, and bunkerage.

The waterway also hosts a marina for small vessels e.g., personal yachts/boats. This is used as a base for visitors to go to quayside shops, cafes, restaurants and other leisure facilities.

The port also has facilities for cruise ships. Vessels up to 160 m length overall can lie alongside at Pembroke Port, while vessels up to 220 m length overall can anchor on Milford Shelf, which is connected to the onshore facilities by a short tender trip.

Figure A1: Satellite view of Milford Haven, including LNG terminals, a refinery and a 2.2 GW gas power plant

1.1.2 Cross Sound Underground Pipeline.

The RWE power plant's natural gas is supplied from the main National Grid pipeline on the other side of the Haven, near to the liquefied natural gas (LNG) import terminals. During the construction process, a 4.5km gas pipeline was drilled under the Haven estuary to facilitate the fuel supply (Figure A2 (reference https://uk-ireland.rwe.com/-/media/RWE/documents/01-der-konzern/betriebsstandorte/pemb-power-station-a4-20pp-brochure.pdf)).

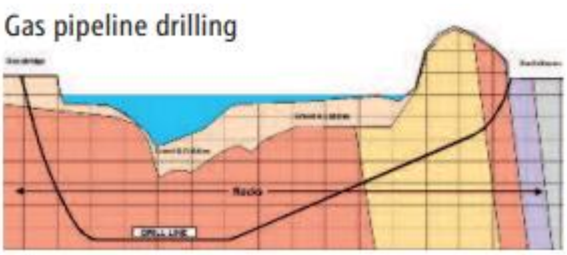


Figure A2: Gas Pipeline under the Sound providing Gas to the RWE Gas Power Plant.

1.1.3 Land Ownership

The Pembrokeshire County Council own tracks of land, as do the National Trust and the MoD (specifically Castle Martin, a tank training range).

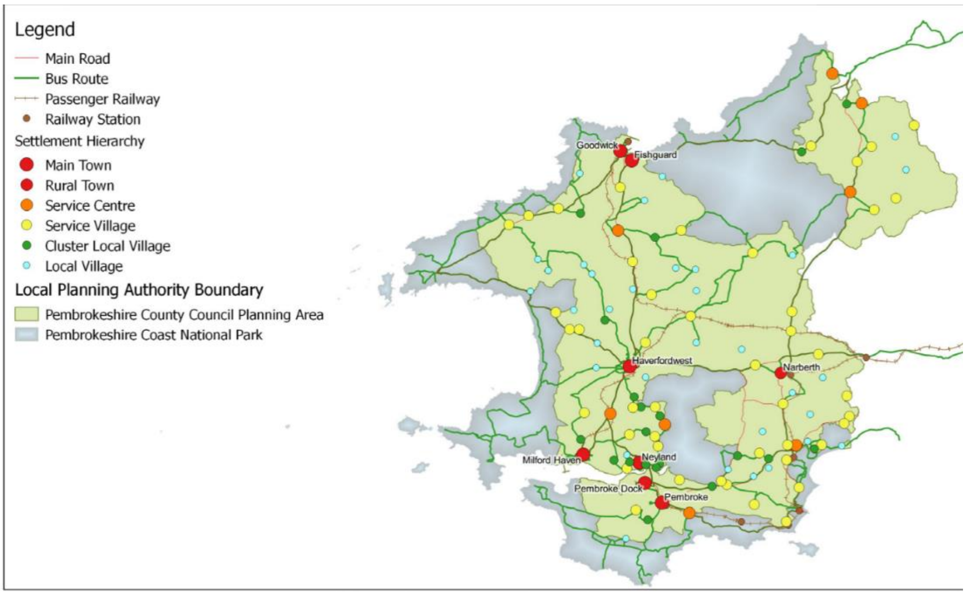


Figure A3: Split of the planning board authorities in Pembrokeshire

1.1.4 Potential Offtake Options

Offtake Option	Offtake Use	Hydrogen (t/day)	Wind Capacity (MW)	Estimated Timeline
Pembroke Council	Vehicle Fleet and Hydrogen refueling hub in Milford Haven	1-2	6	2024
Pembroke Dock	Supply of hydrogen to marine vessels (potentially including Pembroke to Rosslare)	4-8	25	2035
Milford Haven Port	Transport and heating requirements	2-3	10	2030
Pembroke Refinery (Valero)	Industrial Heat/grey hydrogen replacement	>200	800	2030
Pembroke Refinery (Valero)	Low Carbon Synthetic Fuels	>1500	>6000	2040
Pembroke Oil Terminal (Valero)	Bulk scale production and storage of LOHC or Ammonia for export	>1000	>4000	2040
Power Station (RWE)	Blend into single gas turbine (Trial)	20	80	2030
Power Station (RWE)	To fuel future hydrogen gas turbines	>1500	>6000	2040
Local Gas Network (Wales & West)	20% blend into local gas network. Potentially 100% into regional distribution system by early 2030's	9 (20%) 45 (100%)	36 180	2025 2032
National Grid	Potential to inject directly into 100% hydrogen 'backbone') by early 2030's	>250	1000	2030

Table A4: ERM's high level estimates of potential hydrogen consumption in the Milford Haven region.

There are a variety of facilities in Milford Haven which could use hydrogen. For this workshop, focus was on the RWE gas power plant.

1.1.5 Stakeholders Milford Haven Waterway

Stakeholders that will need to consulted on any development of the Milford Haven Waterway and its environs were identified and are presented in Table D4 in Appendix D.

1.1.6 Alternative Floating Wind Turbine array layouts for discussion

The base case layout for the Floating Wind Turbine (FWT) array, a daisy chain arrangement, is shown in Figure A5. Two other layouts, a fishbone arrangement and a star arrangement are shown in Figures A6 and A7 respectively.

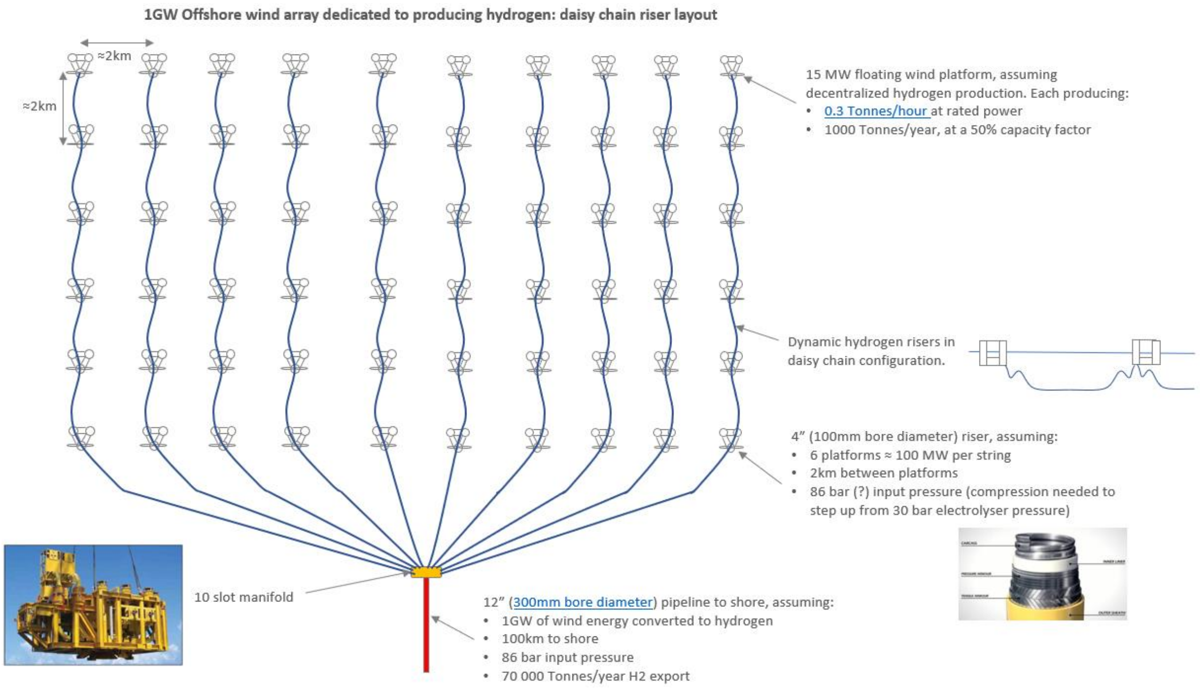


Figure A5: Base layout of repeating units in Option 1, with indicative numbers for a 1 GW set up.

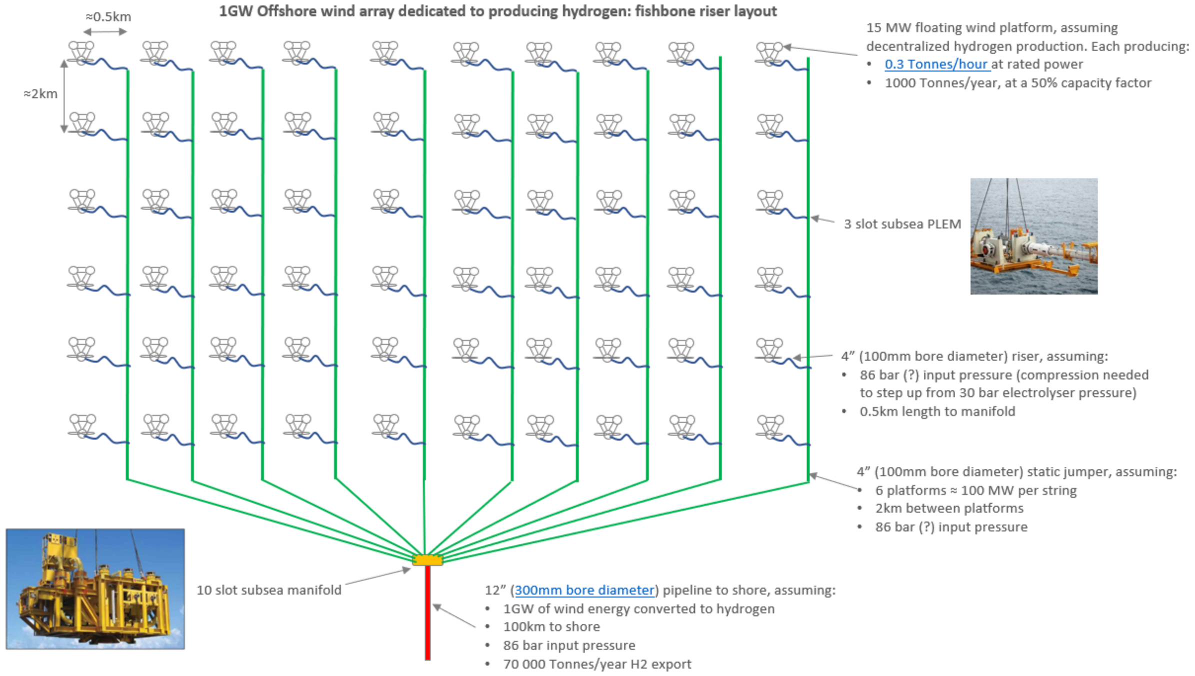


Figure A6: first alternative repeating unit layout for Option 1

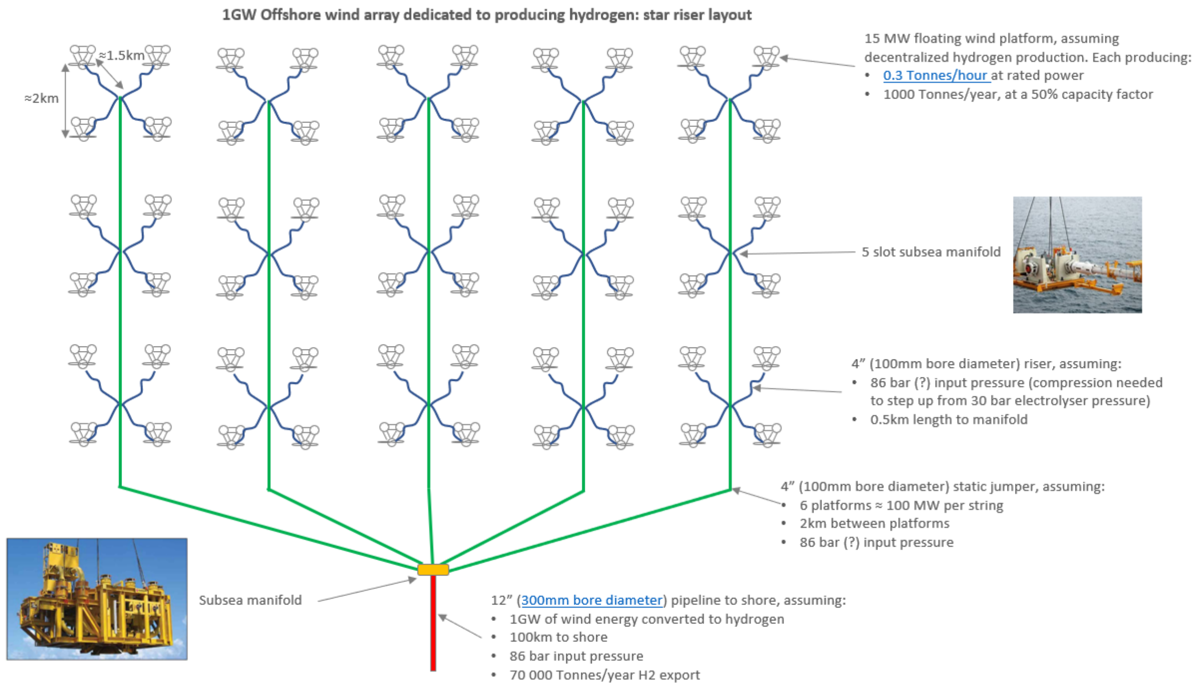


Figure A7: second alternative repeating unit layout for Option 1.

1.1.7 The three options for Capture, Transmission, Storage and Conversion

There are three main possibilities downstream of the wind farm.

The first (figure A8) is offshore decentralized electrolysers, whereby each wind turbine has its own electrolysis plant (figure A9) installed onboard (creating a new interface). This hydrogen then interfaces with the export mechanism (probably a pipeline, potentially a ship), before interfacing with the infrastructure in Milford Haven and the wider energy system.

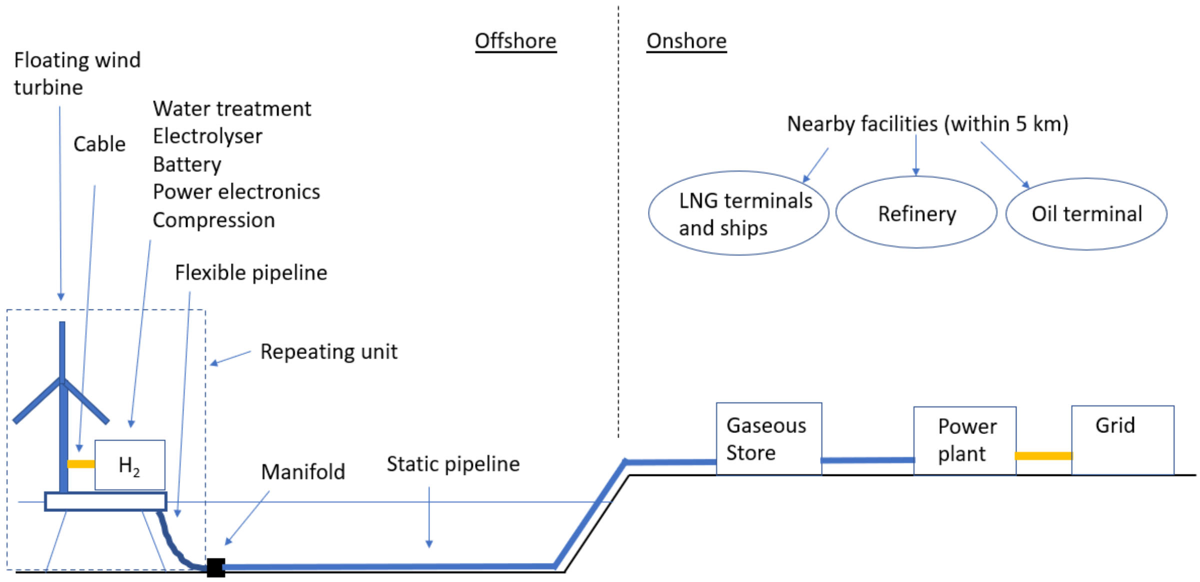


Figure A8: Option 1 - offshore decentralized electrolyzer with hydrogen export via pipeline to storage for use in a gas power plant

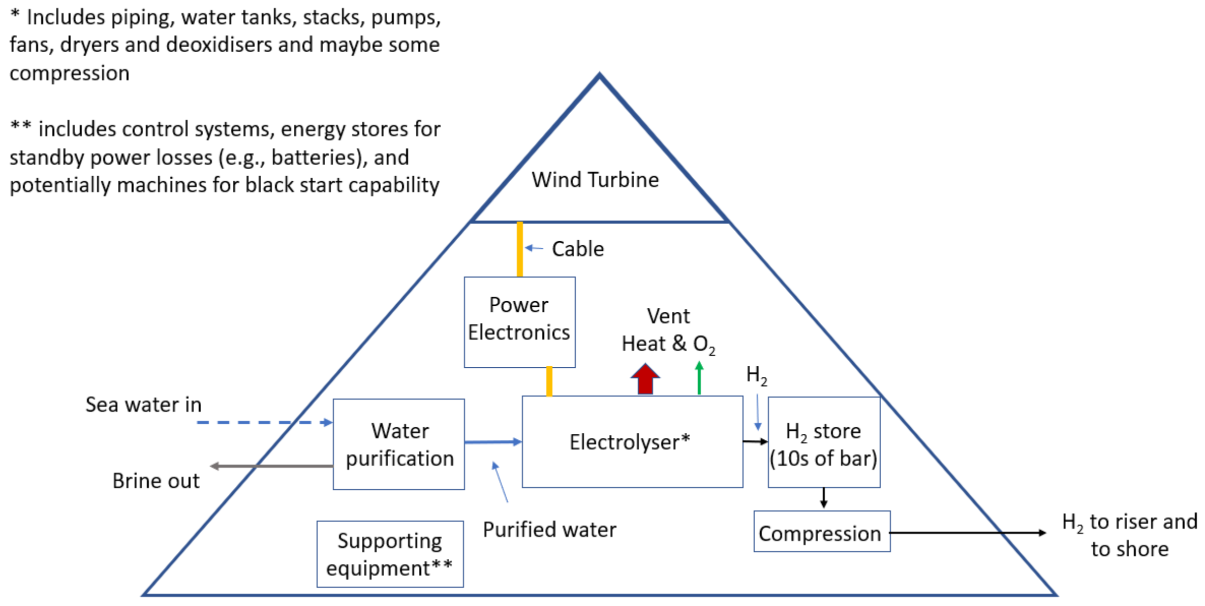


Figure A9: Top down view of repeating unit in Option 1

The second possibility (figure A10) is to have a conventional windfarm connected to an onshore electrolyzer. In this case, the power is collected and processed in a substation and sent ashore as electricity to the electrolyzer (a new interface), which then interfaces with the existing infrastructure and the wider energy system.

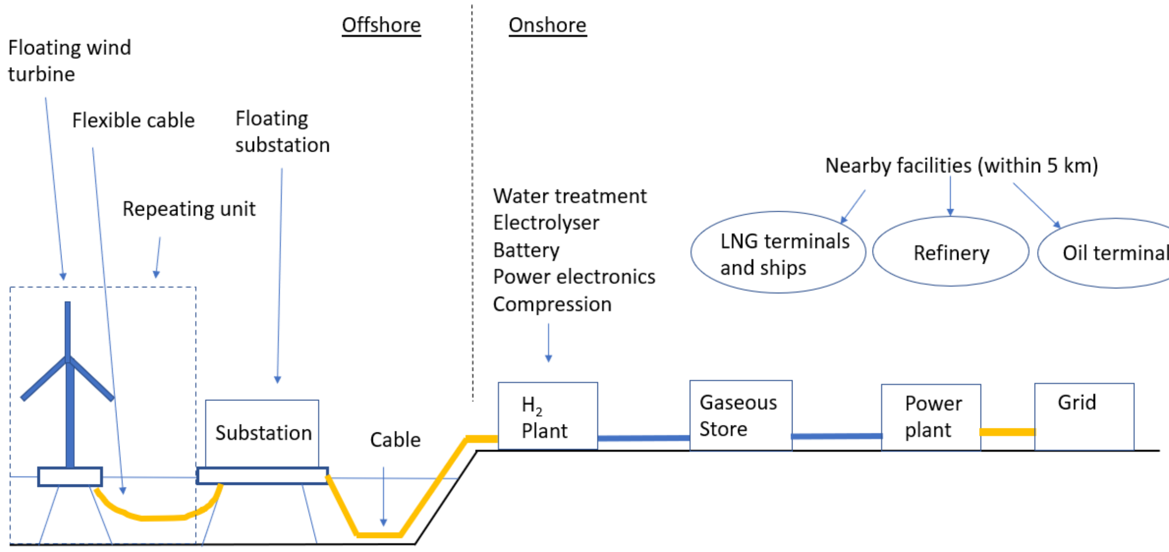


Figure A10: Option 2 - onshore centralized electrolyser with storage for hydrogen which is then used in a gas power plant

The third option (figure A11) is to have an offshore centralized electrolyser, whereby there is a large electrolyzer offshore that interfaces with a number of wind turbines, or the whole wind farm. The produced hydrogen is then shipped to an onshore storage facility. Downstream of this point, this option has the same interfaces as the offshore decentralized electrolysers.

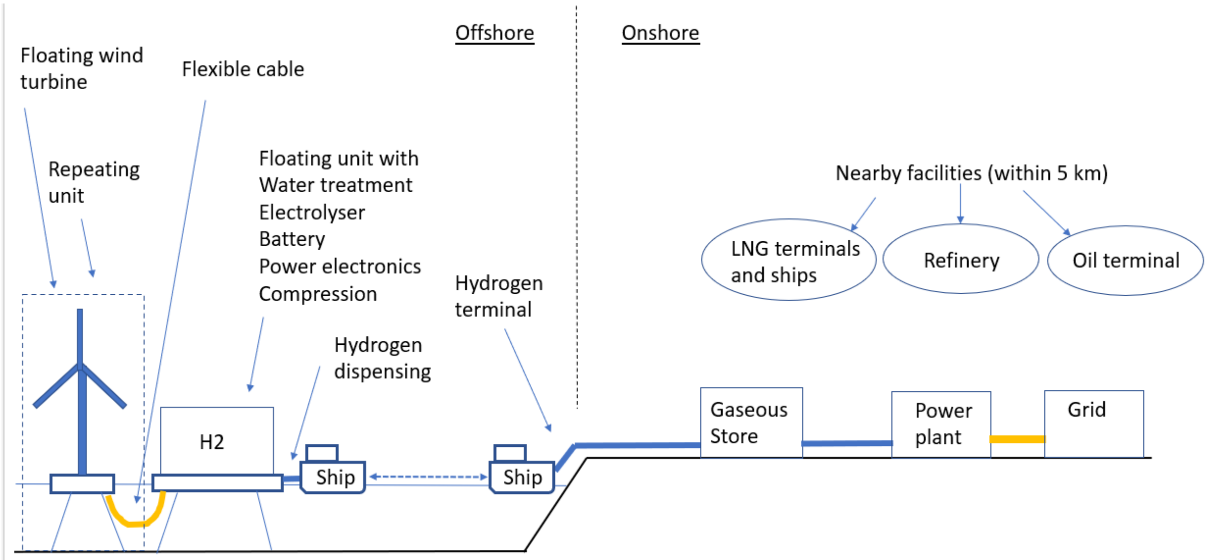


Figure A11: Option 3 - offshore centralized electrolysis with hydrogen export via ship to storage for use in a gas power plant

1.1.8 Alternatives for pipeline/cables/vessels onshoring

Three alternatives were drawn up for routing pipelines/cables/vessels ashore, so to aid the initial discussion, shown in Figure A12, Figure A13 and Figure A14.

Figure A12: possible configuration for landing energy in Option 1 - bringing hydrogen onshore for storage before sending to the power station. Theoretical alternative options are to incorporate hydrogen storage into the existing LNG terminals.

Figure A13: one possibility for landing energy in Option 2 - an electrical cable connected to an electrolyser with storage.

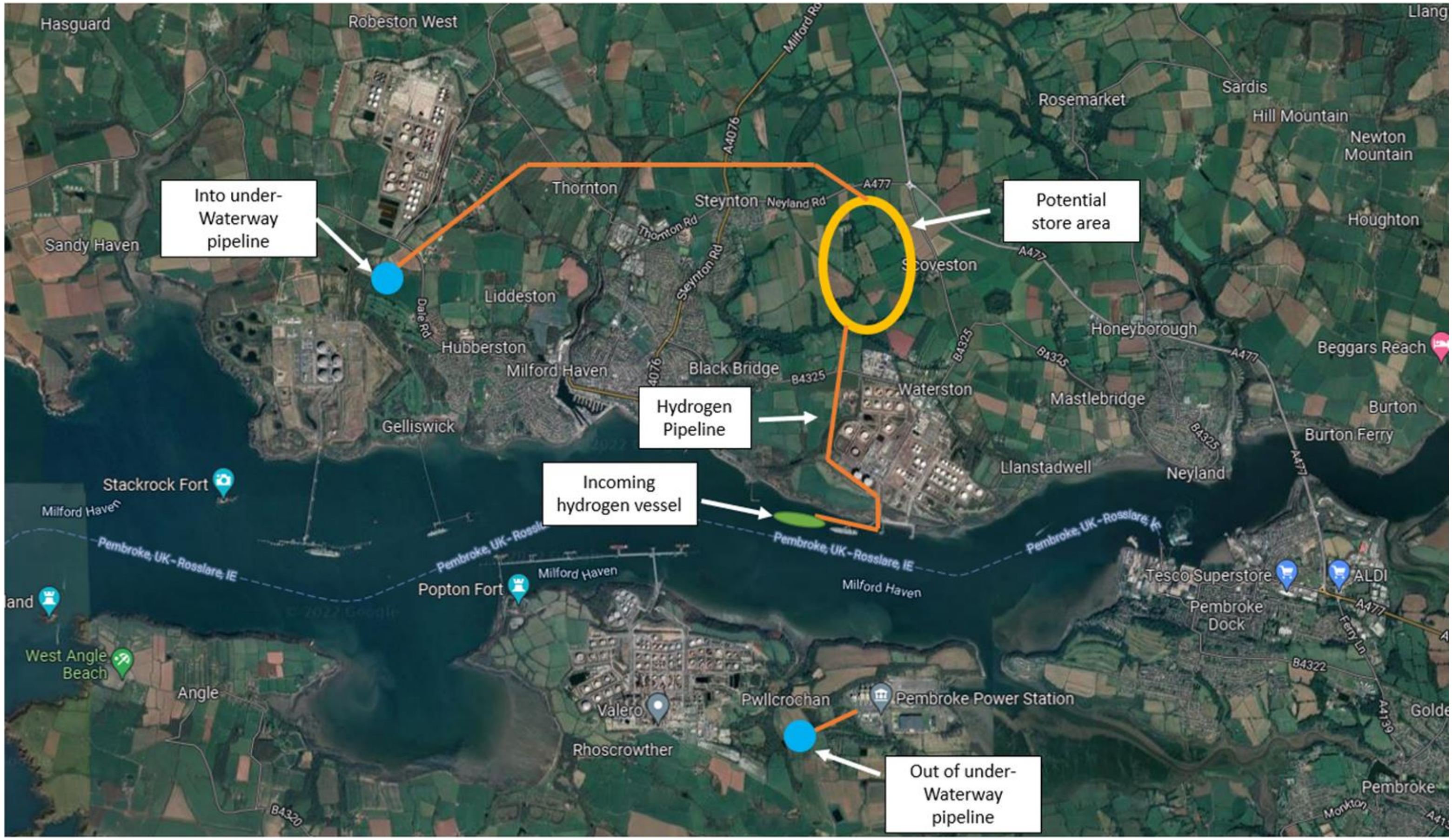


Figure A14: one possibility for landing energy in Option 3 - hydrogen imported via a ship.

Appendix B Workshop Methodology

Methodology

The workshops were based on a structured brainstorming approach that went through the following main steps:

- Description of the system boundary and interfaces across that boundary
- Review and assessment of the different steps/phases of the system concept to identify divergence from intended operation
- Assessment of the credible consequences (safety and operational) of the divergences from intended operation
- Capture of arising considerations / recommendations / follow on actions

The above steps are described in more detail below

- Description of the system boundary and interfaces – the intent was to build on the detail of the system description (with Option 1 being the primary consideration) and to understand the system configurations and interfaces. This was done through a structured brainstorming approach using the following prompts:
  - Operational phases – this was intended to develop understanding of the development of operation of the system
    - Installation and commissioning
    - Operation and maintenance (planned & unplanned)
    - Retirement and replacement
  - Interfaces – there are multiple different interfaces across the system boundary. These fall broadly under the following categories
    - Physical – such things as pipe and High Voltage cable connections
    - Logical – such things as command-and-control signals or meteorological data used to provide array management (NB these may closely align with physical interfaces)
    - Organisational – such things as necessary relationships with first responders for incident/accident response
- Identification of divergences from operation – this was primarily based on the attendees' knowledge and experience, but to support that assessment the following initial prompts were used during the workshop:
  - Safety
    - High pressure gas
    - Flammable / explosive gas – jet fire / explosions
    - High voltage electricity
    - Impact / collisions
  - Operational
    - Loss of transmission / function / service
    - Degradation in transmission / function / service
    - Disruption to other users / operators
- Assessment of credible consequences – this was based on the workshop attendees' experience organised under the following broad categories
  - Consequences within the system boundary
  - Consequences to parties outside the system boundary

- Capture of recommendations / actions – these were captured as the workshop was conducted and are linked to a line of assessment. However, there was also a ‘parking lot’ for other emerging discussions so that they are captured for future follow up

Agendas

Based on the previously described Scope and Methodology the following outline agendas were followed.

20th April

14:00 – Welcome and introductions
14:10 – Outline description of system and operations – focused on Option 1 - Offshore
14:30 – Start detailed review of system boundary and interfaces
15:30 – Break
15:40 – Start assessment of divergences and consequences - offshore
16:20 – Break
16:30 – Continue assessment of divergences and consequences - offshore
17:00 - Finish

22nd April

14:00 – Welcome and introductions
14:10 – Review of previous system boundary and interfaces - focused on Option 1 - Onshore
14:30 – Start assessment of divergences and consequences - onshore
15:30 – Break
15:40 – Continue assessment of divergences and consequences - onshore
16:20 – Break
16:30 – Continue assessment of divergences and consequences - onshore
17:00 - Finish

29th April

14:00 – Welcome and introductions
14:10 – Review of previous system boundary and interfaces - Option 1 Onshore & Offshore & other Options if possible
14:30 – Start assessment of divergences and consequences – offshore & onshore
15:30 – Break
15:40 – Continue assessment of divergences and consequences - offshore & onshore
16:20 – Break
16:30 – Continue assessment of divergences and consequences - offshore & onshore
17:00 - Finish

Appendix C Workshop Record

Attendees and Workshops held remotely on 20th, 22nd and 29th April 2022.

1.0 Workshop Attendance

Attendees	20th April 2022
Name	**Organisation**
James Ferguson	ORE Catapult
David Lockwood	MHPA
Alex Shields	CPH2
Andrew Sneddon	ERM
Michael Smailes	ORE Catapult
Mathieu Kervyn	ORE Catapult
Ed Macfarlane (Chair)	ARC
Ian Holmes (Scribe)	ARC

Attendees	22nd April 2022
Name	**Organisation**
James Ferguson	ORE Catapult
Tam Bardell	MHPA
Alex Shields	CPH2
Andrew Sneddon	ERM
Michelle Hitches	ORE Catapult
Michael Smailes	ORE Catapult
Mathieu Kervyn	ORE Catapult
Ed Macfarlane (Chair)	ARC
Ian Holmes (Scribe)	ARC

Attendees	29th April 2022
Name	**Organisation**
James Ferguson	ORE Catapult
Michelle Hitches	ORE Catapult
Michael Galvin	Simply Blue Group
Adam Hollis	RWE
Will Brindley	ORE Catapult
Paul McKeever	ORE Catapult
Mathieu Kervyn	ORE Catapult
Ed Macfarlane (Chair)	ARC
Ian Holmes (Scribe)	ARC

2.0 Boundaries for Option 1

No.		Prompt	Observations	Contributor
1	Operational phases	Installation and commissioning	690V or 3.3kV coming off the turbines.	Michael Smailes
2			Option 1 includes sub options for the turbine array namely; daisy chain layout, fish bone layout and star layout.	James Ferguson
3			Pipeline to be landed away from the channel. Option 1 on north side. Option 2 on south side.	James Ferguson
4			Potential for installing north pipeline across Dale Bay	David Lockwood
5			Turbines to be located wholly within UK waters? Potential for receiving power from Welsh and Irish waters. Interface with Irish interests.	James Ferguson
6			New store to be built. Above the 50T COMAH limit? We shall make that assumption.	James Ferguson
7			It is better practice to introduce export from each turbine incrementally, not all at once (option 1). Ed: we shall make this as a baseline consideration.	Andrew Sneddon
8		Operation and maintenance (planned & unplanned)	Maintenance during faults, enabling of breaking in and out of pipework chain.	Alex Shields
9			Large pipelines can prevent safe anchorage for smaller vessels.	David Lockwood
10			Pipelines not up channel for safety reasons (e.g. ship can drop anchor and puncture pipeline). 2000 large vessels entering harbour per year. Large pipelines reduces MHPA ability to operate as a port.	David Lockwood
11			Wake steering concept to optimise the array performance - Wind speed and direction inputs for this WSS. Incorporated into each turbine, referred to as wind farm (WF) control. Not sure where these inputs are to come from. A data interface required. From the WF central control. Data link by Fibre Optic cable alongside power output cable. Potential for alternative data link. Consider alternative routing for FO and hydrogen power to prevent outage from a common incident.	Group
12			Daisy chaining allows you to work on a one by one basis whilst the rest of the array can continue to produce. Ed: Another baseline consideration. It does go against Hydrogen best practiced reduce number of connections. Increased connections can lead to increased probability of leakage. Assume an isolation valve for each turbine. Alex: Recommends this for electrolysers. Make this as another baseline assumption.	Group
13			Potential for vessels with wet cargo and use of anchorages not currently used.	Tam Bardell
14			Export of hydrogen to approximately 90bar, after the buffer tank on each turbine.	James Ferguson
15		Retirement and replacement	Potential for adding turbines to increase capacity. Dolphyn have not considered expansion of their project.	Andrew Sneddon
16			Potential for collective infrastructure with future competitor suppliers.	Michael Smailes

17	Interfaces	Physical	Transition from marine authorities to local council to be physically marked on the pipeline. Sufficient marking to notify public. Interface with land owners when considering the routing. Location also close to national park. Cannot expect to have an exhaustive stakeholder list. Ed: Just looking for context. Will not be final list. Plenty of environmental concerns and SSSIs to be consulted with. 2km distance between turbines	Group
18			Connection to utilities, e.g. drains, water supply, sewage treatment and the like. Shared infrastructure. Capacity constraints associated with this infrastructure.	Ed Macfarlane
19			Boundary to consumer defined by an isolation valve. Feedback from consumers on any unexpected issues with the supply (on either side). Monitor the fiscal metering.	James Ferguson
20			Green link from Ireland to Wales.	James Ferguson
21			Supply to LNG facilities? Pipeline connecting the storage / facility? Discussion required with the operators. Good place to blend gas into the hydrogen stream.	Michael Galvin
22			Need to consider hazardous event at either end of this pipeline. Modelling of shockwave down pipeline from explosion at either end.	Ed Macfarlane
23			Potential for tanker offloading for delivery to consumers. How that impacts on emergency responders access.	James Ferguson
24			Details of the MHPA emergency response plans should there be a accident scenario in the haven. We should put together questions we'd like to put to the MHPA.	James Ferguson
25			How to convert gas turbines to h2 fuel. Need to put questions to RWE or the OEM, the operator at the gas power plant. Increased Ammonia in the fuel could result in higher NOx levels. Being made out of cast iron (Power turbines) there can be embrittlement issues not associated with aero turbines.	Group
26		Logical	Consider sufficient independence of process and safety control systems.	Ed Macfarlane
27		Organisational	Boundary around turbine array. Charts drawn up by UKHO At Taunton. Natural Resources Wales. Coast Guard for emergency plans. Marine Management Org. will need interface. Plenty of French, Spanish fishing. DEFRA. DFT. Need to talk to MoD regarding local fire range, submarine activity. Also CAA and Irish civilian air orgs (name?). Low volume of fixed wing activity. Trinity house for lighthousing.	Group
28			Uncertain who to be the first responders for emergency planning. Expect permanent maintenance team on site. How to size storage? James: Backbone of gas supply from grid. Expect the power generation will require tonnes of fuel per hour. Need to crunch numbers to determining the most viable solution. Gaseous / ammonia / even subterranean. Ed: This can introduce various hazardous situations. Requirement to prevent "feeding a fire" - SSIVs for example.	Group
29			Potential for helipad for use by maintenance crew	Tam Bardell
30			Do expect the manning levels associated with a LNG facility. Expect that required resource will have to move in to the area. Required technical capabilities will need to be determined. LNG will not be operating at the pressure the H2 plant will.	Michelle Hitches

3.0 HAZID Notes Option 1

No.	System Element	Operation Phase	Prompt	Cause	Consequence	Safeguards	Recommendations	
							Recommendation Description	Responsibility
1	Offshore	Safety	High pressure gas	daisy chain line rupture	Localised gas release, leading to a reduction of buoyancy of vessels passing through.	Local traffic routed around the array. Shutdown philosophy would segregate and reroute appropriately		
2					Pipe whip damage to turbine anchor system.			
3				Pipe rupture or buffer store tank rupture	Potential debris damage, collateral damage to other equipment in the enclosure.			
4				Pipeline rupture, hydrogen embrittlement of line	Localised gas release, leading to a reduction of buoyancy of vessels passing through.		Modelling for high pressure gas release	Project Developer
5			Flammable / explosive gas – jet fire / explosions	Hydrogen/oxygen mix in the line from the electrolyser	Explosion within the buffer tank or in the line.	Oxygen monitoring at the outlet. Oxygen scavenging. Emergency shutdown - how to return the system to service ASAP(?)		
6				Hydrogen/air mix in the electrolyser enclosure (buffer store)	Fire explosion in enclosure housing	Electrolysers to be outside the turbine housing. Hydrogen detection philosophy within the enclosure. Hydrogen venting philosophy and vent location.	Find a safe solution for venting, considering both individual turbine and wind array.	Project Developer
7				Oxygen venting			Assess credible oxygen concentrations around single turbine and array as a whole. Strategy for venting of oxygen. Expect only a very small zone (approx. 6 metres). Consider an option to disperse into the water.	Project Developer
8				Large leak with immediate ignition	Jet fire impinging on other equipment causing escalation of damage.		Assess credibility of underwater jet fire	Project Developer
9					Potential for water ingress to the pipeline		Modelling of impact of water ingress on flexible and fixed lines. Consider remediation replacement philosophy. Assess requirement for pigging capability. Isolation philosophy should not permit water ingress throughout the system - impact on ability to return to operation. Each turbine is expected to be isolatable.	Project Developer

10			Electrolyser technology	Leak from alkali electrolyser	Alkali damage to enclosure. Environmental impact of alkali leakage.	Bunding of the electrolyser.		
11			High voltage electricity	Arcing of Circuit Breaker in the presence of a local hydrogen cloud.	Potential ignition of flammable gas.		Consider electrical isolation philosophy for such a scenario. (Physical switchgear and power control circuitry) Consider the physical segregation philosophy.	Project Developer
12				Shorting as a result of turbine movement in the presence of a local hydrogen cloud.	Potential ignition of flammable gas.		Ensure earthing philosophy and methodology is consistent with specifics of the wind array architecture and technologies used.	Project Developer
13							Fire fighting philosophy; fire suppression systems on board to be thought through.	Project Developer
14			Impact / collisions - pipeline	Impact with merchant shipping in the area. Note that there is a high volume of traffic through the Irish sea.	Potential for line rupture where the pipeline is in shallow waters as it is coming inshore. (12" bore pipeline).	Potential of a Vessel Traffic Services system to help identify wind farms that are being developed. Merchant shipping likely to stay on the main channel.	Ensure minimal shallow run of the piping. Potential for trenching where coming ashore to mitigate the risk.	Project Developer
15				Impact with private shipping	(bounded by merchant shipping consequences)			
16				Impact of Anchor dragging / trawling	Potential for line rupture. Potential for vessel loss. Vessel can be stuck in position.	Pipeline inventory segregation with isolation valves. Fibre optic system to identify pipeline rupture with appropriate system response. Fibre Optics can be part of the communications with array.	Mark off areas where vessels are not to go. Consider routing away from area that big vessels would want to anchor. Consider inventory isolation and depressurisation philosophy. Ensure it covers daisy chained pipelines as well. Emergency planning regarding stuck vessel. How to identify this happens. Gas line escape needs to be modelled to identify the potential impact to the vessel.	Project Developer
17				Dropped object	Potential for line rupture. Damage to main manifold.	Control of lifting operations, to ensure not over any lines. Pipeline inventory segregation with isolation valves. Fibre optic system to identify pipeline rupture with appropriate system response. Fibre optic system can be part of the communications with the turbine array.		
18			Impact / collisions - wind array	Impact with merchant shipping in the area. High volume of traffic through the Irish sea.	Damage to anchor systems so the turbines are no longer anchored correctly. Damage to the wind turbines. Damage to the turbine ladder for onboarding; staff could be		Consider movement control during infield operation.	Project Developer

19				Impact with private shipping	marooned. Damage to daisy chained pipelines.			
20				Impact with infield vessels				
21				Impact with fishing vessels / trawling impact	Damage to anchor systems so the turbines are no longer anchored correctly. Damage to the wind turbines. Damage to the turbine ladder for onboarding; staff could be marooned. Damage to daisy chained pipelines.		Consider the issue of discarded nets and options to remove them.	Project Developer
22				Turbine breaking free	Partial loss of anchorage could mean they are only lightly tethered. Potential for loss or overturned turbine to release to the local environment.		Look at the different floating configurations to understand turbine behaviour on loss of moorings. Consider scenarios where turbines sweep out an area and potential impact on neighbouring turbines in the array.	Project Developer
23			Impact / collisions - third party	Turbine breaking free	Turbine breaking free, uncontrolled floating turbine in open water. Potential collision with third parties.	Will be identified on radar systems. Radar identifiers are installed on each turbine.		
24		Operational	Inspection / Repair/ Maintenance	3 monthly - consumables, changeover, walkdown inspection, access confirmation	Crew transfer, infield vessel movements, (assume: drop load not a concern)	Condition monitoring, predictive maintenance. To minimise unplanned maintenance.		
25				6 monthly - alkali swap over, strainers/filters, Calibration. Any SIF assurance tasks (e.g. sequential shutdown)	Crew transfer, infield vessel movements. Potential for significant bulk transfers of alkali.			
26				annual - changeover water treatment, shutdown to allow more extensive maintenance activities. RWE written scheme of examination or HP gas systems (RBI or NDT). Any SIF assurance tasks (e.g. sequential shutdown)	Multiple crew transfers, infield vessel movement. Extended period of time for work on turbines. Planning and scheduling for desired downtime. Ensure correct isolations. Multiple bulk transfers. Potential for third parties on site. Considered task scheduling around meteorological conditions. Extensive emergency plans.			

27				five yearly - PEM changeover, recertification, Hull inspection, riser, other structural inspections	Increased downtime. Greater lifts required (each stack 1T). Swung loads. Potential diving / ROV operations. Remove turbine from the array. Potential for ROV entanglements. Co-ordination with clients, big service disruptions. Greater maintenance personnel crews required. More co-ordination with third party services. Potential for dry dock service. SOLAS or DNV marine certification requirements.	Redundancy of design to improve availability of critical systems and allow duty/standby without disruption of process. Ensuring safe accommodation for turbine crews (consider greater number of crew members, currently 2). Plan to minimise maintenance crew and crew exposure to minimal practical.	Overall array architecture to support rolling maintenance. Compare expected scheduled downtime depending on array architecture. Is the concept of hydrogen generation per turbine going to meet business objectives? RAM modelling. Digital twins.	Project Developer
28				Unplanned - compressor failure, pump failure, turbine failure, anchor, instrument	Prolonged disruption of service. Time pressure to complete activities.	monitor strain at the cables / chains. Harmonic modelling of the cables / chains. Maintenance team to carry out safe job analysis.		Project Developer
29	Onshore	Safety	High pressure gas	Overpressure in the storage system	Potential for explosion with debris acting as shrapnel. Potential for pipe whip and escalation damage at a significant distance (miles).	Flaring to atmosphere rather than venting (Probably not allowed to vent large quantities of Hydrogen).	Siting of control room, explosion proof or outside of the pressure contour. Is the flare system design for O&G suitable for Hydrogen. Would need a flare area, a large space underneath, and maybe an exclusion, no-fly zone. Speed of flaring system must be suitable for Hydrogen over pressure. Consider potential scenarios for venting rather than flaring. Blast protection design is based on hydrocarbons, is it suitable for Hydrogen too.	Project Developer
30				Human error when working with High Pressure Hydrogen Systems.	Potential for serious injuries or death during construction and operation.		Ensure personnel are suitable trained to work with High Pressure Hydrogen Systems.	
31			Flammable / explosive gas – jet fire / explosions	Fire/explosion crossing boundary line	Potential for Fire / explosion to travel further downstream via pipelines.		Consider methods of deflagration isolation. Blast protection design is for Hydrocarbons. However hydrogen burns differently; this needs to be reassessed. Offsite emergency plan – if co-locate with an LNG facility, would need to think about escalation between sites. Consider escalation scenarios between sites. Co-ordinate with local first responders, ensure they are prepared for Hydrogen fires. Plan for common fire drills, integrated fire alarm and fire response. Request for Port of Milford Haven Authority, request for emergency response plans.	Project Developer
32		Operational	Loss of transmission / function / service	Hydrogen gas saturation. By compressing and then cooling there has significant water drop out in the line.	Potential for line rupture.	Potential for drying capability within the electrolyser itself.	Some drying / water trap approach required. Would get a good few years out of desiccant material	Project Developer

33				Hydrogen embrittlement in the pipeline.	Potential for line rupture.		Material selection to combat the mechanism of embrittlement.	Project Developer
34			Disruption to other users / operators	Incident or accident with LNG ship that is collecting Hydrogen from the Port.	Potential for fire and explosion		Emergency plan for something going wrong in the haven, and for facilities along the haven to be discussed with MHPA and other sites, do other sites need to halt operations while another site experiences problems? Permit to work process required. Co-ordinate with other facilities on scheduled and unscheduled shutdowns.	Project Developer

4.0 HAZID Option Notes 2 & 3

No.	System Element	Operation Phase	Prompt	Cause	Consequence	Safeguards	Recommendations	
							Recommendation Description	Responsibility
1	Offshore	Safety	Flammable / explosive gas – jet fire / explosions	Leakage of oxygen leading to significant oxygen cloud from the oxygen store.	Potential for explosion		Handling of large volumes of Oxygen has significant safety hazards associated. These must be identified and acted upon.	Project developer
2				Bleed over between hydrogen and oxygen streams. Potential for significant volumes getting in each other's tanks.	Potential for explosion		Look for suitable active isolation system.	Project developer
3			High voltage electricity	Anchors dragging the main power cable	Potential for shorting and power outage.		Impact of Anchor dragging ot be further risk assessed.	Project developer
4	Onshore	Operational	Loss of transmission / function / service				Risks associated with diesel day tanks for diesel generator.	Project developer

5.0 Parking Lot for Option 1

No.	When/ Where Raised	Discussion / Action	Contributor
1	Offshore	Pipeline routing needs requirements for ship location and safe anchorage	Ed Macfarlane
2		Feasible piping routes to consumer locations.	Ed Macfarlane
3		Confirm use and application of LNG pipeline (capped with concrete today)	Ed Macfarlane
4		Impact of release of concentrated brine produced as part of the desalination activity on local environment.	James Ferguson
5		Cyber security issues.	Ed Macfarlane
6		Potential for accident propagation between turbines via explosion or shock propagation down the daisy chain pipeline.	James Ferguson
7		Look at venting philosophy. Potential ignition sources during venting.	Ed Macfarlane
8		Understand earthing route design. Consider lightning protection.	Mathew Kervyn
9		Target for theft of rare materials.	James Ferguson
10		Fouling at the seawater inlet of the Water Purification Unit, marine life etc can damage the inlet pumps. Need for strainers at the inlet.	Adam Hollis
11		It was advised to have an initial one month maintenance schedule due to expected poor reliability of the multi-component train. This could be extended later in life backed by operational experience. Overall system architecture and maintenance philosophy need to be done at the same time.	Adam Hollis
12	Onshore	Storing hydrogen as hydrogen not looking a starter. Green ammonia probably the best way forward.	Michael Galvin
13		Communicate with other facilities on sharing infrastructure such as water, power drains sewage, fire water. Ensure proper integration with common infrastructure.	Michael Galvin
14		It is expected people will have to move into the area to man the Hydrogen plant. There is not the capacity locally. People will require training, to operate and construct, different from natural gas requirements.	James Ferguson
15		During construction and operation will there be a requirement for additional accommodation near or on the site.	James Ferguson
16		Use of hydrogen in the power plant: Retrofit of drivers for turbines, compressors etc as hydrogen flame burns differently to hydrocarbons. Wobble index, energy per volume and how this impact driver performance. Gas detection and control systems would need to be updated Training of personnel Inertia to the grid – will the actual system behave in the same way ? Ramp up rates. Potential for Hydrogen embrittlement of the drivers. Existing emergency plans will have to be re-assessed. Risk assessments for the power plant will have to be re-assessed.	Ed Macfarlane

17		Use of Ammonia in the power plant: More NOx emissions as a result. Study will be required to assess the feasibility of using Ammonia.	Ed Macfarlane

6.0 Parking Lot for Options 2 and 3

No.	When/ Where Raised	Discussion / Action	Contributor
1	Onshore	Oxygen production right by refinery. Large volumes of water required. Potential for a reservoir? Electrolyser capacity will GW scale. Waste water (twice level of impurities it had coming in) - could have common infrastructure with gas plant. Volume of water waste of up to 9 million litres (this figure is the upper bound of what a 1 GW electrolyser will use in one day (at about 20 litres of water per kg of hydrogen)). Could do with a buffer (reservoir). Is there a history of drought in the area?	Group
2		Deionising units for the desalination system will consume resins and filters.	Group
3		Handling of large volumes of Oxygen has significant safety hazards associated.	Group
4		Might want to find a local consumer of Oxygen.	Group
5		Bleed over between hydrogen and oxygen streams. Potential about getting in each other's tanks.	Group
6		If cables go overground there is the potential for shorting. Need quick acting protection systems.	Group
7		Should HVDC transmission should be employed from the wind farm to shore, it is recommended to bury the onshore cables all the way to the substation, which may be 20-30 miles inland. The HVDC power will need to be converted to a lower voltage through an inverter and a transformer. The electrolyser has its own converter to rectify back to DC, but this is outside of the scope of this HAZID.	Group
8		There needs to be start up power source to allow black start on the wind turbines. The electrolyser process can be powered directly on black start up so will not need an ancillary power source. Potential to restart with alternative renewables in the medium future (5-10 years). Perhaps have sufficient energy store at the substation to do a restart.	Group
9		Risks associated with diesel day tanks for diesel generator, should a diesel generator be used as the start up power source. There are alternative generators available.	Group
10	Offshore	Expect reduced Preventative Maintenance regime to option 1. So probably less requirement for maintenance crews boarding and off boarding each turbine. Also smaller volume of spare parts to be housed locally.	Group
11		Especially with tides – floating, high voltage dynamic cables are difficult to acquire. Flexibility of cables with movement during tides. Potential for failure mechanism as a result. Power protection systems are bulky for offshore installations. So there maybe the need for a second platform. Pipelines more established for transporting lots of energy, compared to cables. Electrical cables considered more unreliable (AH disagrees). Need to be able to isolate on demand for corrective action. ACDC transmission cost cut-off distance at 100km.	Group
12		The layout of equipment needs to be improved for ease of access to equipment.	Group

13		Marine life will congregate around the HV cabling as it comes to shore. What impact will that have on the marine environment. Usually bury the cables.	Group
14		What is the impact of anchors dragging the main power cable?	Group
15		Cables for 1 GW projects, take up a lot of space. Similarly for the grid connection onshore. Depending on the energy throughput, the electrical transmission systems may require a greater footprint compared to pipeline of similar capacity. Subsequent environmental impact and visual impact. Footprint for electrolyser module approx. 17 hectares for 1GW unit. No such issue with using pipelines.	Group
16		Use of Ammonia in the power plant: More NOx emissions as a result. Study will be required to assess the feasibility of using Ammonia.	Group

Appendix D Information Provided Post Workshop

Requested Information during Workshops.

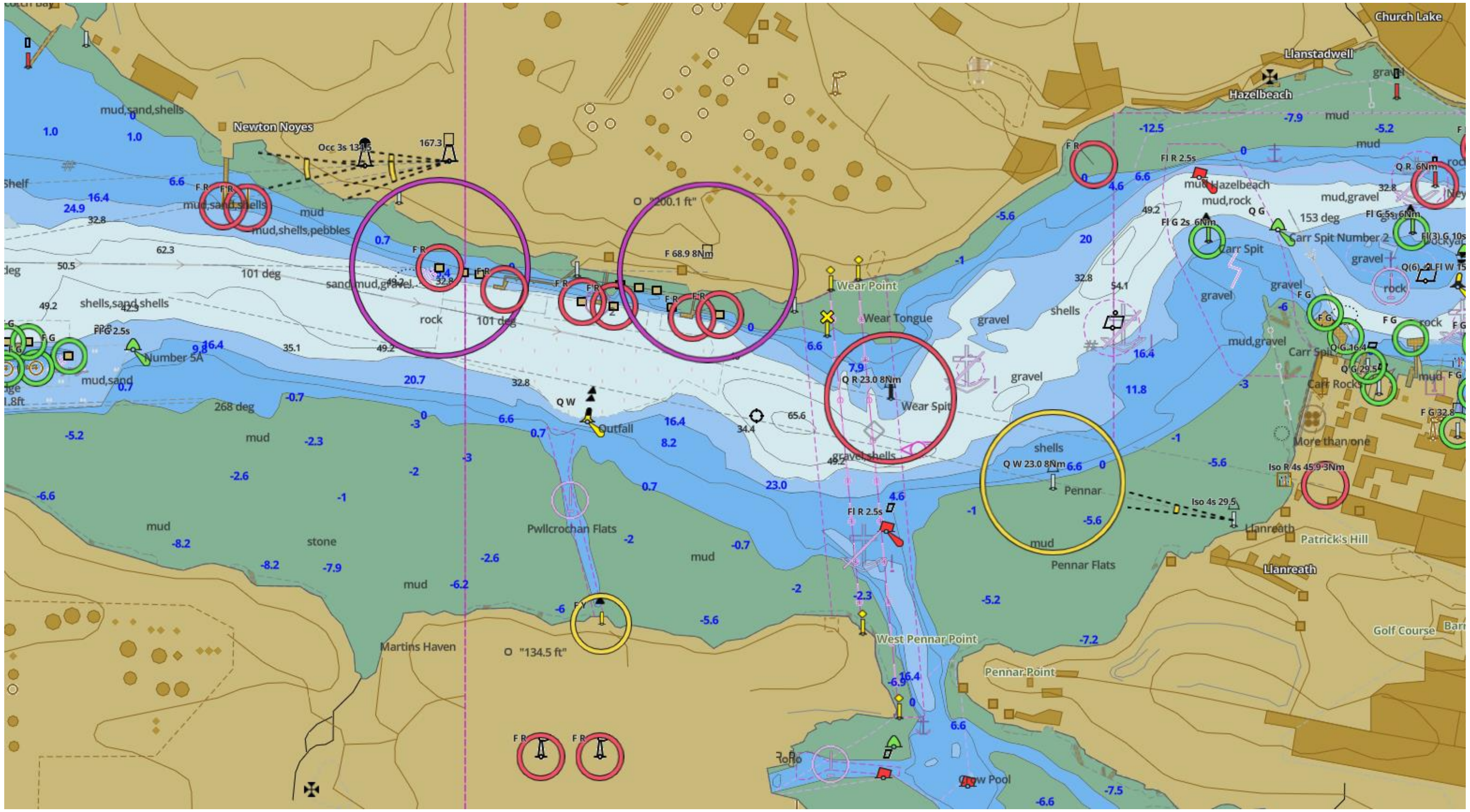
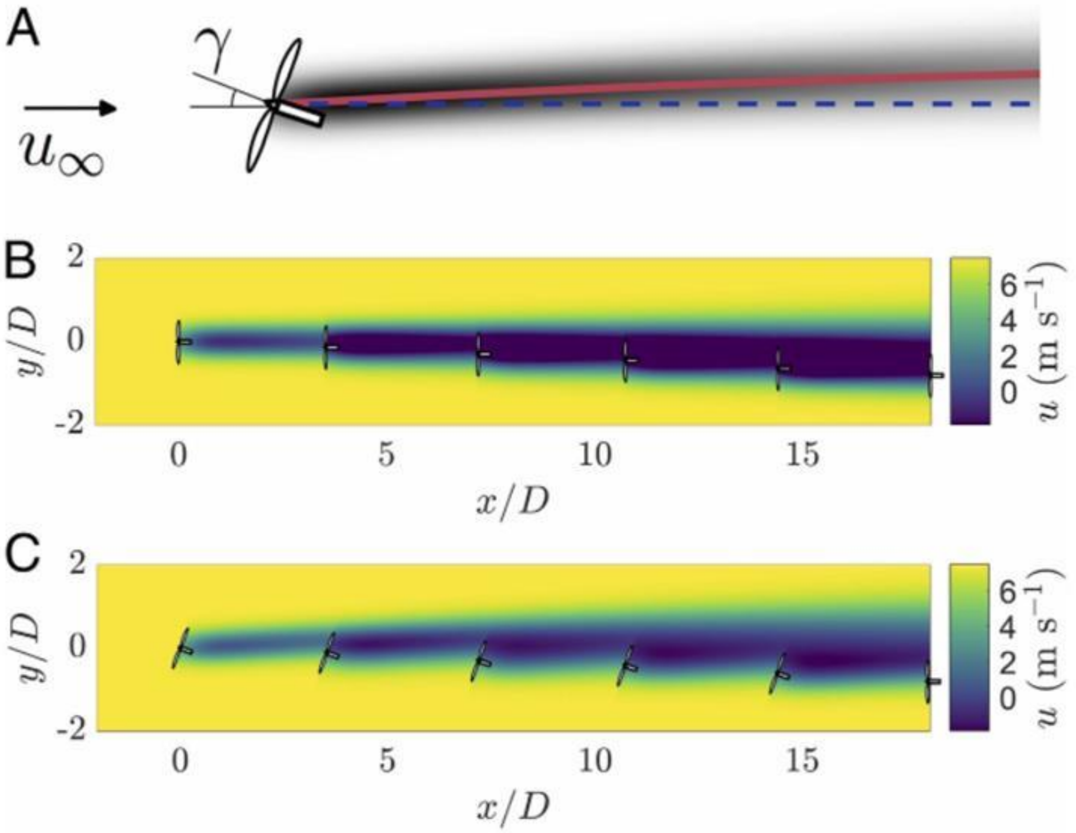


Figure D1 Chartlet showing location of the two pipelines crossing the Haven in the region of Wear Spit. (Provided by David Lockwood of the Milford Haven Port Authority)

Fig. 1.



(A) A wind turbine with diameter D yawed at angle γ with respect to the incoming wind and viewed from above. The incoming wind at speed u_∞ is incident from the left. The centerline of an unyawed, standard operational wake would follow the dashed blue line. The centerline of the yawed wake follows the solid red line. (B and C) Wake model streamwise velocity field for baseline maximum power point tracking control (B) and optimal yaw control (C). The incoming wind speed at the most upstream turbine is $u_\infty = 7.5\ \mathrm{m \cdot s^{-1}}$ and there are six turbines modeled. The wake following turbine six is not shown since the wake model automatically neglects calibration of the parameters for turbine six to increase computational efficiency.

Figure D2: Wake Steering (Provided by Michael Galvin, OREC. Source: Wind farm power optimization through wake steering | PNAS)

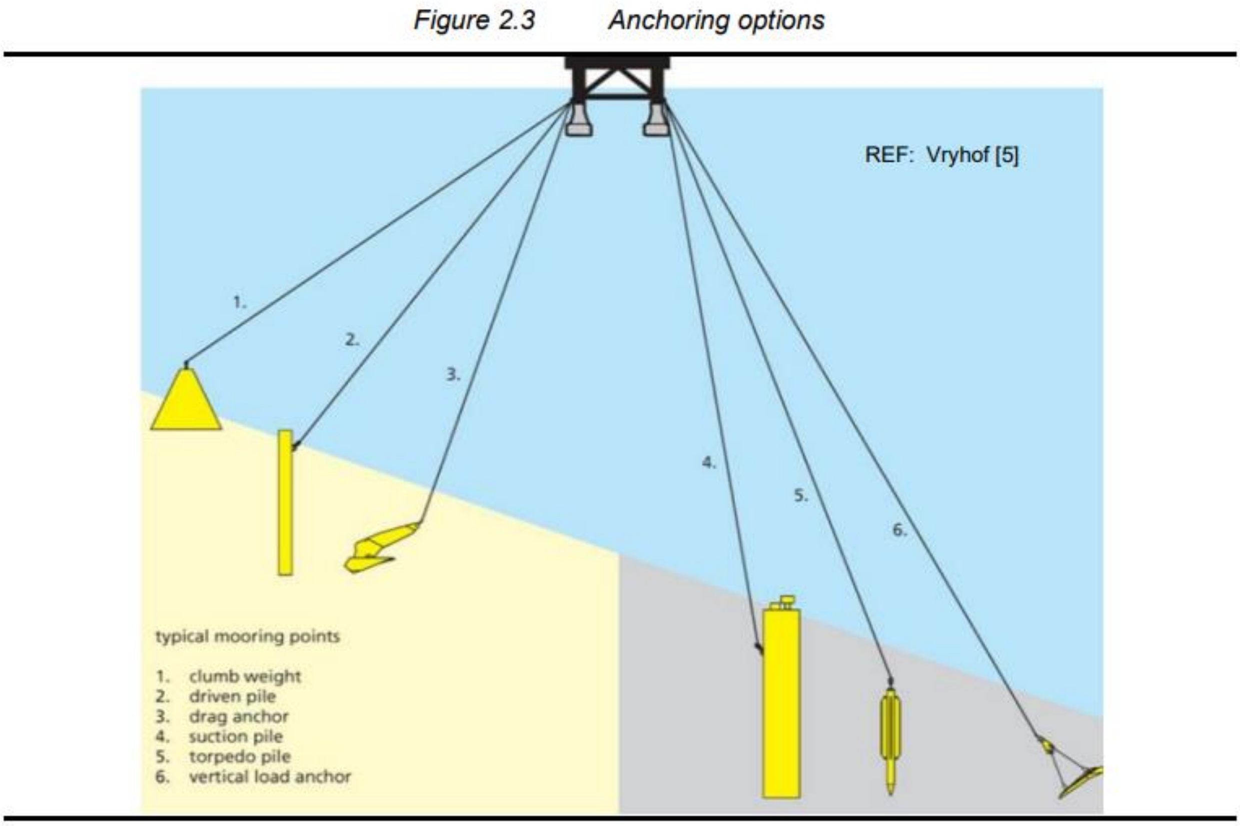


Figure D3: Anchoring Options (source Dolphyn Hydrogen - phase 1 final report (publishing.service.gov.uk))

Organisation.	Address	Email / Phone
Natural Resources Wales (Marine Licencing Team)	29 Newport Road Cambria House Cardiff CF24 0TP	marinelicensing@naturalresourceswales.gov.uk Telephone: 0300 065 3000
Pembrokeshire County Council (Planning Acts)	County Hall, Haverfordwest, Pembrokeshire SA61 1TP	Telephone: 01437 764551
Pembrokeshire Coast National Park Authority	Llanion Park Pembroke Dock Pembrokeshire SA72 6DY	Telephone: 0845 3457275
Trinity House	Trinity House Lighthouse Service, Trinity House, Tower Hill, London. EC3N 4DH	Telephone: 020 74816900
Welsh Minister /Secretary of State		(EIA Screening, PCC / PCNPA, Marine Works (EIA) Regs 2007. The Marine Works (Environmental Impact Assessment) Regulations)
Port of Milford Haven (Marine Works Licensing Team)	Gorsewood Drive, Milford Haven	mwl@mhpa.co.uk Telephone: 01646 696 100

Table D4: Stakeholders in the Milford Haven Waterway (Provided by David Lockwood of the Milford Haven Port Authority)

In addition to the MHPA Marine Works or Dredging License, developers will frequently require other consents for operations below the Mean High Water Mark, depending on the type and location of the works proposed. The issue of a Marine Works Licence or Dredging Licence does not obviate the need
for the holder to obtain other approvals which may include the following:

- Marine Licence
- Planning Consent (under the Town & Country Planning Acts, as amended)
- Agreement of the land owner (often The Crown Estate)
- Consent of the Natural Resources Wales. (Waste Management Licence, - Environmental Protection Act 1990 / Waste Management Licensing Regulations 1994; Discharge or Drainage Consents- Water resources Act 1991 / Land Drainage Act 1991)
- The Wildlife and Countryside Act, 1981 as substituted by Schedule 9 to The Countryside and Rights of Way Act, 2000. Section 28 SSSI Consent
- DECC Department of Energy and Climate Change. - Electricity Act 1989 (Offshore energy generation) Petroleum Act 1998 (oil & gas installations/pipelines)

Table D4 (continued): Stakeholders in the Milford Haven Waterway (Provided by David Lockwood of the Milford Haven Port Authority)